U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

DOT HS 809 752 **November 2004**

Wireless Phone and AutoPC Related Technology: Driver Distraction and Use Effects on the Road

This document is available to the public from the National Technical Information Service, Springfield, Virginia 22161.

DISCLAIMER

NOTE REGARDING COMPLIANCE WITH

AMERICANS WITH DISABILITIES ACT SECTION 508

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

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS 809 752		

4. Title and Subtitle
Wireless Phone and AutoPC Related Technology: Driver Distraction and Use Effects on the Road

5. Report Date
November 2004

6. Performing Org. Code
NHTSA/NVS-312

7. Author(s)
Elizabeth N. Mazzae, MSE, National Highway Traffic Safety Administration (NHTSA)
G. H. Scott Baldwin, MSE and Thomas A. Ranney, Ph.D., Transportation Research Center Inc.

8. Performing Org. Report No.

9. Performing Organization Name and Address
National Highway Traffic Safety Administration
Vehicle Research and Test Center
P.O. Box 37
East Liberty, OH 43319

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Highway Traffic Safety Administration
400 Seventh Street, S.W.
Washington, D.C. 20590

13. Type of Report
Final Report

14. Sponsoring Agency Code

15. Supplementary Notes
The authors wish to thank Frank Barickman (NHTSA) and Adam Andrella (TRC) for technical contributions.

16. Abstract
A naturalistic, on-road study using instrumented vehicles was conducted to: 1) to assess the effects of wireless phone use while driving on driver distraction and driving performance as a function of wireless phone interface type (i.e., hand-held, conventional hands-free, and enhanced hands-free with voice dialing), and 2) to characterize the conditions under which drivers elect to use wireless phones. Ten participants drove instrumented vehicles for 2 weeks with each of three wireless phone interface conditions. Driving performance and eye glance activity were measured during wireless phone use and baseline driving.

The hand-held interface was associated with more calls, calls of longer duration, and shorter dialing periods than the hands-free interface. More than half of calls made in the voice dialing interface condition were dialed manually despite instructions to use voice dialing, suggesting drivers found voice dialing difficult to use. Drivers engaged in fewer calls when driving in conditions of high traffic density, particularly when using the hands-free phone interfaces.

Overall, the robustness of eye glance data provided useful information regarding drivers' glance behavior during conversations and how this glance behavior can change as the conversation progresses in time. Drivers spent 21 percent less time glancing at the forward roadway during hands-free voice dialing than during baseline driving. Drivers spent proportionately more time looking at the road ahead during phone conversation (all interfaces) than during baseline driving. Drivers made more glances away from the forward roadway while talking on a hands-free wireless phone than while talking using a hand-held interface. Drivers glanced frequently at the hands-free wireless phone equipment during conversation, despite that there was no functional need to direct their glances or head toward the equipment. During longer conversations (2 minutes duration or greater), the percent of time spent looking at the forward roadway increased steadily. This may indicate that drivers become more cognitively engrossed in the conversation as it progresses, which could lead to a "looked but did not see" situation.

The percent of time that participants were observed driving with two hands on the steering wheel was quite low. During baseline driving, participants steered using only one hand 87 percent of the time. Drivers spent proportionately more time steering with two hands during hands-free conversations than during hand-held conversations. The percentages during hands-free conversation (13-16 percent) were similar to those observed during baseline driving (13 percent), however, the corresponding percentage during hand-held conversation was less than 1 percent.

While some differences were found between phone interfaces for dialing and conversation durations, significant differences in driving performance were not found. Similarly, driving performance measures did not exhibit differences between phone conversation and baseline driving. Given that these analyses have demonstrated a large amount of variability in driving conditions and based on the fact that many studies have shown performance degradation due to conversation generally, the absence of such affects in this study suggests that the experiment did not have the sensitivity necessary to detect differences in driving performance due to the interface conditions.

17. Key Words
Driver distraction, cell phone, wireless phone, AutoPC, driver performance, voice interface, eye tracking

18. Distribution Statement
Document is available to the public from the National Technical Information Service, Springfield, VA 22161

19. Security Class. (of this report)	20. Security Class. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	81	

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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This research examined the effects of wireless phone interface type on driving performance and wireless phone usage behavior. Naturalistic (i.e., observational method, involving no specified route or commanded tasks), on-road data collection with instrumented vehicles was conducted to examine patterns of drivers' use of wireless phones as a function of phone interface type (i.e., hand-held vs. hands-free). Specifically, driver eye glance activity, driver vehicle performance measures, and wireless phone use were examined. This comparative analysis examined the response measures to better understand how wireless phones change the driver's behavior and performance. The objectives of this research were: 1) to assess the effects of wireless phone use while driving on driver distraction and driving performance as a function of wireless phone interface type (i.e., hand-held, conventional hands-free, and enhanced hands-free), and 2) to characterize the conditions under which drivers elect to use their wireless phones as a function of phone interface type. More specifically, this research was intended to provide empirical data to support or refute the move toward hands-free wireless phones.

In this study, 10 participants drove an instrumented vehicle unaccompanied on public roads for a period of 6 weeks. Participants were instructed to drive safely and were instructed on the use of the wireless phone equipment present in the vehicle. Observation over a period of time during normal, unrestricted driving provided the gathering of naturalistic driving data with a minimum of experimental artifacts. This method also provided insights into frequency of use, duration of use (e.g., conversation), and driving situations during use as a function of the technology. However, this unrestricted driving led to highly variable driving conditions that complicated data analysis.

One important question this research sought to answer was whether drivers would make more calls and longer calls with a hands-free phone than with a hand-held phone due to presumed increased ease of use. Drivers in this study did not make more calls or longer calls with hands-free wireless phones than with hand-held wireless phones. In fact, the hand-held wireless phone interface used in this study was associated with more calls and calls of longer duration. This could be attributable to increased familiarity with hand-held phones, as well as poor performance of the voice recognition system use for the Enhanced Hands-Free (EHF) interface. Anecdotal evidence based on video data suggests that some drivers had considerable difficulty in dialing using the enhanced hands-free wireless phone (voice) interface supported by an in-vehicle computer (AutoPC). More than half of calls made in the EHF condition were dialed manually. Drivers ignored instructions to use hands-free (voice) dialing, suggesting drivers found voice dialing difficult to use. The hand-held wireless phone was associated with shorter dialing periods.

Drivers engaged in fewer wireless phone calls when driving in conditions of high traffic density, particularly when using the hands-free phone interfaces. Ninety-two percent of calls were made when there were less than 10 vehicles present in the vicinity of the participant's vehicle. Seventy-five percent of calls were conducted in the presence of five or fewer surrounding vehicles. The mean number of surrounding vehicles was highest during Hand-Held (HH) calls (4.5 vehicles) and lowest during EHF calls (3.2 vehicles), suggesting drivers may have felt more comfortable engaging in calls using the HH phone interface.

Significant trends that would distinguish the effects on driving performance of hands-free wireless phone use from hand-held wireless phone use were not found. However, some interesting findings were obtained relating to glance behavior during wireless phone use:

- While hands-free (voice) dialing showed a modest benefit in terms of glances to the phone relative to manual dialing, it still involved a 20 percent reduction in time spent looking ahead, relative to baseline driving.

- Hands-free (voice) dialing methods allow the driver to look at the road more during dialing episodes, however, the distraction level is still significant relative to conversation on a wireless phone.

- Drivers look away from the forward roadway more during dialing episodes than during conversation on a wireless phone.

- Enhanced hands-free conversation was associated with more time spent looking left and right as compared to hand-held or conventional hands-free conversation, suggesting a slight benefit over the other phone interfaces in terms of lateral situational awareness.

- Drivers made more glances away from the forward roadway while talking on a hands-free wireless phone than while talking on a hand-held wireless phone.

- Drivers glanced frequently at the hands-free wireless phone equipment during a hands-free call, despite that there is no functional need to direct their glance or head toward the equipment.

- Drivers spent more time looking at the road ahead during phone conversation (all interfaces) than during baseline driving.

- During longer conversations (2 minutes duration or greater), the percent of time spent looking at the forward roadway increased steadily. This may indicate that drivers become more cognitively engrossed in the conversation as it progresses, which could lead to a "looked but did not see" situation. Research to examine whether the observed increase in percent of time spent glancing at the forward roadway may be attributable to increased attention to the driving task or increased cognitive complacency would provide helpful insight into the safety implications of these findings.

- The percent of time that participants were observed driving with two hands on the steering wheel was quite low. During baseline driving, participants steered using only one hand 87 percent of the time. Drivers spent proportionately more time steering with two hands during hands-free conversations than during hand-held conversations. The percentages during hands-free conversation (13-16 percent) were similar to those observed during baseline driving (13 percent), however, the corresponding percentage during hand-held conversation was less than 1 percent.

In summary, while some differences were found between phone interfaces for dialing duration and conversation durations, significant differences in driving performance were not found. Significant differences in driving performance during conversation versus driving performance during baseline driving were also not distinguishable based on data collected in this study. However, the robustness of eye glance data provided useful information regarding drivers' glance behavior during conversations and how this glance behavior can change as the conversation progresses in time.

Given that the analyses reported here demonstrated the large amount of variability in driving conditions and based on the fact that many studies have shown performance degradation due to conversation generally, the absence of such affects in this study suggest that the experiment did not have the sensitivity necessary to detect differences in driving performance due to the interface conditions.

1.0 INTRODUCTION

As of May 2004, there were over 162 million wireless phone subscribers [1] in the United States. The number continues to grow rapidly. A substantial portion of this group uses their wireless phone while driving, at least occasionally. The crash-related effects of wireless phone use while driving has become a popular issue, and has been under public scrutiny in recent years.

Numerous efforts are under way to pass legislation that allows only hands-free wireless phones to be used while driving. In the past year virtually every state government and the District of Columbia have considered legislation specifically related to the prohibition, restriction or ban of the use of cellular phones while driving. New York was the first state to enact a ban that restricts the use of hand-held phones by drivers while their vehicles are in motion. Most recently, the District of Columbia passed similar legislation prohibiting distracted driving in general as well as banning the use of hand-held mobile telephones or other electronic devices while operating a moving motor vehicle. Also in 2004, the state of New Jersey passed legislation making the use of hand-held phones while driving a secondary traffic offense. It should also be noted that several states -- including Massachusetts, Illinois, New Jersey, Rhode Island, as well as the District of Columbia -- have enacted legislation restricting cellular phone use by school bus and/or novice drivers, in particular. The state of Massachusetts only permits cellular phone use by the driver as long as it does not interfere with the operation of the vehicle and one hand remains on the steering wheel at all times. Since enactment of the New York state law, the proportion of observed New York drivers using hand-held phones reportedly dropped by about 50 percent; a recent study suggests that observed use is on the rise again. It is too soon to know the impact of the laws in New Jersey and the District of Columbia, which took effect July 1, 2004.

The assumption behind these legislative initiatives is that any technology that reduces the visual-manual demands of wireless telecommunications must be safer, since the driver can keep both hands on the wheel and both eyes on the road when using a hands-free system. However, hands-free wireless phones most commonly allow only for hands-free conversation; accessing the phone, dialing, and hanging up still involve visual-manual tasks. Furthermore, research evidence is increasingly highlighting the point that there is no difference between hands-free and handheld use of cell phones while driving in terms of risk. Some experts suspect that the distraction levels caused by phone use is independent of the interface design due to the fact that the cognitive demand of conversation tasks are the same no matter what the interface.

As the federal agency concerned with highway safety, the National Highway Traffic Safety Administration (NHTSA) has both a mandate and an opportunity to contribute to a better understanding of the implications of hands-free wireless phone operations while driving. Research conducted by NHTSA provides guidance to lawmakers in the interest of automotive safety. In the current context, this may be characterized in terms of research on: a) the effects of wireless phone use while driving on driver distraction and driving performance as a function of wireless phone interface type (i.e., hand-held, conventional hands-free, and enhanced hands-free), and b) the effects of hands-free wireless phone functionality on drivers' willingness to engage in phone calls while driving. Both of these topics are the subject of this research. Research on these issues will allow a better understanding of the relationship between wireless phone use and crash occurrence.

1.1. BACKGROUND

It is important to recognize that trends in the development of in-vehicle technologies are moving towards multifunction systems with greater integration into vehicles in terms of control of vehicle subsystems (e.g., audio system, heating/AC), crash avoidance warning systems, and a variety of communications and information access capabilities (e.g., voice, address books, in-vehicle signing, email, navigation). Central to this integration is a move towards a hands-free voice interface that would allow both access and control through simple voice commands. The most publicized system incorporating this architecture is the Clarion AutoPC released in 1999. This system was intended to integrate a variety of communications and information access functions, making them available through a hands-free voice interface. AutoPC represents a new voice recognition and voice display technology that purports to revolutionize the auto industry.

Through voice, vehicle subsystems can now be controlled (e.g., cabin temperature, radio station), email can be reviewed, route navigation systems can be interacted with, and address books can be searched. As with wireless phones, there are a number of issues concerning user acceptance, behavioral changes over time, and the safety-relevant benefits/disbenefits of the hands-free interface within this family of systems. The commonality of hands-free voice interface between the wireless phone and the trend towards a voice interface for a variety of in-vehicle technologies highlights the relevance and importance of this research as a companion to planned research relating directly to the AutoPC and similar technologies. The wide availability and use of wireless technology makes it particularly attractive as a mechanism for gaining insight into some fundamental questions, the answers to which will help system designers ensure that intended benefits can be achieved with a positive impact on safety.

This research examined the effects of wireless phone interface type on driving performance and wireless phone usage behavior. This naturalistic (i.e., observational method, involving no specified route or commanded tasks), on-road data collection with instrumented vehicles was conducted to examine patterns of drivers' use of wireless phones as a function of phone interface type (i.e., hand-held vs. hands-free). Specifically, driver eye glance activity, driver-vehicle performance measures, and wireless phone use were examined. This comparative analysis examined the response measures to better understand how wireless phones change the driver's behavior and performance. This program of research is important to developing a deeper understanding of the benefits and disbenefits that may accrue from these technologies.

1.2. PURPOSE

The objectives of this research were: 1) to assess the effects of wireless phone use while driving on driver distraction and driving performance as a function of wireless phone interface type (i.e., hand-held, conventional hands-free, and enhanced hands-free), and 2) characterize the conditions under which drivers elect to use their wireless phones as a function of phone interface type. More specifically, this research was intended to provide empirical data to address the controversial issue of whether or not hands-free wireless phone use while driving is safer than hand-held wireless phone use.

Wireless phone interface type has been said to affect phone usage behavior patterns. Wireless phone interface designs that are easier to use can cause drivers to be more willing to engage in phone calls (i.e., increase the number of calls) and can also increase the amount of time drivers spend using the phone while driving. This increased use may have an impact on safety by increasing the incidence of bad driving performance (e.g., lane departures), which in turn, increases the driver's exposure to crashes. The following hypotheses regarding wireless phone usage patterns were tested in this study:

1. Drivers will make more calls with hands-free wireless phones than with hand-held wireless phones due to the perception of increased ease of use.
2. Drivers will make longer calls with hands-free wireless phones than with hand-held wireless phones due to the perception of increased ease of use.
3. Drivers will engage in fewer wireless phone calls in conditions of high traffic density.

In addition, this study tested the following hypotheses relating to driving performance:

1. Driving performance will be less degraded when drivers use enhanced hands-free wireless phones than when using hand-held or conventional hands-free wireless phones, since with an enhanced hands-free interface both hands are available for use in steering during dialing and phone conversation.
2. Driving performance will be less degraded when drivers use conventional hands-free wireless phones than when using hand-held wireless phones, since with a hands-free interface both hands are available for use in steering during phone conversation.
3. Drivers will spend more time glancing away from the forward roadway while talking on a hands-free wireless phone than while talking on a hand-held wireless phone.
4. Drivers will glance frequently at the hands-free wireless phone equipment during a hands-free call, despite that there is no functional need to direct their glance or head toward the equipment.

Research to examine the relationship between wireless phone interface, wireless phone usage behavior, and driving performance must be conducted to develop an understanding of how these factors relate to safety. This may be characterized in terms of research on: a) drivers' acceptance of hands-free phone use, and b) the empirical basis of safety-relevant benefits/disbenefits of hands-free wireless phone use (versus hand-held phone use). NHTSA's hope in performing this research was that the knowledge gained would assist the development of a comprehensive picture of the safety benefits/disbenefits of conventional hands-free and enhanced hands-free wireless phones, as compared to hand-held wireless phones. This knowledge of safety impacts could provide a rational basis for setting public policy in this important area of driver performance and behavior.

2.0 METHOD

2.1. EXPERIMENTAL DESIGN

The experimental design for this study was a one within, one between mixed factor design. The within-subjects (i.e., repeated) measure in this study was type of in-vehicle wireless phone. The between-subjects factor was frequency of wireless phone use (self-reported: moderate or frequent) while driving. Gender was balanced across experimental conditions.

The study was naturalistic, in which members of the general public were recruited to drive instrumented test vehicles for a period of six weeks as part of their normal daily routine. Thus, the test vehicles were to take the place of participants' normal vehicles during the course of their participation in the study. Since only six test vehicles were available for use, the data were collected in two, 6-week phases.

In total, 13 drivers participated. One participant was unable to complete the 6 weeks due to reasons unrelated to the study. Due to problems encountered during the course of data collection, data were obtained for only 10 of the remaining 12 participants.

2.1.1. Wireless Phone Interface Variable

Participants used three wireless phone interfaces, as outlined in Table 1. Wireless phone equipment used included the Clarion AutoPC Model 310C (see Figure 1) and a Motorola Piper (650E) (see Figure 2). All three wireless phone interface conditions used the same wireless phone. The AutoPC system provided an "enhanced hands-free" (EHF) phone interface condition and served to mask the study objectives (examination of wireless phone use) by presenting the study as an examination of in-vehicle computer use. A phone cradle, used in the Conventional Hands-Free (CHF) and EHF conditions, was mounted on a gooseneck arm located to the right of the center console.

Table 1. Explanation of wireless phone interface conditions

Phone Interface Abbreviation	Phone Interface Description	AutoPC Control Method	Phone Location
HH	Hand-held (Manual phone dialing and talking)	Manual control of AutoPC	Driver's choice
CHF	Conventional hands-free (Manual dialing, hands-free conversation)	Manual control of AutoPC	Cradle
EHF	Enhanced hands-free (AutoPC voice controlled dialing, hands-free conversation)	Voice control of available AutoPC functions including voice	Cradle

Figure 1. Photograph of AutoPC

Figure 2. Photograph of wireless phone model used in this study

The wireless phone interface conditions were varied along with the AutoPC control method (i.e., manual versus verbal) in an effort to mask the focus of the study. AutoPC features available to the participants included radio, CD player, address book, and phone base. Navigation and messaging functions of the AutoPC were not used in this study. Use of the voice memo function was permitted in the enhanced hands-free condition.

2.1.2. Call Frequency Variable

Participants' normal frequency of wireless phone use was planned to be one of the independent variables for this study. During the initial phone interview, persons calling to inquire about participation who reported having a wireless phone were asked, on average, how many wireless phone calls they engaged in per day while driving. The self-reported average number of wireless calls per day was examined graphically. Prospective participants were categorized as "occasional," "moderate," or "frequent" users. Figure 3 contains this graph, showing both Phase 1 and Phase 2 participant recruitment data. Using this graph, a "moderate" user was defined as one who engaged in 3 to 9 calls per day (no callers in Phase 1 recruitment reported making between 6 and 9 calls per day; i.e., all reported more than 9 or fewer than 6). The number of calls per day for a "frequent" user was defined as 10 or more. Occasional wireless phone users were not included since it was thought likely that the number of wireless calls made by "occasional" users would be insufficient to permit the assessment of driver performance during wireless calls for this group. Thus, participants were chosen from the set of self-reported "moderate" and "frequent" wireless phone users, who met all of the other qualifying conditions for participation.

Despite these efforts to group participants according to their normal rate of wireless phone use, this variable was found to be problematic. Due to the loss of subjects, an equal number of moderate (6) and frequent (4) users was not obtained. In addition, call behavior differed, in terms of number of calls, from the level expected based on self-reported phone use information provided in the pre-participation phone interview. Namely, all participants made fewer calls than the number they reported normally making, as shown in Figure 4. Thus, it is not clear whether participants' calling behavior was similar to that which they would exhibit normally (i.e., with their own phone, during normal daily driving). As a result, the call frequency independent variable was dropped from the experimental design.

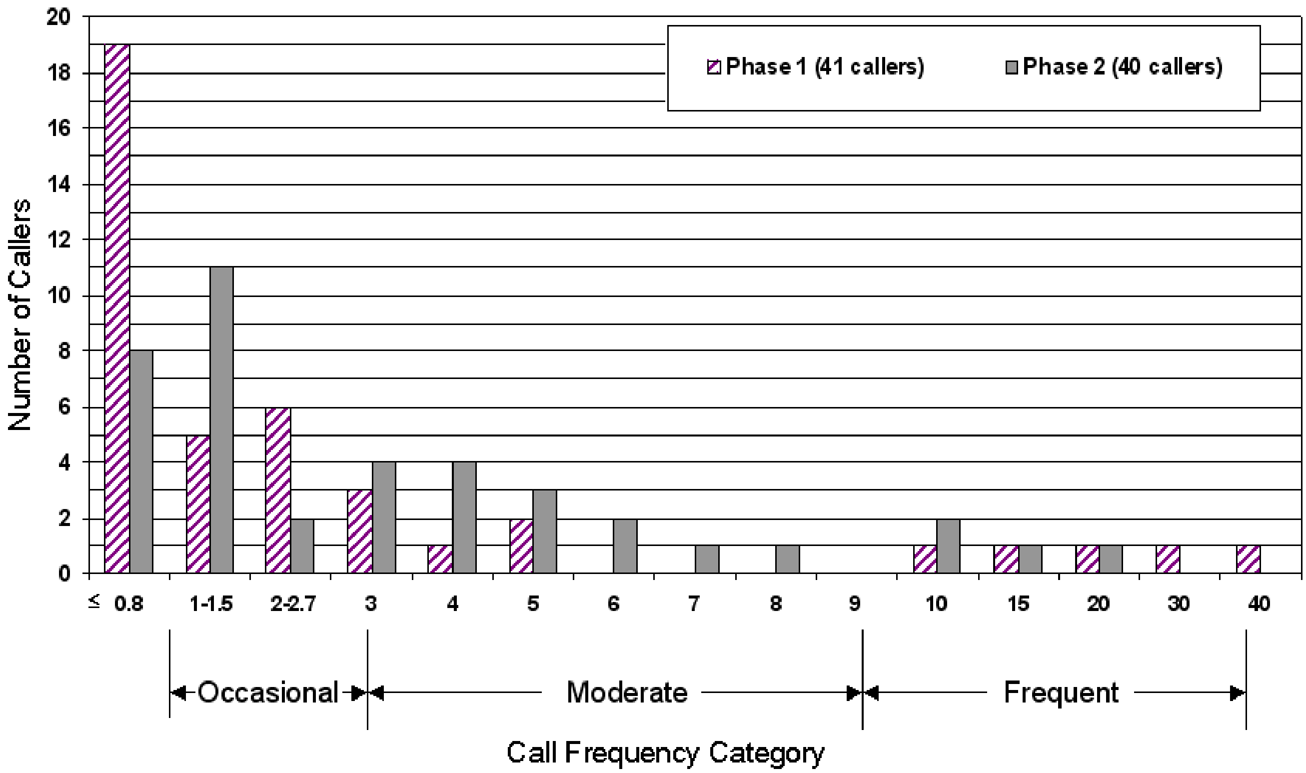

Figure 3. Self-reported number of calls per day by all prospective participants (per recruitment data)

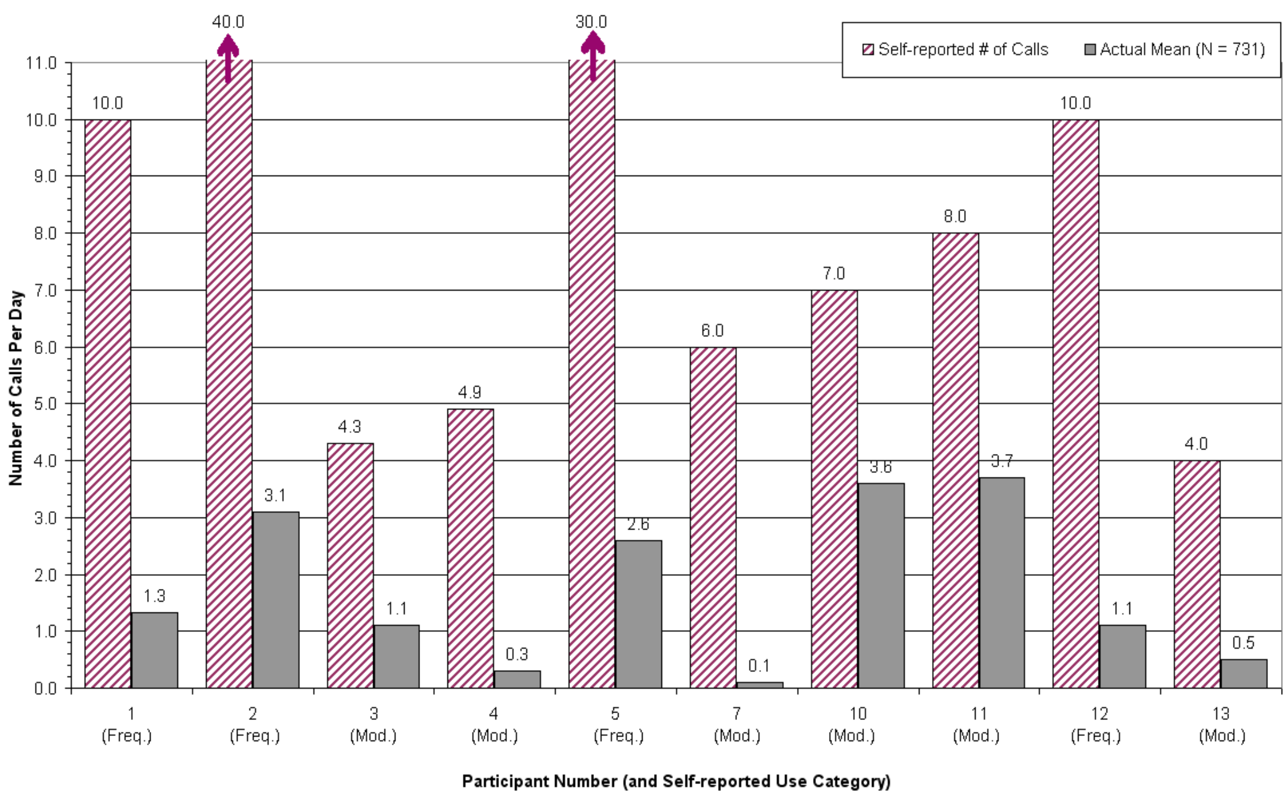

Figure 4. Participants' self-report (during recruitment) 'average wireless calls per day' versus actual calls per day (during study)

2.1.3. Presentation of Conditions

The order in which wireless phone interface conditions were presented was randomized. Assignment of conditions was balanced by gender and test vehicle (car number) to the extent possible. Table 2 shows the presentation orders used.

Table 2. Order of presentation of experimental conditions (1 = HH, 2 = CHF, 3 = EHF)

	PHASE 1		PHASE 2	
Car No.	**Interface Order**	**Gender**	**Interface Order**	**Gender**
1	123	F	321	M
4	312	F	132	M
7	231	M	213	F
3	123	F	321	M
5	312	M	213	F
9	231	M	132	M
2	NA	NA	231	M

Car number 2 was not used in Phase 1 of the data collection. Cells shaded gray in the above table indicate three participants who, for various reasons, were either unable to complete their participation or were removed from the study. Reasons included job change requiring relocation (1 participant), noncompliance with data retrieval procedures (1 participant), and insufficient phone use while driving (1 participant). These participants were later replaced by other drivers who were presented with similar condition orders to the extent possible.

2.2. PARTICIPANTS

Ten drivers (5 males and 5 females) completed participation in this study. Participants were recruited who were between the ages of 25 and 55. The actual age of the participants ranged from 28 to 51 years, with an average age of 40 years. All participants were licensed automobile drivers. Participants were required to have owned a wireless phone for at least 6 months. All selected participants reported that they used their wireless phone while driving. However, prospective participants were not told that wireless phone use was a requirement for participation.

All 10 participants had at least a high school diploma. Four participants completed high school as their highest level of formal education. One participant had some undergraduate schooling at the time of the study. Of the remaining five participants, two had associates degrees, two had bachelor degrees, and one had a graduate or professional degree.

Participants were required to normally drive at least an hour each weekday. Two participants claimed to drive between 8,000 and 13,000 miles per year. Three participants drove between 13,000 and 20,000 miles per year in their personal vehicles. The other five participants all drove at least 20,000 miles per year. Eight of the ten participants reported doing work-related driving, aside from driving to and from work. Work-related driving found 5 of the 8 participants driving an additional 2,000 to 8,000 miles per year, two participants driving an additional 8,000 to 13,000 miles per year, and one participant driving an additional 13,000 to 20,000 miles per year.

Participants were recruited from the Central Ohio area. One goal of the recruitment process was to try to find participants who lived in the same general locale in order to minimize the distance that experimenters had to travel to retrieve data from the vehicles while in the field. As a result, recruitment for Phase 1 was focused in the area of Marysville, Ohio (small city in rural area, approximately 20 miles northwest of Columbus), while the recruitment for Phase 2 was focused in the northern parts of the city of Columbus, Ohio.

Participants were recruited mainly through the placement of advertisements in local newspapers. Some additional recruitment involved phoning local companies and asking them if they would post a recruitment flyer at their offices. The ads and postings sought participants for a "driving research study". All ads stated that participants would receive compensation of $200. When prospective participants called to inquire about participation, the experiment was described to them as a study of driving behavior and drivers' opinions of certain high-technology in-vehicle devices. Callers were asked a number of questions relating to driving behavior, health, and technology-use, to determine their eligibility. The questions regarding driving behavior covered a broad range of topics, in order to not alert callers of the focus of the study.

2.3. TEST VEHICLES

Participants drove a white 1996 Chrysler Concorde as shown in Figure 5. These vehicles were equipped with automatic transmissions and antilock braking systems (ABS). Conventional cruise control, a standard feature on these vehicles, was disabled for this study to permit the examination of travel speed as a dependent measure.

Figure 5. 1996 Chrysler Concorde test vehicle

Within the test vehicle, the AutoPC system was installed in place of the vehicle's original equipment radio. The phone cradle was installed to the right side of the center stack. The conventional hands-free and enhanced hands-free interface systems both had phone cradles. Although these two cradles were different, they could be mounted to the same "gooseneck arm". Due to the difficulty involved in removing the arm from the vehicle, it was left installed for the hand-held wireless phone interface condition. However, participants were not required or instructed to use the cradle. The two hands-free interfaces also utilized separate microphones installed in the vehicle.

2.4. INSTRUMENTATION

Each test vehicle was equipped with MicroDAS instrumentation [3, 4]. This system of sensors and processors captures at a sampling rate of 30 Hz. Measurements of driver control inputs and vehicle response measures considered useful in the characterization of driving performance quality were recorded. All channels identified as useful in this determination are listed in Table 3. A brief explanation of the planned use of these channels in the assessment of driving performance is also included in the table. A more detailed explanation of how these measures were used in the assessment of driving performance is provided in Section 3.1.

Table 3. MicroDAS data channels

Data Channels	Definition / Meaning	Units / Value	Data Use
Left turn signal	Left turn signal activated	On / off	Examine rate of turn signal use
Right turn signal	Right turn signal activated	On / off	
Brake light	Brake light indicator	On / off	Identify brake inputs
Longitudinal acceleration	Longitudinal acceleration / deceleration	G	Identify high deceleration events
Left lane tracker	Track vehicle position with respect to lane lines	Volts (converted to feet)	Examine lane position variability and lane Exceedences
Right lane tracker			
Steering wheel	Steering wheel angle is collected with a relative encoder and derived into an absolute position	Degrees	Examine steering wheel input magnitudes and rates
Steering wheel angle, corrected	Steering wheel angle zeroed from offset;; New channel, "HW_Angle_Zero," is created	Degrees	Identify magnitude and rate of steering inputs
Leica range MSB	Range	Meters	Examine distance to forward vehicles
Leica range LSB			
Range rate MSB	Range rate	Meters per second	Examine time-to-collision with forward vehicles
Range rate LSB			
Leica throttle MSB	Throttle position	Percent displacement	Examine throttle reversal rates
Leica throttle LSB			
UTC time	UTC time of day	HH:MM:SS	Time basis
Leica speed	Vehicle speed from Leica sensor	Mph	Examine vehicle speed, speed variability, and speed range
Video active	Video recording on	On / off	Identify video data availability
Phone activation	Determination of when phone is transmitting	On / off	Identify periods when the wireless phone is transmitting (i.e., in a call)

Sensors were installed in each test vehicle to assist with the determination of when wireless phone calls were taking place and to indicate this in the recorded data stream. The sensor used was the "MicroAlert" radio/microwave alarm from Alphalab Inc. This device produced an alarm whenever it detected radio waves stronger than the selected threshold level. The device was able to sense when a wireless phone was transmitting a signal within its range. The sensitivity of the device was set such that it would not detect phones in other nearby vehicles. The MicroAlert device was designed to emit an alarm when a signal was detected. However, the device was modified for use in the study such that a stepped voltage output was produced rather than an audible alarm. The "phone activation channel" recorded this output. An output value of "1" indicated in a wireless phone was transmitting within the test vehicle. A value of "0" in the data file indicated that no wireless phone was transmitting within the test vehicle at that time. This data channel was useful for quickly finding data for wireless calls while performing data reduction and analysis. However, due to occasional false alarms in urban areas some calls did have to be verified through manual review of video data.

Table 4 contains a list of dependent measures based on the MicroDAS data channels.

Table 4. Dependent variables derived from MicroDAS data channels

Dependent Variable(s)	Definition / Meaning	Units / Value	Collection / Calculation
Lane position	Lane position as determined using left and right lane tracker channels	Volts (converted to ft)	Average deviation from lane center determined using output from NHTSA-designed lane tracker
Number of lane exceedences	Number of times the test vehicle left its lane	Volts (converted to ft)	Determined using lane tracker data, vehicle width, and lane width flagging criteria to determine if the lateral vehicle displacement of the vehicle found it exceeding a lane boundary
Longitudinal deceleration	Severity of accelerations and decelerations	g	Determined by differentiating the speed channel data
Steering reversals	Number of steering reversals	Number	MicroDAS steering sensors; inputs >6 degrees were considered "valid inputs"
Throttle application percentage	Degree of throttle application	%	Two Leica sensor channels (MSB, LSB: Most/Least Significant Bit) were converted and combined using addition of constants and multipliers to obtain Leica_Throttle as a percentage. The mean and standard deviation of throttle percentage were computed for each data segment.
Time headway	Time to collision with a forward object at current relative speeds	Seconds	Calculated using Leica headway sensor Create channel that sets flag when range rate >0; Create channel that divides range by range rate; Average all values for which range rate was >0
Time headway, verified	Time to collision with a forward object at current relative speeds	Seconds	Calculated time headway values for which it could be confirmed (from video data reduction) that a lead vehicle was present and when range to this forward vehicle was greater than zero, were retained for analysis.
Vehicle speed	Subject vehicle velocity	Ft /s, mph	MicroDAS speed sensors

In-vehicle audio data were collected using a microphone installed in the vehicle. Participants' voices were recorded during hand-held wireless phone use to support the assessment of cognitive load as a function of conversation type. In-vehicle audio data were also recorded during baseline driving and non-call driving. Participants gave permission for video and audio data to be recorded by signing an informed consent form. In the two hands-free interface conditions, the microphone was switched such that it would turn off when the wireless phone was transmitting in the vehicle (to prevent recording the voice of the person on the other end of the phone line).

Digital (MPEG) video data were recorded using four cameras and synchronized to the engineering data. The driver's face was recorded using a video camera hidden in a compass mounted on top of the dashboard. This face camera incorporated an IR light source for nighttime illumination of the driver's face. Other video views included the forward road scene, driver's hands (view from over the right shoulder), and the central console area including the phone cradle. The cameras relayed signals to a quad-multiplexer, which combined the four video signals to be recorded as single quad-view video frames, via MicroDAS. Since the available MicroDAS video storage limit was 50 hours, a technician was sent out to retrieve the data at frequent intervals. Table 5 presents the dependent measures extracted through manual data reduction of MicroDAS video data. The processes used to manually reduce these video data to obtain phone use and eye glance metrics are described in Section 3.

Table 5. Dependent variables calculated from manually analyzed MicroDAS video data

Dependent Variable(s)	Definition / Meaning	Units / Value
Number of calls	Numbers of calls attempted/completed	Number
Dialing duration	Time period spent dialing	Seconds
Conversation duration	Time period spent listening and/or speaking during a call	Seconds
Traffic density	Vehicles observable in forward camera view at start of dialing or start of talking	Number
Glance location	Glance location, i.e., where driver is looking at a given time	Defined locations
Glance duration	Duration of the driver's glance dwell at a certain location	Seconds
Glance frequency to a given location	Number of glances to a given location	Number

2.5. PROCEDURE

Eligible participants were determined using a phone recruitment survey. Once an eligible participant was identified, an appointment was arranged with him/her for the vehicle to be delivered to their residence or workplace. At this appointment, informed consent paperwork was completed as well as presentation of instructions regarding test procedures and equipment use. Vehicles were delivered to the participant's home or workplace by an experimenter and a technician driving an "instruction vehicle." The instruction vehicle contained a television and video cassette recorder in the back seat, and was used to present video-based instruction to participants.

At the initial appointment, the experimenter reviewed the information summary with the participant (see Appendix A). The Test Participant Information Summary contained brief descriptions of the study, the in-vehicle instrumentation, and how the participant should care for the vehicle while in his/her possession. The summary also contained a list of the vehicle's safety features (e.g., driver's side air bag), and the type of in-vehicle technology present/functional in the vehicle. After reviewing the information summary, the participant signed an informed consent statement, as well as an information disclosure statement.

Also at the time of initial vehicle delivery, glance locations were calibrated. Participants were asked to look at each of 12 locations (listed in Section 3.2) for 10 seconds during which video was being recorded. This video provided video data reduction staff with a guideline to follow in the eye glance reduction process.

Lastly, the participant was instructed on how to use the first phone interface condition. Participants were provided with instruction, training, and handouts describing the use of the wireless phone provided in the vehicle, as well as an AutoPC manual. The first time the participants experienced either the hand-held or conventional hands-free wireless phone interface condition they were shown a video highlighting the manually controllable functions of the AutoPC (they were not shown this video twice). For the conventional hands-free condition, participants were provided with both written and verbal (provided by the experimenter) instructions on how to place and receive calls with that phone interface. For the enhanced hands-free condition, participants were shown a video demonstrating the voice controllable features of the AutoPC including the enhanced hands-free wireless phone function (Phone Base). At the start of each two-week period, participants were instructed in the use of the wireless phone interface they would be using for that two-week period.

Participants were asked to use only the phone provided to them for use in the experiment, rather than to use their own personal wireless phone. To minimize the inconvenience of having a different wireless phone number, participants were required to permit calls to their personal wireless phone to be automatically forwarded to the study phone.

After all information and instruction had been provided, the study staff left and the participant was free to drive the MicroDAS-equipped test vehicle on public roadways as part of his/her normal daily routine for 6 weeks (three 2-week periods). All driving was fully discretionary, and presumably would have taken place regardless of involvement in this study. This, together with the absence of an in-vehicle experimenter and the unobtrusive nature of MicroDAS, represent a comprehensive effort to gather naturalistic driving data with a minimum of experimental artifacts.

To ensure that, in the event of a vehicular or instrumentation failure, technicians could be easily dispatched to resolve the problem, participants were instructed not to drive the vehicles outside of the state of Ohio. This restriction was also used to prevent participants from taking road trips they might not otherwise take with their own vehicle and thus logging unnecessarily high mileage on the test vehicle.

At the end of the six-week test period, participants were interviewed, administered a brief questionnaire, and paid. The purpose of the questionnaire was to gather information regarding the participants' demographics, driving habits, opinions of the performance and handling of the test vehicle, and driver perceptions about the wireless phone interfaces used in the study. This questionnaire is contained in Appendix B and a summary of responses can be found in Appendix C. Participants were also asked about any problems or observations about the in-vehicle technologies, MicroDAS, the test vehicle, or any problems or unusual events that occurred.

Participants were also asked to submit their wireless phone billing records [showing incoming and outgoing call frequency, call duration, the conditions of call occurrence (e.g., time and location of incoming, outgoing, and attempted calls)] for the 3 months prior to their participation in the study. If participants agreed to provide such records, they were asked to sign an additional Informed Consent Form covering usage of their billing records. Participants were asked to mail the records to NHTSA. Upon receipt of these records, a participant was paid an additional $50. A baseline of each participant's normal wireless phone use could be estimated based on these billing records for the 3-month period prior to participation in the study. However, only two participants provided detailed billing information, leading to an inability to estimate normal phone use for most of the participants. Therefore, this information was not analyzed.

2.6. MAIN TEST DATA COLLECTION PERIODS

Due to constraints on the availability of vehicles and personnel, data was collected in two separate phases, with five participants in each phase. Both phases of data collection spanned the 2001-2002 time frame.

2.6.1. Phase 1 Data Collection Strategy

During the first phase of testing, data were collected according to event-based sampling criteria in an effort to minimize the volume of data collected and ease the search for events of interest. The MicroDAS was programmed to collect data at times when the vehicle was in operation and a wireless phone call was in progress, i.e., the "phone activation channel" was recording a value of "1". Measured parameters were sensed continuously and written to buffers in the MicroDAS. When a call was determined to be in progress, the MicroDAS triggered the data recording. Since sensor data was buffered, the 30 seconds prior to whenever the driver initiated a call was recorded, along with the 30 seconds after the end of the call. However, video data were not buffered. Therefore, video data were obtained from the time when the call was in place through when the call was terminated. As a result, only limited video data for dialing episodes (those which happened to occur during the two minute baseline segments) were available for Phase 1.

Baseline data were also collected for comparison. Data were collected continuously during the first two days a participant drove in a particular interface condition (beginning with the day that the vehicle was delivered, regardless of time of day). This permitted the collection of data when participants were engaging in normal driving, as well as when they were talking on the phone. After the first two days, baseline data were collected during the last 2 minutes of every 15-minute period, beginning with the point in time when the vehicle was started. At times when the start of the 2-minute period occurred while the participant was involved in a wireless phone call, the 2-minute baseline data window was not collected so as not to interrupt data collection during the call. Due to limited availability (low reliability) of mileage and driving duration metrics for Phase 1 data, this information is not readily available for exposure or phone usage analyses.

2.6.2. Phase 2 Data Collection Strategy

During preliminary data reduction and analysis of Phase 1 data (prior to the start of Phase 2 data collection), it was realized that, in order to adequately assess both driving performance during dialing and participants' willingness to engage in wireless phone calls as a function of traffic density, additional data was needed. Due to the event-triggered data collection strategy used in Phase I, video data for dialing episodes was only available for the baseline segments (first two days) of each interface condition. To obtain video of all possible phone dialing episodes, changes were made to the MicroDAS data collection scheme to permit data to be collected at all times when the vehicle was in operation (continuous sampling criteria), for every day the participants in Phase 2 had the vehicles. Although this resulted in a larger volume of data, identification of wireless phone call events was still expedited through use of the "phone activation" channel. In addition, baseline data could still be obtained for the last 2 minutes of every 15-minute period using the video time code to identify periods of interest. However, due to a lack of comparable data available in Phase 1 for some analyses, Phase 2 was the primary data set of analysis for some of the comparisons.

3.0 DATA REDUCTION AND ANALYSIS METHODS

3.1. DRIVING PERFORMANCE DATA REDUCTION

Driving performance data were extracted for periods of phone conversation. Each of the MicroDAS data channels listed in Table 3 was individually examined for data quality. Engineering (MicroDAS) data were processed, filtered, and reduced in preparation for reduction and analysis as described below. Some dependent measures were directly obtained from values in the engineering data channels, other values involved the counting of occurrences of events in the channel over a period of time (i.e., the first 30 seconds of a call), while others involved manual reduction of video data to obtain values of interest.

As stated in Section 1.2, distraction is assumed to promote the occurrence of observable characteristics of poor driving performance. Some researchers feel that drivers are likely to exhibit erratic driving inputs to compensate for errors in speed or lane position maintenance relating to decreased attention to the driving task. For the purposes of data reduction and analysis, good driving performance was defined as driving that involves:

- Minimal speed variability, low frequency of throttle reversals
- No lane exceedences, minimal lane variability, low frequency of steering corrections
- Maintenance of a safe following distance (assured clear distance)
- High rate of (appropriate) turn signal use
- Minimal "eyes-off-road time"; regular glances to forward roadway and mirrors, infrequent glances to in-vehicle devices

In addition, prolonged or poorly timed distraction episodes might lead to a situation in which the driver needs to take some crash avoidance action. To identify these situations, peak longitudinal and lateral accelerations were extracted along with peak steering input magnitudes and rates. These metrics were considered indicative of the lack of forward attention causing an obstacle avoidance scenario.

3.2. EYE GLANCE DATA REDUCTION

Eye glance (video) data were also reduced prior to analysis. For selected segments of baseline driving, dialing, and conversation, video images of the driver's face were manually reduced to identify eye glance location and duration. Initially, video data reduction staff attempted to resolve 12 glance locations. However, to increase the accuracy of analyses and simplify the process to a level sufficient for evaluation of desired hypotheses, some glance locations were later combined prior to statistical analysis, as shown in Table 6.

Table 6. Eye glance locations examined

Eye Glance Locations Extracted	Glance Locations Analyzed
Forward roadway	Forward roadway
Rear-view mirror	Rear-view mirror
AutoPC	AutoPC / phone
Wireless phone in cradle	
Over the left shoulder as though checking for traffic prior to lane change	Left
Out the left window as though looking at adjacent vehicle	
Left mirror	
Right mirror	Right
Out the right window as though looking at adjacent vehicle	
Over the right shoulder as though checking for traffic prior to lane change	
Speedometer, instrument panel	Other inside
Glance at a passenger	
Glances not defined by other locations	

Based on these glance locations, eye glance durations were extracted from the video recordings. MicroDAS video data files containing recordings of the face camera view were viewed on a personal computer using the MicroDAS Video Player program. Video files were typically viewed at half-speed (sometimes faster, depending on video quality). The person reducing the eye glance data referenced the video-recorded glance calibrations for each participant, before reviewing the data. Each glance location was assigned a different character key on a PC keyboard. The eye glance data analyst would attempt to determine (to the nearest video frame) when the subject shifted his/her gaze to a new location and press the appropriate key to indicate the start of a new glance. Thus, the time resolution of this measure was approximately the length of one video frame, or one-thirtieth of a second. No attempt was made to distinguish saccades (transitions between glances) from actual glances. As a result, glance durations include both the time that the eyes were focused on a particular location and time spent transitioning to the next glance location.

The MicroDAS Video Player recorded the key presses along with the video's time measurement of the event marked by the key press, and wrote these pieces of information to a line of text in a text file. One text file of glance start times was created for each MicroDAS video data file. Text files were later converted to Microsoft© Excel spreadsheets for analysis. Data in these files were formatted in two columns, in which the first column was the time of the current row's key press, and the second column was the time of next key press (or end of file if no more key presses). The following is an example of the text file format for a series of three key presses:

Glance ....KeyPress NextRowKeyPress

Forward.................................5.1 6.2

Left..6.2 7.5

Other inside 7.5 11.0

Glance duration calculations used each glance made by a participant, rather than by calculating an average glance duration for each participant. Glance durations were determined by calculating the difference between successive glance start times. Therefore, the duration of the glance was the difference between the two columns for a given row.

Thus, using the above example data, forward roadway glance duration can be calculated as follows: 6.2 - 5.1 = 1.1 seconds. By similar calculation, left glance duration in this example can be calculated to be 1.3 seconds and "other inside" glance duration is found to be 3.5 seconds.

3.2.1. Eyes-Off-Road-Time

For a given data segment (e.g., dialing, conversation, baseline), the durations of successive glances to locations other than the forward roadway were added together to produce a value representing the duration of time the eyes were focused "off road," or "eyes-off-road-time" (EORT). Thus, mean EORT for a data segment was defined as the average duration for which the driver's eyes were focused off road.

3.2.2. Glance Data Reduction Issues

This method of glance data reduction via manual key press of glance locations while viewing video was relatively easy. However, some problems were encountered during glance reduction. For example, video images were frequently too dark during nighttime driving to resolve glance locations (and occasionally the image was too bright due to sunlight). Human error was a factor in reducing eye glance data due to the monotony of the task, fatigue issues, and mistyped entries. As a result, accuracy of eye glance data reduced by this method is estimated to be approximately 85 percent based on the evaluation of small data sets performed in separately funded NHTSA research.

3.3. WIRELESS PHONE USE DATA REDUCTION

Using manual video data reduction methods, similar to those described above in reference to eye glance data reduction, values used to determine dialing duration and conversation duration were extracted. Video data analysts pressed a particular key on a computer keyboard to indicate the start of dialing, the start of conversation (indicated by pressing the "talk" button on the phone), and the end of conversation. Using these values, dialing and conversation durations were calculated.

3.4. METHODS USED FOR STATISTICAL ANALYSIS OF DATA

Analyses of the sensor and video data focused on the comparisons between the three wireless phone interface conditions. Data were analyzed by descriptive and inferential methods (e.g., analysis of variance). The analysis model included phone interface type (within-subjects) and participant as variables. The data were analyzed by means of the analysis of variance using the SAS® Proc GLM routine, Type III Sum-of-Squares. Outliers were not deleted from the data set unless they were clearly erroneous (e.g., a verified manual data reduction error for eye glance data).

4.0 RESULTS

4.1. SELECTION OF PHONE CALLS TO BE ANALYZED

Originally, it was assumed that the output from a phone activation sensor could be used to identify time frames in the data during which phone calls occurred. However, upon inspection of the video data, it was deemed there was too much 'interference' affecting the detection device, leading to erroneous information. Therefore, calls were categorized and labeled via video data reduction methods. This method identified a total of 731 phone calls made successfully while the participants occupied the vehicles. Upon reviewing the conversation durations and the comments made by the video reduction staff, the 731 calls were reduced to what were deemed to be 519 "good calls." The eliminated calls were ones in which a certain factor or combination of factors may have been present. These factors, or criteria, listed below, were necessary to maintain consistency across experimental conditions.

- Phone used by means of the wrong interface condition;
- Conversation durations being less than 30 seconds (assumed to be failed calls);
- Calls in which passengers dialed and used the phone rather than the participant;
- Calls made while the test vehicle was not moving (e.g., vehicle was in a driveway or parking lot with the vehicle in park);
- Calls in which not all data for a call was captured (such as in the case of Phase I where data was not collected all the time); and
- Calls made using the participant's own phone instead of the study phone.

The 519 selected calls were then used in analyses involving the comparisons among the three phone interface conditions. However, some planned analyses required a matched control sample. An interval of 30 seconds ending 15 seconds before each phone call was selected for use as the baseline, to maximize similarity in driving and environmental conditions between the baseline and conversation samples. These control (baseline) intervals were available for 223 matched pairs, obtained during the first two days of each interface condition in Phase 1 and all of Phase 2. (Note: to obtain matched pairs and account for data complications as previously mentioned, many metrics were based on a number somewhat less than the full 223 available). Figure 6 depicts the call screening and reduction process.

Thus, all analyses comparing a phone condition with a baseline counterpart reported here are based on the 223 calls having such counterparts available. However, when phone interfaces are being described, or compared to one another without the use of baseline information, these statistics cover the data available from the total possible 519 calls, unless otherwise noted.

To expedite data reduction and analysis, data for vehicle-based measures were only reduced for the first 30 seconds of conversation. Eye glance data were analyzed for both the first 30 seconds of conversation (for conversations of duration 30 seconds or greater) and the first 2 minutes of conversation (for conversations of duration 2 minutes or greater). Results based on data corresponding to these periods are presented in the following sections.

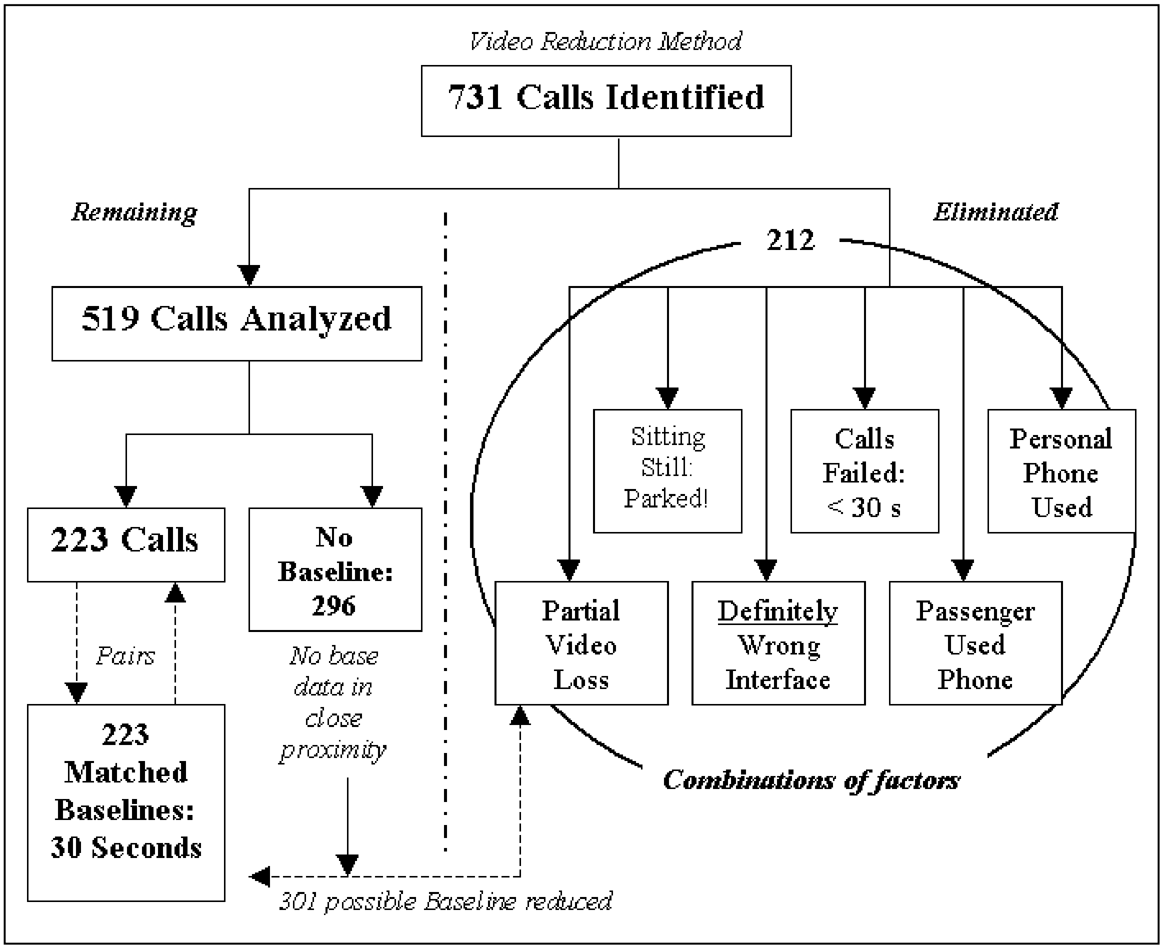

Figure 6. Phone call screening and reduction process

4.2. WIRELESS PHONE USAGE RESULTS

Wireless phone usage by participants while driving was examined. Types of calls examined included incoming calls, outgoing calls, and voice mail calls. The set of 519 calls, having durations of at least 30 seconds and made by the participant while driving and using the correct phone interface, was used in examining wireless phone usage behavior. The following sections present quantitative measures of phone usage described as a function of phone interface.

4.2.1. Number of Calls

The mean numbers of wireless phone calls per subject by phone interface condition (in a two-week period) are listed in Table 7. Outgoing calls included those made to persons as well as those made to check for voice mail messages. This metric also included calls in which it could not be determined whether or not the calls were incoming or outgoing due to video data limitations. Incoming calls included all calls answered by the participant (determined using video data). The relatively low number of incoming calls may be due to participants failing to program their personal wireless phones to forward calls to the study phones.

Table 7. Descriptive statistics for number of calls per subject by phone interface

Phone Interface	Dependent Measure	Mean	SD	Minimum	Maximum	Total
HH	Number of Calls	20	21.3	2	63	200
	Number of Outgoing Calls	18.9	19.8	2	59	189
	Number of Incoming Calls	1.1	0.8	0	4	11
CHF	Number of Calls	21	16.6	0	45	210
	Number of Outgoing Calls	21	16.6	0	45	210
	Number of Incoming Calls	0	0	0	0	0
EHF	Number of Calls	10.9	10.8	2	33	109
	Number of Outgoing Calls	9.7	9.7	1	26	97
	Number of Incoming Calls	1.2	2.3	0	7	12

The number of calls by phone interface was significantly different (F=3.68, P=0.0457). There were fewer calls with the EHF interface than with the other two interfaces (as shown in Table 7). The number of outgoing calls by phone interface was also significantly different (F=4.64, P=0.0237). One of the main reasons that the number of calls for the EHF condition was much lower than for the other conditions is that calls made using the wrong phone interface were not included in the analysis. In the EHF condition, some participants tended to dial manually rather than by using the hands-free dialing option of the in-vehicle computer, thus invalidating the call.

4.2.2. Traffic Conditions Under Which Calls Were Made (Traffic Density)

One of the hypotheses associated with this research stated that drivers would engage in fewer wireless phone calls in conditions of high traffic density. To assess whether traffic conditions affected a driver’s willingness to engage in a phone call while driving, traffic density was examined. Vehicles visible in the forward view video frame (excluding vehicles on side streets and in driveways) were counted for a specified 5-second period. Traffic density was calculated as an average of values from the available 5-second time frames pertaining to the calls, depending upon the availability of these time frames in the video data. These periods included the 5 seconds prior to initiation of dialing (for outgoing calls), the 5 seconds prior to pressing the send button (for both outgoing and incoming calls), and the first 5 seconds of conversation, as illustrated in Figure 7. For the baseline metric, the time frame used was the first 5 seconds of the 30 seconds of baseline data.

Table 8 presents observed traffic density by phone interface and baseline. The results show that the mean number of surrounding vehicles was highest during HH calls and lowest during EHF calls. This trend suggests that participants may have felt more comfortable making calls using the HH interface than they did using the EHF or CHF interfaces. One might expect mean traffic density to be higher for EHF than for the other two interfaces (due to the assumption that drivers would find the EHF interface easier to use); however, this was not the case. No statistically significant differences were found for traffic density as a function of phone interface. The lack of significant differences is attributed to the large variability in observed traffic density.

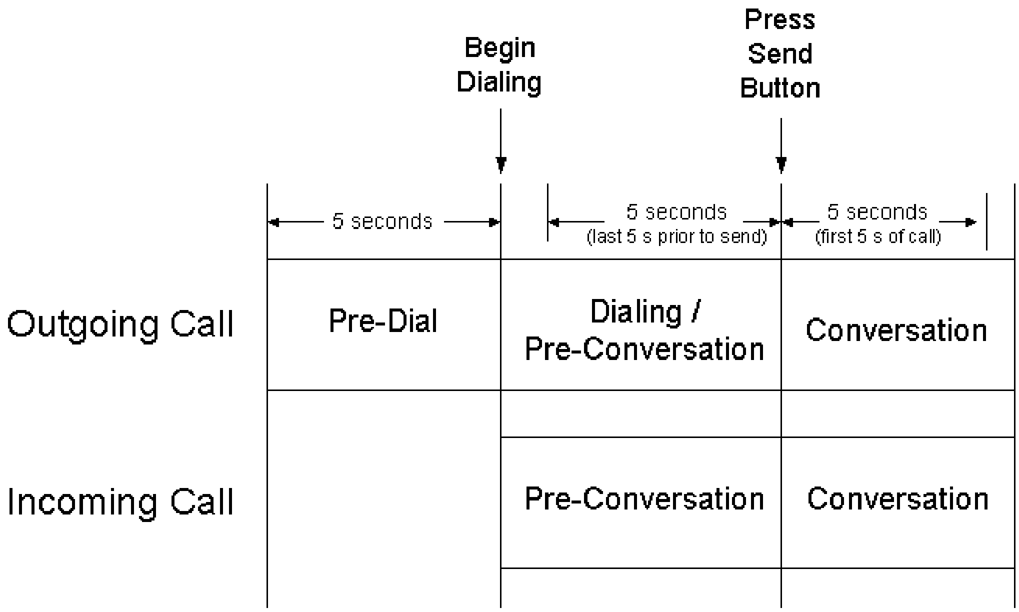

Figure 7. Illustration of time periods used in the extraction of traffic density data

Table 8. Descriptive statistics for traffic density by phone interface

	Traffic Density (Number of Vehicles)				
Phone Interface	**N**	**Mean**	**SD**	**Minimum**	**Maximum**
Baseline	184	6.5	7.4	0	50.0
HH	166*	4.5	5.3	0	28.5
CHF	210	4.2	5.0	0	30.7
EHF	109	3.2	3.4	0	21.0
All Calls (total)	485	4.1	4.8	0	30.7

*Note: No forward video on 34 of 200 cases.

Figure 8 contains a graph of the number of phone calls made as a function of traffic density, rounded to the nearest 0.5 vehicles. Results show that participants made fewer calls under conditions of high traffic density. Specifically, 92 percent of calls (445 of 485) were made when there were less than 10 vehicles present in the vicinity of the participant's vehicle.

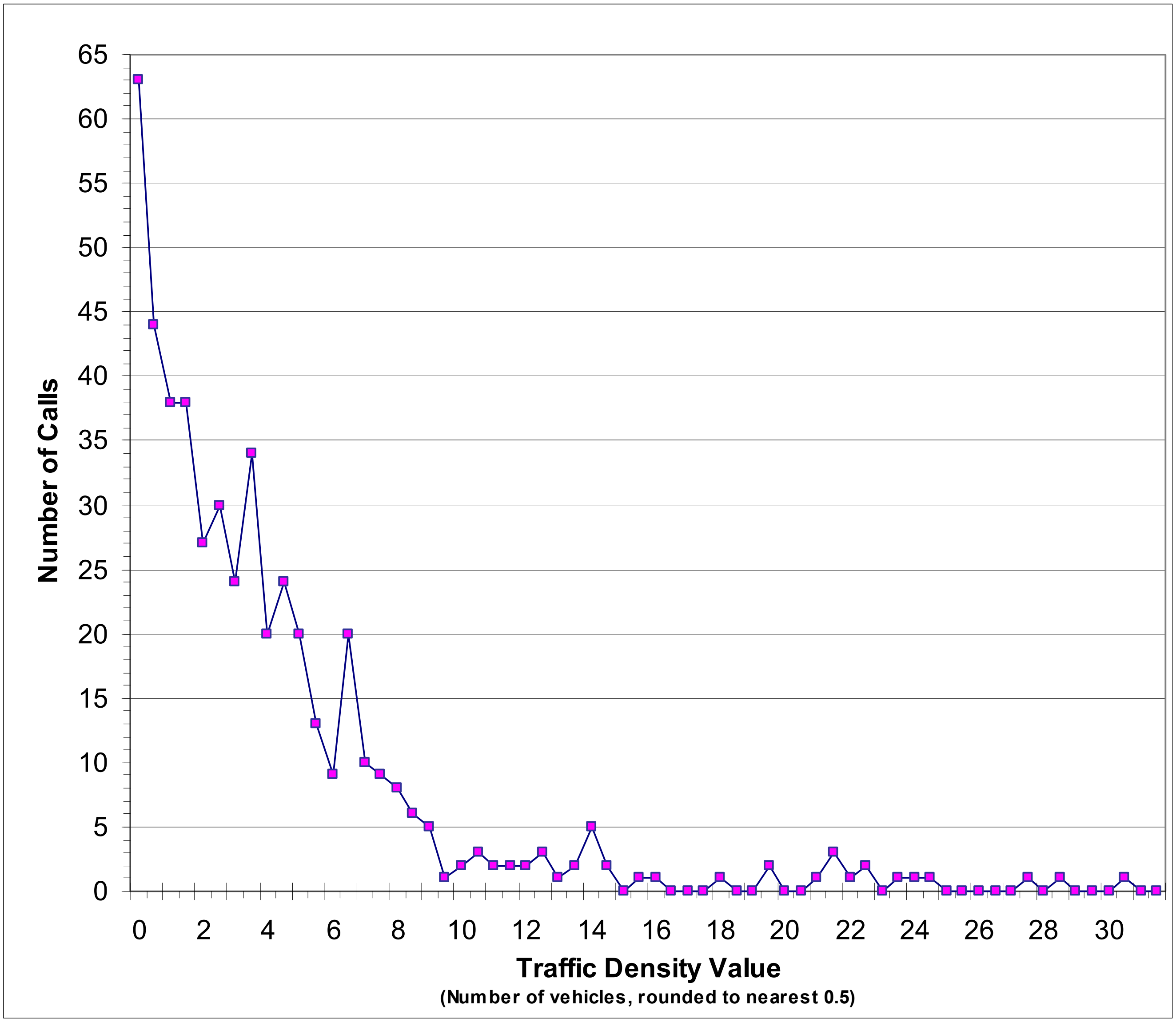

Figure 8. Number of phone calls as a function of traffic density

4.2.3. Dialing Duration

Due to several uncontrolled factors (such as video data loss, unavailability of dialing data for Phase 1, and variance in participants' phone usage patterns), dialing durations were not determinable for all of the 496 "good" outgoing calls. In fact, only 216 dialing durations were collected, which is approximately 44 percent of the number of good, outgoing calls.

Descriptive results for the dialing duration measure are presented in Table 9. The mean dialing duration was somewhat lower for the HH interface than either of the other two conditions. However, the difference was not significant at the $\alpha < 0.05$ level (F=0.83, P=0.4613).

Table 9. Descriptive statistics for mean dialing duration (s) by phone interface

Phone Interface	N	Mean	SD	Minimum	Maximum
HH	73	9.31	4.30	3.24	14.86
CHF	102	10.85	4.27	6.57	14.76
EHF	41	12.16	9.15	2.78	21.74

The mean dialing duration for the EHF condition was not significantly different from any other interface condition due to a large variability in dialing duration, which may suggest that some participants had difficulty performing the dialing task with this interface. Conversely, some participants used the "last number redial" feature, which resulted in shorter dialing times in some cases. Lastly, the operational definition of dialing used for data analysis did not capture the entire interval during which the participant may have been attempting to initiate a phone call. The definition used sought to maximize comparability between conditions. However, some calls involved significantly longer periods during which the driver was entering preliminary verbal commands needed to get to the point (i.e., "Phone Base") at which the dialing command would be accepted.

4.2.4. Conversation Duration

Conversation was defined to begin at the end of dialing as signaled by the "talk" button being pressed. Table 10 presents results for conversation duration by phone interface over both phases of data collection. Phone interface did not have a significant effect on conversation duration at the $\alpha < 0.05$ level ($F=0.04$, $P=0.9651$).

Table 10. Descriptive statistics for mean conversation duration (s) by phone interface

Phone Interface	N	Mean	SD	Minimum	Maximum
HH	200	187.97	250.82	50.63	292.83
CHF	210	135.56	181.39	66.45	206.19
EHF	109	136.54	185.03	35.72	210.72

4.3. DRIVING EXPOSURE AND PHONE USE

Exposure analyses were performed on Phase 2 data to determine how much the participants actually drove during the study. Mileage and driving time estimates were compared for each participant, and subsequently for each interface condition, to determine the amount of opportunity available to the participants to use the phone while driving.

Table 11 presents total driving hours, miles, phone calls, calls per mile, and calls per hour by interface condition. The results summarize the total driving of the five Phase 2 participants over their respective six-weeks of participation. Across all interface conditions, participants engaged in an average of 2.25 wireless phone calls per hour of driving, or 7 calls per 100 miles of driving.

Table 11. Phone usage rates by driving time and mileage (all Phase 2 moving calls)

Phone Interface	Driving Hours	Driving Miles	Number of Phone Calls	Calls Per Hour	Calls Per Mile
HH	100.3	2919	214	2.13	0.07
CHF	87.1	2549	213	2.45	0.08
EHF (*includes manual dialing instances)	109.2	3343	237*	2.17*	0.07*

The percentage of driving time spent on the phone for each interface is presented in Table 12. This table represents the calls made while the vehicle was in motion. Wireless phone calls took place during 5 to 9 percent of the driving time for Phase 2 participants.

Table 12. Percentage of driving time spent on phone calls (all Phase 2 moving calls)

Phone Interface	Driving Hours	Phone Calls (N)	Total Phone Hours	% Driving Hours
HH	100.3	180	9.13	9.1
CHF	87.1	163	5.79	6.7
EHF (*includes manual dialing instances)	109.2	214*	5.78*	5.3*

Conversation durations for these calls are shown in Table 13. Across all phone interface conditions, the average wireless phone call duration was 150 seconds (2.5 minutes) in length (SD = 210 seconds [3.5 minutes]). The longest call was approximately 27 minutes in duration. The median call duration was 1.2 minutes. Participants used the HH phone interface more often and for longer durations. More than half of the calls made in the EHF condition were made by dialing manually, rather than by voice dialing as instructed.

Table 13. Conversation durations (all Phase 2 moving calls)

Phone Interface	N	Mean Duration (s)	SD
HH	180	204.8	288.4
CHF	163	136.6	198.6
EHF (*manual interface)	93 121*	120.8 107.1*	174.0 138.9*

4.4. DRIVING PERFORMANCE RESULTS FOR VEHICLE-BASED MEASURES

This section presents driving performance measure results as a function of wireless phone interface, along with comparisons to baseline data. Unless otherwise noted, each dependent variable utilized the full experimental design in the statistical analysis. Results taken from partial designs are noted and reasoning given as appropriate.

As stated previously, a total of 519 calls were selected for analysis. However, only 223 calls had a suitable baseline segment associated with them. The 30-second baseline samples ended 15 seconds before the start of a phone call episode (dialing or answering). Summary measures computed over 30-second baseline and conversation intervals implicitly assume homogeneous (consistent) behavior over the entire sampling interval. Driving performance data such as speed,

speed variability, accelerations, and lane position were examined. The analysis was based on the assumption that measures of variability (e.g., SD of lane position) and extreme values (e.g., maximum lateral acceleration) were most likely to be influenced by minor deviations resulting from short-term distractions. Mean values (e.g., mean speed) were most likely to be influenced by more consistent changes in driving behavior.

The three wireless phone interface conditions provided an internal consistency check for the data. For example, both hands-free conditions used the same vocal interface, so they should have the same level of influence over driving conditions during conversation. Any observed differences between a hands-free conversation condition and a baseline or hand-held conversation condition are expected to be similar for both of the hands-free conversation conditions. Similarly, the hand-held and conventional hands-free conversation conditions both had the manual phone-dialing interface. Thus, any differences in driving effects would be expected to be similar for both of those conditions.

Five sets of analyses were performed on driving performance data. Each set of analyses used a different approach to parsing the data to achieve maximum homogeneity of driving conditions, while also providing for matching baseline comparisons as appropriate. Selection of an appropriate baseline was a significant challenge in the data analysis process.

For the first analysis of the 519 calls, the approach was to separate those calls into three groups according to the three phone interfaces, and use only the first 30 seconds of data at the beginning of the conversation. The use of the first 30-second time frames created a consistent sampling interval resulting in a more homogeneous data set while maximizing the number of possible calls available for the analysis. The following driving measures were examined:

- Lane exceedences and standard deviation of lane position
- Longitudinal deceleration: maximum and standard deviation
- Lateral acceleration: maximum and standard deviation
- Steering reversals
- Throttle position: standard deviation
- Speed: maximum, standard deviation, range, and speed changes
- Time headway

The results of Analysis of Variance (ANOVA) showed no meaningful differences among the three wireless phone interface conditions. On average, model R-square values were approximately 0.10, indicating approximately 10 percent of the variance was explained by factors in the statistical models.

For the second set of analyses, the subset of 223 calls was compared with the matched baseline samples. Again, the first 30 seconds of conversation were used for comparison of the three wireless phone interface groups with their respective baseline pairs of 30 seconds in duration. All pairs were used to compare phone conversation with matched driving, independent of the phone interface. Analyses were also conducted within and between interface conditions.

Analysis of the 223 calls with matched control samples (using t tests) showed driving behavior did not differ between phone conversation and matched control driving. There was a wide range of variation found among driving conditions, which introduced significant unwanted variability into the driving measures analyzed. These results motivated the search for better controls.

The third set of analyses looked deeper into the 223 matched pairs for a subset having homogeneous driving for both the conversation and baseline samples. The selection criteria included consistent road geometry and relatively constant driving speeds. Of the 223 matched pairs, 75 percent involved either stopping episodes (speed < 5 mph) or significant turns (lateral acceleration > 0.1 g). Only 24 of the 223 matched pairs (11 percent) actually satisfied the homogeneity criteria. For these 24 matched pairs, driving behavior still involved significant inconsistency, which created significant obstacles for conducting valid comparisons. Results of analyses of the 24 matched pairs showed no differences associated with phone use or interface condition.

A fourth set of analyses looked deeper into the original 519 calls (without matching baselines) for a subset having consistent homogeneous driving during the first 30 seconds of the phone conversation duration. Of the 519 calls, 149 calls (29 percent) involved no stopping or turning during the first 30 seconds of phone call conversation. The three wireless phone interface conditions were compared using the 149 calls with no baseline comparisons. No differences were found between phone interface conditions. Comparing the fourth analysis to the first analysis, the R-square values increased on average from 0.10 to 0.22. The controls provided an improvement of the homogeneity of the data, however, there was still a large percentage of unexplained variance (Mean = 78 percent) due to differences in driving situations.

A fifth set of analyses was performed to compare driving measures for the entire duration of the 519 calls (not just the first 30 seconds) with the 223, 30-second baseline samples (that were each 30 seconds in duration). These analyses were performed to test hypotheses that distraction effects were more likely during extended durations of a phone call, as opposed to the beginning of a call. In these analyses, some effects consistent with distraction were found between all interfaces and the baselines. No differences between interface conditions were found. Driving measures for baseline samples were less than all wireless phone interface conditions for:

- Standard deviation of lane position ($p = 0.04$)
- Maximum deceleration ($p = 0.06$)
- Standard deviation of speed ($p = 0.01$)
- Speed range ($p = 0.003$)

Caveats to the interpretation of these findings as indications of distraction effects exist. First, summary measures for baseline samples of 30 seconds in duration can be expected to be less than for calls with an average duration of 120 seconds. Second, most driving measures showed a significant correlation with call duration. Lastly, 90 percent of the calls involved stops or turns at some point during the conversation, and 63 percent of the baseline samples involved stops or turns, further challenging the validity of short baseline samples.

Due to the bias associated with the use of shorter baseline samples, a sixth set of analyses was performed using longer baseline samples. In this analysis, 1040 baseline samples were gathered. These baseline samples were taken from the last 2 minutes of every 15 minutes of driving (when there was not a phone call in progress), since the 2-minute data existed in both Phases 1 and 2. These samples were each 2 minutes in duration, and were compared with the entire duration of the 519 calls. Analysis of variance was computed using the data from the entire call durations and the 2-minute baseline samples. No significant results were found in these analyses, suggesting previous differences were due to incompatible 30-second baseline samples. Figure 9 provides a comparison between the 30-second baseline samples, the 2-minute baseline samples, and the three phone interface conditions for the standard deviation of lane position metric. The graph shows that the appearance of a difference in standard deviation of lane position differs according to which baseline is used.

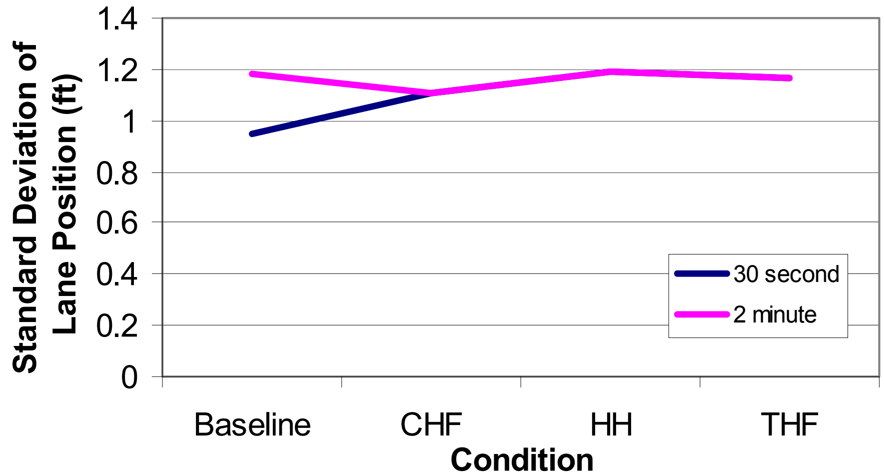

Figure 9. Standard deviation of lane position effects using different baseline samples

4.4.1. Limitations of Vehicle Based Measures

As stated in the previous section, 75 percent of the 223 matched pairs involved either stopping episodes (speed < 5mph) or significant turns (lateral acceleration > 0.1 g). A large percentage of unexplained variance was found due to differences in driving situations. Variability in driving conditions, including stopping and starting, created speed range and time headway values that represented driving conditions more than they reflected possible distraction effects. The variable driving conditions caused large degrees of observable variation in the vehicle speed and time headway data. As a result, these measures were dropped from the analysis.

4.4.2. Descriptive Statistics of Driving Performance Measures

Distraction effects on driving measures during dialing were examined using 216 dialing periods. No comparable baseline period was available. This analysis revealed no meaningful difference between interface conditions. The percent of explained variance for dialing averaged 16 percent (versus 10 percent for conversation). The short duration of dialing episodes was considered to be a disadvantage in terms of analysis of driving performance.

Tables 14 through 17 provide descriptive statistics for dependent measures of driver performance during conversation by phone interface and baseline. The four conditions corresponding to the tables are, in order: baseline, HH, CHF, and EHF. The measures summarize performance over the first 30 seconds of the 519 calls and 223 baseline periods. Some metrics were not available resulting in the exclusion of those calls from the analysis of a particular metric.

Table 14. Driving performance descriptive statistics for 223 baseline driving periods

Dependent Measure	N	Mean	SD	Minimum	Maximum
Lane Position Deviation (Ft)	214	-0.0641	0.9476	-3.5442	3.0837
Number of Lane Exceedences per Segment	191	0.34	0.74	0	5
Number of Turn Signal Activations per Segment	191	0.30	0.55	0	3
Number of Steering Reversals per Segment	191	7.37	4.70	0	24
Throttle Percentage	184	6.31	4.72	0.01	15.90

Table 15. Driving performance descriptive statistics for HH phone interface (200 of 519 calls)

Dependent Measure	N	Mean	SD	Minimum	Maximum
Lane Position Deviation (Ft)	160	-0.1786	0.8271	-4.8619	2.5660
Number of Lane Exceedences per Call	200	0.38	0.80	0	5
Number of Turn Signal Activations per Call	200	0.32	0.56	0	3
Number of Steering Reversals per Call	200	8.41	4.66	0	23
Throttle Percentage	175	6.56	5.01	0.18	19.54

Table 16. Driving performance descriptive statistics for CHF phone interface (210 of 519 calls)

Dependent Measure	N	Mean	SD	Minimum	Maximum
Lane Position Deviation (Ft)	178	-0.0773	0.7720	-3.5806	3.4271
Number of Lane Exceedences per Call	210	0.32	0.72	0	4
Number of Turn Signal Activations per Call	210	0.31	0.60	0	3
Number of Steering Reversals per Call	210	7.03	4.70	0	24
Throttle Percentage	183	6.23	4.33	0.08	16.81

Table 17. Driving performance descriptive statistics for EHF phone interface (109 of 519 calls)

Dependent Measure	N	Mean	SD	Minimum	Maximum
Lane Position Deviation (Ft)	83	0.0504	0.7813	-3.9949	4.3050
Number of Lane Exceedences per Call	109	0.43	1.04	0	8
Number of Turn Signal Activations per Call	109	0.32	0.52	0	2
Number of Steering Reversals per Call	109	8.14	4.78	0	22
Throttle Percentage	100	6.38	4.54	0.21	17.30

For metrics such as lane position deviation and throttle percentage, the standard deviation was an appropriate measure of the variability. In these cases, the standard deviation values will actually be the mean of the standard deviation values taken from each of the segments of data – the first 30 seconds of each phone call. With that in mind, the maximum and minimum values of metrics will be an actual mean value of a segment – the segment which was the maximum or minimum of the group of segments used for a particular condition such as wireless phone interface type, or baseline (unless otherwise noted).

No significant differences were found nor obvious trends observed for measures of driving performance. Mean lane position deviation per call was smallest for EHF, however this interface was associated with the greatest mean number of lane exceedences per call (0.43). The values for mean number of lane exceedences were slightly greater than the values for mean number of turn signal activations. Mean number of turn signal activations was essentially the same across all conditions, suggesting that phone use while driving may not have had an effect on drivers' use of turn signals. However, no attempt was made to determine whether driving conditions warranted turn signal use in this study.

In examining driver input frequency (i.e., frequency of inputs to correct vehicle position), mean number of steering reversals and standard deviation of throttle percentage were both greatest for the HH interface, followed by EHF, baseline, and CHF, respectively. This indicates that, on average, the HH condition was associated with participants making the greatest number of inputs to correct the vehicle's speed or position within the lane.

4.4.3. Cases of Significant Vehicle Motion as Possible Indicators of Distraction

In order to further study driver behavior beyond the descriptive data, a search was made for signs of driver inputs and vehicle motion characteristics having larger than typical magnitudes. Such signs might be useful in identifying situations of driver distraction. For example, greater than typical longitudinal deceleration values resulting from significant braking may reflect a failure to detect a potentially hazardous event. Previous, unpublished NHTSA research involving naturalistic data collection found that drivers rarely braked at a level that produced a deceleration greater than 0.25 g. Therefore, instances of deceleration greater than 0.25 g could be associated with a crash avoidance maneuver.

Two driving performance metrics were examined to determine whether phone use was associated with a higher likelihood of vehicle control inputs having large magnitudes and/or rates (i.e., possible incidence of distraction). Pre-defined thresholds of longitudinal deceleration and steering inputs were identified based on previous NHTSA research [6] involving drivers responding to an unexpected crash-imminent event. These thresholds are shown in Table 18. If a phone call had at least one event meeting one of the criteria, it was considered to meet the criteria for indication of the possible incidence of distraction. For example, a call during which a steering input of 45 degrees made at a rate of 260 deg/s was observed would qualify as an extreme event. Table 18 contains the number of calls meeting these criteria.

Table 18. Number of calls (N = 519) containing an instance of significant longitudinal or lateral vehicle motion

Event Type	Level	HH	CHF	EHF	Total
Longitudinal Deceleration (g)	N	198	206	108	512
	> 0.2	38	31	19	88
	> 0.3	3	3	3	9
	> 0.4	0	0	0	0
Steering Inputs (deg @ deg/s)	N	181	182	91	454
	> 45 @ 260	11	12	11	34
	> 60 @ 260	11	11	11	33
	> 45 @ 400	0	3	2	5
	> 60 @ 400	0	2	2	4

Longitudinal deceleration values were determined by differentiating the Leica Speed channel to obtain an acceleration channel. Before differentiating speed, data first had to be filtered using a 4 pole Butterworth lowpass phaseless filter with a 0.2 Hz break point frequency to smooth it out since the Leica Speed originally had a low sample rate, leading to a step appearance between differing speed values in the channel. After differentiation, a conversion constant of 0.0455854 was applied to arrive at the proper units. Results showed that 17 percent (88) of the 512 calls contained an event involving a longitudinal deceleration of greater than 0.2 g. Less than 2 percent of the 512 calls were associated with longitudinal decelerations of greater than 0.3 g.

Steering inputs having a rate of 260 deg/s were generally consistent across interfaces. For both magnitudes examined, steering inputs exceeding a rate of 400 deg/s were not observed for the HH phone interface condition, but were observed for the CHF and EHF conditions, although in very small numbers.

Table 19 contains the results sorted by phone interface for matched pairs in which the call met any of the large control input criterion. For calls, 15.6 percent contained an event involving a longitudinal deceleration of greater than 0.2 g, while 17.4 percent of the baseline events met this criterion. The percent of calls with longitudinal decelerations of greater than 0.3 g was also similar between baseline and calls at approximately 2 percent. Steering inputs having rates of 260 deg/s or greater were nearly twice as prevalent during calls than during their associated baselines, however no such trend was seen for inputs of greater than 400 deg/s. To suggest negative effects of distraction due to wireless phone use, baseline values in this table would need to be less than the corresponding call data values. However, there is no such consistent pattern present.

Table 19. Number of calls / baselines (223 matched pairs) containing an instance of significant longitudinal or lateral vehicle motion

Event Type	Level	Baseline HH	HH	Baseline CHF	CHF	Baseline EHF	EHF	Baseline Total	Call Total
Longitudinal Deceleration (g)	N	71	71	95	95	52	52	218	218
	> 0.2	12	12	20	14	6	8	38	34
	> 0.3	2	1	3	1	0	1	5	3
	> 0.4	0	0	1	0	0	0	1	0
Steering Inputs (deg @ deg/s)	N	65	65	83	83	44	44	192	192
	> 45 @ 260	2	5	4	5	2	5	8	15
	> 60 @ 260	2	5	4	4	2	5	8	14
	> 45 @ 400	0	0	2	2	0	1	2	3
	> 60 @ 400	0	0	2	1	0	1	2	2

4.5. HANDS ON STEERING WHEEL RESULTS

Video data were examined to determine when the driver had one, both or none of their hands on the steering wheel while driving and during wireless phone use. This timing information was used to determine the percent of time that hands were on the wheel during dialing, conversing, and baseline driving. These results are presented in Figure 10.

These data show that during baseline periods, drivers tended to have both hands on the steering wheel only 13.4 percent of the time. This number dropped to 2.5 percent during dialing and was 8.5 percent overall during conversation. On average, 72 percent of baseline driving involved drivers steering with only the left hand while 7.3 percent involved driving with only the right hand. Driving with no hands on the wheel was seen during 7.4 percent of baseline driving.

During conversation, participants drove with both hands on the steering wheel 16 percent of the time in the EHF condition, 12.7 percent of the time with the CHF interface, and 0.1 percent of time spent conversing using the HH interface.

During conversation using a hand-held phone, participants were seen to be driving with no hands on the wheel 10.8 percent of the time, with the remaining time spend steering with only the left (61.5 percent) or right (27.6 percent) hand. Surprisingly, the next highest levels of percent time spent driving with no hands on the steering wheel were associated with EHF baseline (9.8 percent) and EHF dialing (9.2 percent).

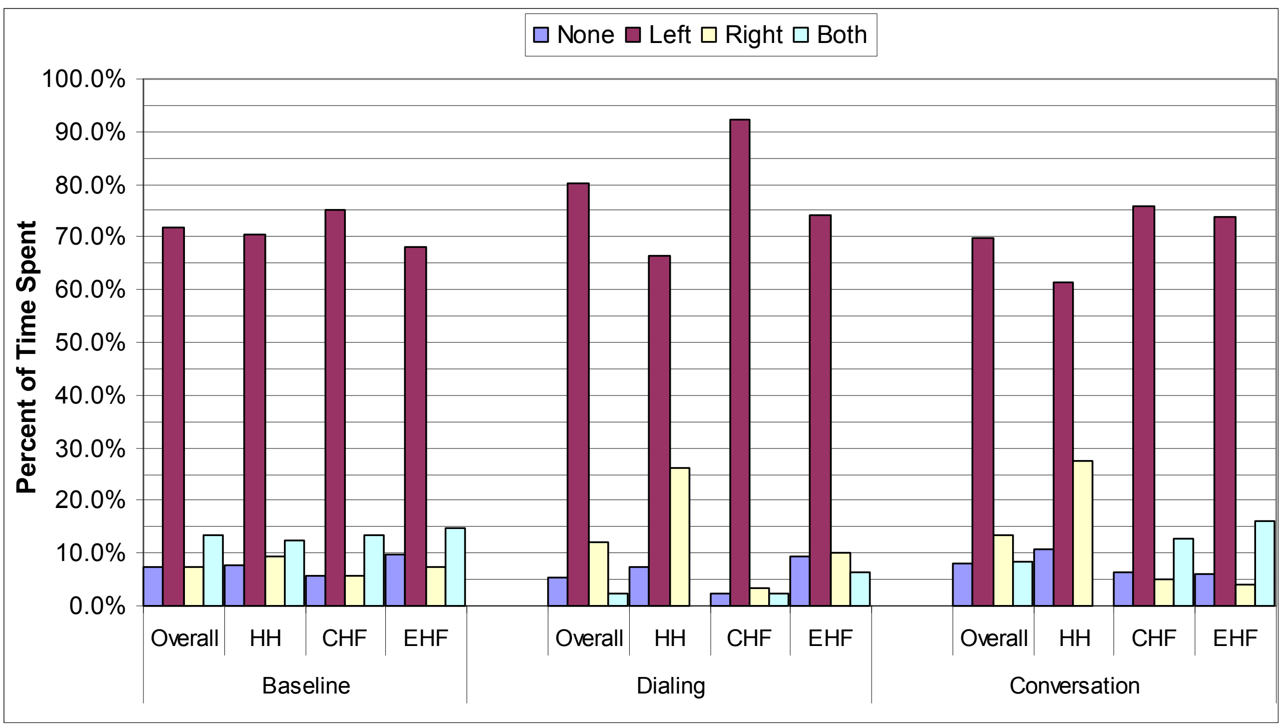

Figure 10. Percent of time that the left, right, or both hands were on the steering wheel by task and Phone Interface condition.

4.6. EYE GLANCE BEHAVIOR RESULTS

Eye glance analyses were performed for episodes of dialing, conversation, and baseline driving. Eye glance data for conversation periods analyzed included the first 30 seconds of conversation for conversations of duration 30 seconds or greater and the first 2 minutes of conversation for conversations of duration 2 minutes or greater. Results based on data corresponding to these periods are presented in the following sections. Analyses examined the number of glances, percent of glances, and glance durations to specific locations.

4.6.1. Eye Glance Data During Phone Dialing Episodes

Eye glance data were available from 216 dialing episodes. Table 20 presents the total number of dialing episodes, the total number of glances made to the AutoPC / phone during dialing, and the average number of glances to the AutoPC / phone per dialing episode. Although the total number of glances differed as a function of dialing interval duration, these data represent the number of glances required to accomplish the real-world driving task. More glances to the AutoPC / phone location were made when dialing in the CHF interface condition than with the other two interface conditions.

Table 20. Number of eye glances to the AutoPC / phone by phone interface during dialing

Phone Interface	Glances to AutoPC / Phone	Number of Dialing Episodes	Glances / Dialing Episode
HH	313	73	4.3
CHF	534	101	5.3
EHF	171	41	4.2

Table 21 shows the percentage of glances to each of the six glance locations by wireless phone interface for dialing episodes, along with baseline data. Since the "other inside" category includes glances to the speedometer, this indicates that participants did not glance at the speedometer during hand-held dialing, and rarely glanced at the speedometer during hands-free dialing. Figure 11 illustrates this point.

Table 21. Percent of eye glances by location and phone interface during dialing

Phone Interface	Forward Roadway	AutoPC / Phone	Other Inside	Rear-View Mirror	Left	Right	Total
HH	50.3	47.0	0.0	1.5	0.6	0.6	100.0
CHF	48.7	47.8	0.1	1.3	1.6	0.4	100.0
EHF	49.5	41.1	0.5	2.6	4.8	1.4	100.0
Baseline	48.2	9.3	12.0	15.3	11.0	4.3	100.0

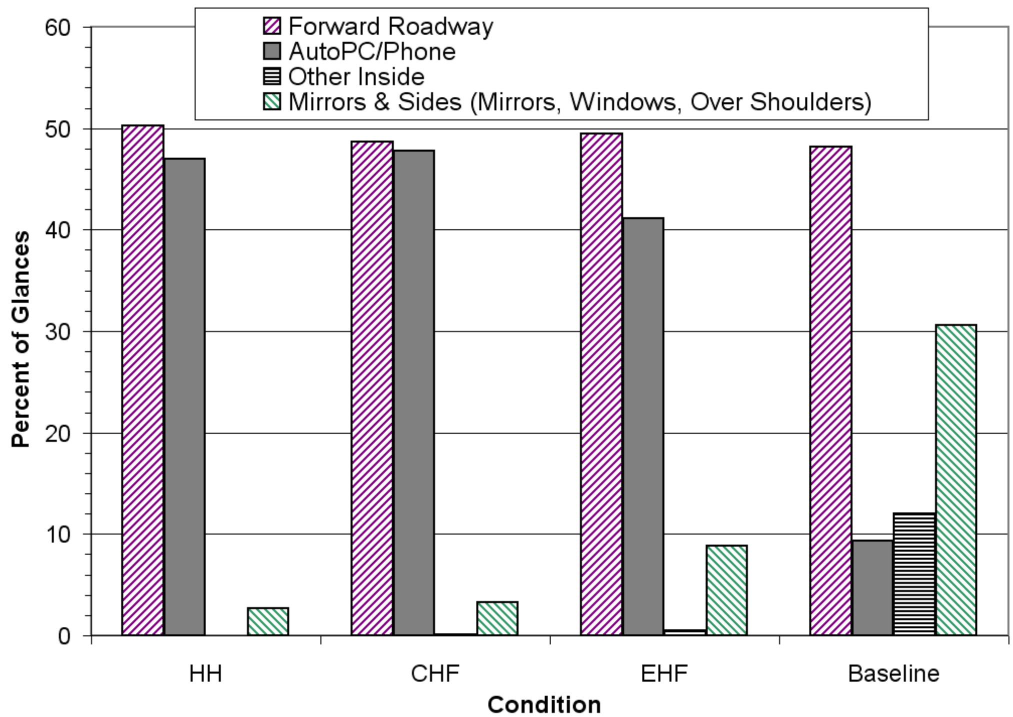

Figure 11. Percent of eye glances by location during dialing and baseline driving

Table 22 shows the proportion of glance time by location and condition for the dialing and baseline episodes. During dialing, participants glances shifted almost entirely between the forward roadway and AutoPC / phone locations, resulting in a negligible amount of time spent glancing at mirrors and "other" locations.

Table 22. Proportion of time spent glancing at various locations during dialing by phone interface

Phone Interface	Forward Roadway	AutoPC / Phone	Other Inside	Rear-View Mirror	Sides	Total
HH	0.39	0.60	0.0	0.01	0.01	1.0
CHF	0.38	0.60	0.02	0.01	0.01	1.0
EHF	0.49	0.46	0.0	0.01	0.03	1.0
Baseline	0.70	0.08	0.09	0.06	0.08	1.0

4.6.2. Eye Glance Characteristics During Initial 30 Second Conversation Episodes

Glance data results for conversation periods are presented below. This includes all glances recorded during the 519 30-second conversation segments and 223 30-second baseline periods.

The mean glance duration and mean number of glances per 30-second sample by phone interface are presented in Table 23. Participants' average glance activity was noticeably decreased during conversations (<15 glances per 30-second period) as compared to the baseline (22.8 glances per 30-second period). Participants glanced at fewer locations and showed longer mean glance durations for the HH phone interface as compared to the two hands-free conditions and baseline.

Table 23. Eye glance duration and number of glances by phone interface during conversation

Phone Interface	Mean Number of Glances per 30-Second Sample	Mean Glance Duration (Seconds)*
HH	8.6	2.65
CHF	13.9	1.75
EHF	14.8	1.80
Baseline	22.8	1.21

* Excludes first and last partial glances resulting from 30-second time interval chosen.

Table 24 presents the percentage of glances by location and wireless phone interface condition. These data show that participants glanced at the forward roadway more often during hand-held phone conversations than during hands-free phone conversations or baseline periods. Participants glanced more frequently at the rear-view mirror and other locations inside the vehicle (not including AutoPC / phone location) during baseline driving than when engaged in phone conversation. Relative to both conversation and baseline driving, participants glanced more often at the AutoPC / phone during dialing. In the hands-free phone interface conditions, participants glanced more frequently at the AutoPC / phone location and forward roadway than they did during baseline driving, at the apparent cost of glances to the rear-view mirror. During hand-held conversation, drivers glanced less frequently at the AutoPC location, as might be expected.

Table 24. Percent of eye glances by location and phone interface during conversation

Phone Interface	Forward Roadway	AutoPC / Phone	Other Inside	Rear-View Mirror	Left	Right	Total
HH	56.2	12.3	2.0	8.9	13.5	7.2	100.0
CHF	51.3	22.5	2.4	5.5	11.6	6.7	100.0
EHF	50.4	21.9	2.3	6.8	11.6	7.1	100.0
Baseline	48.2	9.3	12.0	15.3	11.0	4.3	100.0

Table 25 presents the proportion of glance time for each glance location and wireless phone interface condition for the 30-second conversation and baseline episodes. Relative to the baseline condition, participants glanced a larger proportion of time at the forward roadway during a wireless phone conversation using any interface. However, participants glanced less at the rear-view mirror and 'other inside' locations during wireless phone conversation as compared to baseline driving. Comparing the three wireless phone interface conditions, participants looked less at the AutoPC during hand-held conversations than during the other two conditions.

Table 25. Proportion of time spent glancing at various locations during conversation by phone interface

Phone Interface	Forward Roadway	AutoPC / Phone	Other Inside	Rear-View Mirror	Sides	Total
HH	0.88	0.04	0.0	0.01	0.06	1.0
CHF	0.78	0.12	0.01	0.02	0.08	1.0
EHF	0.76	0.11	0.01	0.02	0.10	1.0
Baseline	0.70	0.08	0.09	0.06	0.08	1.0

The mean glance durations during conversation (and baseline) for the six primary glance locations are provided in Table 26. Engaging in wireless phone conversation seems to have affected glance durations primarily by increasing glance durations to the forward roadway as compared to baseline driving. This is particularly apparent for the hand-held condition, for which glances to the forward roadway were longer during conversation than during baseline driving and hands-free conversation. Mean glance durations to the AutoPC / phone locations were extremely consistent, at 1.0 to 1.1 s across all conditions. Glances to the right were also similarly consistent, at 0.8 to 0.9 s.

Table 26. Mean eye glance duration (s) by location and phone interface during conversation

Phone Interface	Forward Roadway	AutoPC / Phone	Other Inside	Rear-View Mirror	Left	Right	Overall (across all glances)
HH	4.5	1.1	0.9	0.5	0.9	0.8	2.7
CHF	2.6	1.1	0.7	0.7	0.9	0.8	1.8
EHF	2.8	1.0	0.5	0.6	1.0	0.9	1.8
Baseline	1.8	1.1	0.9	0.5	0.6	0.9	1.2

Table 27 shows the proportion of glance time to all six glance location categories for the 223 matched pairs of conversation and 30-second baseline samples by phone interface. The proportion of time spent glancing at the forward roadway during conversation was approximately 12 percent less for the hands-free phone interface conditions than for hand-held. Participants appear to have had a tendency to glance at the AutoPC / phone location during hands-free conversation, as evidenced by the observed 15-16 percent of glances to that location for hands-free compared to only 7 percent for the hand-held condition. These data show that during hand-held phone conversation, participants' spent more time looking at the AutoPC / phone and forward roadway and less time looking everywhere else than during baseline driving. However, during conventional hands-free conversation, participants glanced at the forward roadway the same amount of time as in their comparable baseline periods. Both hands-free conditions differed from HH in that they were associated with very little difference in time spent looking at the right and left mirrors as compared to their baseline periods. The enhanced hands-free interface condition saw no difference in time spent looking at the AutoPC / phone condition as compared to baseline driving, but did show a slight increase in time spent looking at the forward roadway as compared to baseline.

Table 27. Proportion of eye glance time by location for conversation (223 matched pairs)

	HH (59 matched pairs)		CHF (76 matched pairs)		EHF (52 matched pairs)	
Glance Location	Baseline	Conversation	Baseline	Conversation	Baseline	Conversation
AutoPC / phone	0.043	0.068	0.065	0.161	0.152	0.149
Forward roadway	0.680	0.866	0.764	0.744	0.617	0.742
Left	0.069	0.035	0.037	0.043	0.051	0.056
Right	0.038	0.014	0.024	0.025	0.028	0.034
Rear-view mirror	0.073	0.013	0.046	0.018	0.050	0.016
Other inside	0.098	0.003	0.063	0.009	0.103	0.003
TOTAL	1.0	1.0	1.0	1.0	1.0	1.0

4.6.3. Eyes Off Road Time (EORT) During First 30 Seconds of Conversation

Eye glance data from the first 30 seconds of conversation and the baseline samples were analyzed to determine the time between individual glances to the forward roadway. This length of time between forward glances was defined as "eyes off road time," or EORT. Thus EORT encompasses all glances made to locations other than the forward roadway, such as glances to the mirrors, glances out the vehicle's windows, glances over the shoulder, and glances directed within the vehicle. The EORT results are presented in Table 28. Since EORT, as defined in this way, includes glances into the mirrors and over the shoulders, the metric does not necessarily imply that drivers are not attending to the driving task during the EORT glances.

Table 28. Eyes off road time during conversation vs. baseline

Phone Interface	Mean Off-Road Glance Duration (s)	SD	Percent of Off-Road Glances Longer Than 2 Seconds
HH	0.84	0.93	6.3
CHF	1.01	1.07	8.5
EHF	0.98	1.09	9.5
Baseline	0.83	0.99	6.9

On average, drivers glanced away from the forward roadway for periods of 1 second or less. While engaged in conversation using the hand-held interface, drivers' glances away from the forward roadway were somewhat shorter than in the other phone interface conditions. The percentage of glances greater than 2 seconds was also smallest for this interface. The characteristics of the EORT glances in the hand-held interface condition were most similar to those for the baseline condition.

4.6.4. Eye Glance Behavior During Conversations of Duration 2 Minutes or Longer

The subset of phone conversations that lasted at least 2 minutes were also examined to determine whether eye glance behavior changes during the course of a conversation. There were 171 such calls (CHF = 55; HH = 81; EHF = 35). We segmented the eye glances recorded during the first 120 seconds of these calls into 4 30-second segments and looked at the total amount of time spent looking at three primary locations including the forward roadway, inside the vehicle, and to the right or left. Figure 12 shows the percentages associated with these three glance locations by 30-second segment. This figure shows that as the conversation progresses, the percent of time spent looking at the forward roadway gradually increases from 80 percent to nearly 90 percent. Meanwhile, the percent of time spent glancing at locations within the vehicle gradually decreased from approximately 7 percent to 2 percent. The percent of time spent looking left and right also gradually decreases from approximately 9 percent to 6 percent.

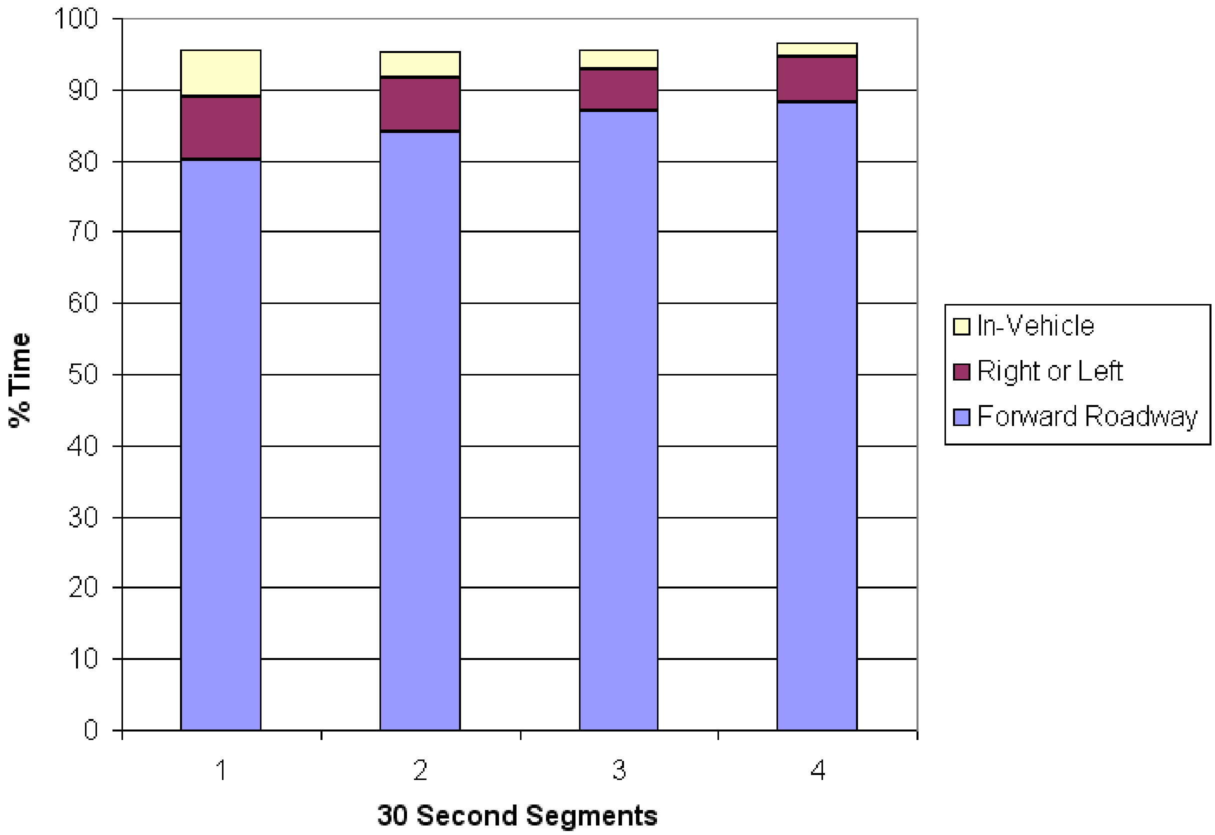

Figure 12. Aggregate percentage of time spend looking inside and outside the vehicle by 30 second segment of phone conversation (N = 171 calls of minimum duration of 120 seconds)

Figure 13 presents the percentages of time spent looking at the same three locations separated by 30-second phone conversation segment and interface condition. This figure shows that as the duration of the conversation increased, participants spent more time looking at the forward roadway. The trend was evident for all three phone interface conditions. In addition, the CHF condition was associated with a higher percentage of time spent looking inside the vehicle than the other two interface conditions. The EHF interface condition was associated with a higher percentage of time spent looking right or left during phone conversation than was seen for the other two interface conditions. Lastly, when using the HH interface, the drivers spent the least amount of time looking inside the vehicle during the phone conversation.

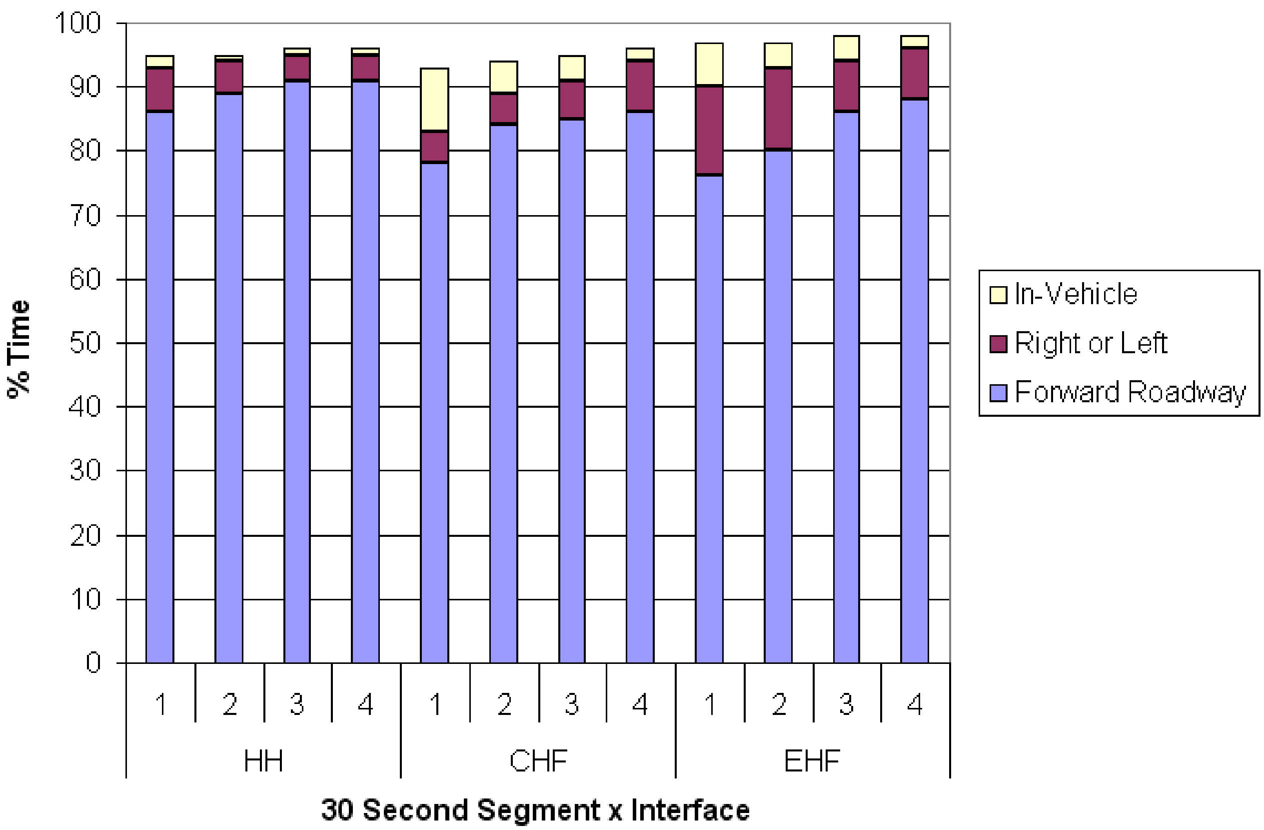

Figure 13. Aggregate percentage of time spend looking inside and outside the vehicle by 30 second segment of phone conversation and interface condition (phone calls of minimum duration of 120 seconds)

4.6.5. Comparisons of Eye Glance Data Between Dialing and Conversation

Table 29 presents the proportion of total glance time for selected locations during dialing and the first 30 seconds of conversation by phone interface, including baseline driving. Generally, drivers looked proportionally more often at the AutoPC / phone while dialing and at the forward roadway during conversation. Voice dialing was associated with a slightly higher proportion of time spent looking at the forward roadway relative to manual dialing.

Table 29. Proportion of glance time comparisons between dialing and conversation (first 30 s)

Phone Interface	Task	N	AutoPC / Phone	Forward Roadway
HH	Dialing	73	0.60	0.39
	Conversation	191	0.04	0.88
CHF	Dialing	101	0.60	0.38
	Conversation	199	0.12	0.78
EHF	Dialing	41	0.46	0.49
	Conversation	107	0.11	0.76
Baseline	Driving	182	0.08	0.70

5.0 DISCUSSION

The goal of this research was to gather data from which to draw inferences regarding whether any potential safety benefits exist for a hands-free wireless phone interface over a hand-held interface. These inferences would be drawn by examining drivers' frequency of phone use, phone use performance, driving performance during phone use, and eye glance behavior during phone use.

5.1. PHONE USE

This study sought to assess whether (presumed) ease of use might lead to increased prevalence of use. Hands-free wireless phone functionality is intended to free the drivers' hands to steer the vehicle, therefore promoting safety and increasing ease of use. Some believe that increasing ease of use through the provision of a hands-free interface may promote increased use. Thus, the first two hypotheses for this research asserted that drivers will make more calls and longer calls with a hands-free phone interface than with hand-held.

5.1.1. Number of Calls

The hypothesis that drivers will make more calls with hands-free phones than with hand-held phones due to increased ease of use was not supported by the results of this study. Tables 7 and 9 showed that participants used the hand-held wireless phone more, in terms of number and duration of calls, than the two hands-free conditions. Greater familiarity with hand-held over hands-free phone interfaces may have contributed to this finding.

5.1.2. Conditions Under Which Drivers Choose to Make Calls

This study also sought to determine the nature of the relationship between driving conditions (e.g., traffic density) and willingness to be distracted. Thus, a third hypothesis stated that drivers would make fewer calls under conditions of higher traffic density. Results showed that a majority of calls were made when there were fewer than 10 vehicles present in the vicinity of the participant's vehicle. Mean traffic density during calls (4.1 vehicles) was less than the mean traffic density for baseline periods (6.5 vehicles). This result suggests support for the noted hypothesis. However, based on this data it is not possible to show that the percentage of calls made under high-density traffic conditions is less than the percentage of driving under the same conditions. Traffic density was highest during hand-held phone calls (4.5 vehicles), followed by CHF (4.2 vehicles) and EHF (3.2 vehicles), respectively. Participants' willingness to engage in calls with the HH interface under higher traffic density conditions may again be attributable to familiarity with the phone interface. Participants' conceptual idea of the degree to which they would be able to maintain their visual attention on the forward roadway during a call may have also impacted the decision to engage in a call under higher density traffic conditions.

There was a wide range of variation found among driving conditions, which introduced significant unwanted variability into the driving measures analyzed. Of the 519 calls, 71 percent involved a stopping (speed < 5 mph) or turning (lateral acceleration > 0.1 g) event during the first 30 seconds of phone call conversation. Of the 223 matched pairs, 75 percent involved similar stopping or turning events. Many calls were initiated while the vehicle was stationary, such as in a parking lot, or at the onset of a drive. Most calls were conducted under conditions of low traffic density, however information about other aspects of the driving conditions are not available.

5.1.3. Dialing Duration

Dialing durations were longer for the hands-free phone interfaces than for the hand-held interface. On average, dialing durations for the EHF interface were approximately 31 percent longer than durations for the HH interface, with the CHF interface falling between these. The observed difference in dialing duration was not significant due to the large standard deviation for EHF dialing duration values. However, the operational definition of "dialing duration" used here may have limited the magnitude of the difference observed between these phone interface conditions. This definition was created to maximize comparability between the three wireless phone interface conditions. The dialing durations covered the time frames from when the phone number entry commenced to when the 'send' function was inputted (manually or verbally). Therefore, some of the voice interaction interface commands a participant used to navigate around the AutoPC to get to the phone number entry mode were not part of the dialing duration as it was defined. In some cases of frustration where the system was not responding correctly, these command navigating actions took a significantly longer period of time. So, the operational definition of dialing did not capture some of the intervals during which participants were attempting to initiate phone calls in the enhanced hands-free interface condition. Otherwise, significantly longer dialing times may have been found for the enhanced hands-free dialing condition.

5.1.4. Conversation Duration

The second hypothesis, "Drivers will make longer calls with hands-free phones than with hand-held phones due to increased ease of use," was not supported for the interfaces used in our study. Hand-held conversation duration turned out to be somewhat greater than both the conventional hands-free and the enhanced hands-free conversation durations, as shown in Table 9. Although phone interface was not found to have a significant effect on conversation duration at the $\alpha < 0.05$ level, the results suggest that increased ease of use may not have been afforded by the hands-free conditions.

5.2. DRIVING BEHAVIOR DURING PHONE USE

The effects of phone use on driving behavior were examined during episodes of both conversation and dialing. Since phone use data were captured for Phases 1 and 2, both phases were used in these analyses (10 participants), with the purpose of determining differences among the three interface conditions.

Distraction is assumed to promote the occurrence of observable characteristics of bad driving performance. Thus, in order to address these hypotheses, an operational definition of "good driving performance" was established, as noted in Section 3.1. Any decrement in driving performance noted here, is assumed attributable to wireless phone related distraction. The following hypotheses were set forth regarding driving performance during wireless phone use:

1. Driving performance is improved when drivers use enhanced hands-free phones over when they use hand-held or conventional hands-free phones.

2. Driving performance is improved when drivers use conventional hands-free phones over when they use hand-held phones.

As seen in the analyses, some effects consistent with distraction were found when comparing the entire call of the 519 calls with the 30-second baseline samples preceding a call. The differences found were not between the wireless phone interface conditions, but were between the baseline samples and all of the wireless phone interface conditions. However, it was noted these differences were most likely due to the short duration of the baseline samples. No meaningful differences were found between the three wireless phone interface conditions.

General differences between driving conditions also reduced the sensitivity for detecting differences, thereby masking distraction effects. This created driving behavior that was not consistent during phone calls. The low R-square values reflected the large contribution of situational variability in the driving conditions. Samples involving stops and turns invalidated summary measures such as lane position, steering, and speed behavior. Eliminating conversation samples with stops and turns may have somewhat increased the amount of explained variance, but it also reduced the sample size by 75 percent or more.

5.2.1. Driving Behavior in Terms of Longitudinal Vehicle Control

No significant differences were found nor obvious trends observed for measures of driving performance in terms of longitudinal vehicle control. Observations regarding specific metrics follow.

The examination of speed range during conversation was intended to address an anecdotal hypothesis that drivers may gradually slow down during a wireless phone call due to decreased attention to speed maintenance. This hypothesis assumes that drivers are using the phone on a highway where the driver would try to maintain the speed limit throughout the call without having to stop to respond to traffic control devices. However, as stated previously, 71 percent of the 519 calls and 75 percent of the 223 matched pairs involved stops (speed < 5 mph) or significant turns (lateral acceleration > 0.1 g) during the conversation period examined (first 30 seconds of phone call). Due to this large percentage of call segments involving stops or turns, it was difficult to determine whether any changes in speed would be due to phone use or roadway-related factors. Therefore, it was not possible to confirm this anecdotally reported phenomenon.

Mean vehicle speed was examined for each data segment. For each data segment, the mean, minimum, and maximum speed values were extracted. However, since the road type (e.g., arterial, highway) and speed limits were not determined, it was not possible to distinguish the cause of speed variations. Thus, mean vehicle speed without information about driving conditions was not found to be useful.

Time headway was calculated using data obtained from a Leica laser range sensor located on the front of the test vehicles. Time headway equaled the range (R, distance) to a forward (lead) vehicle divided by the speed of the subject vehicle (V, velocity). Due to difficulties with the sensor reliability and variation in available traffic conditions affecting time headway measures, there was not enough time headway data available for analysis. Less than 13 percent of calls had available headway data.

Increased throttle deviations may be interpreted to indicate the driver is more active, or attentive, in trying to maintain his/her longitudinal position. Standard deviation of throttle percentage was highest for the HH condition. This finding is not surprising given that participants spent a larger proportion of time glancing at the forward roadway and exhibited longer individual glances to the forward roadway. Thus, participants had greater opportunity to monitor the distance to forward vehicles.

5.2.2. Driving Behavior in Terms of Lateral Vehicle Control

Increased steering deviations, or corrections, would suggest poor lateral control. No significant differences were found nor obvious trends observed for measures of driving performance dealing with lateral control. Mean lane position deviation per call was smallest for EHF, however this interface was associated with the greatest mean number of lane exceedences per call (0.43). The values for mean number of lane exceedences were slightly greater than the values for mean number of turn signal activations. This suggests that wireless phone use while driving was not associated with more inadvertent or unsignaled lane excursions than driving while not on the phone. Mean number of turn signal activations was essentially the same across all conditions, suggesting that phone use while driving may not have had an effect on drivers' use of turn signals. However, no attempt was made to determine whether driving conditions warranted turn signal use in this study.

5.2.3. Results for Extreme Driver Inputs as Possible Indicators of Distraction

Driving performance data were examined for potential indications of driver distraction including extreme driver inputs and vehicle motion that might suggest the occurrence of an evasive or aggressive recovery maneuver. Two driving performance metrics were examined to determine whether phone use was associated with a higher likelihood of vehicle control inputs having large magnitudes and/or rates (i.e., possible incidence of distraction). This examination, however, showed no clear trends that would suggest that phone use-related distraction may have led to an increase in evasive or aggressive maneuvers. Although the analysis of the 519 calls showed that 30 percent of calls involved an incident of longitudinal deceleration greater than 0.2 g, analysis of the 223 pairs showed an equal percentage of incidents of longitudinal deceleration greater than 0.2 g for both calls and baseline segments. To suggest negative effects of distraction due to wireless phone use, baseline values in this table would need to be less than the corresponding call data values. However, no such consistent pattern was detectable. Furthermore, no noticeable patterns across phone interface conditions were seen.

5.2.4. Data Availability Issues

Some problems experienced during this study resulted in less data being collected than was planned. Participants made fewer calls while driving than was originally expected. In fact, a large number of calls were made when the vehicles were stationary. Many participants started using the phones while in driveways, parking lots, or other locations where they were either parked or moving at a slow speed. The data acquisition system, which turned on when the vehicle was started, took a few moments to boot up. Video data for calls that took place while the data acquisition system was booting could not be obtained. Thus, both phases of data collection had some loss of data during the first few moments of each drive (approximately 90 seconds), while the computer went through its startup process.

Due to legal issues associated with recording audio of non-participants on the other end of the phone line, audio data could not be recorded during either of the hands-free conversation modes. Audio data of the driver's side of the conversation was available during the hand-held conversation mode of phone interaction. These recordings of the driver's side of the conversation will later be part of a conversation content analysis effort to be reported on separately.

5.2.5. Data Quality Issues

Many data quality issues were encountered which, unfortunately, are inherent to naturalistic data collection. These issues involved: (1) difficulty in distinguishing the true cause of changes present in driving performance metrics, (2) the high degree of unanticipated variability in driving conditions observed in this study, and (3) the quality of roadways and lane lines which affected driver's ability to control lane position and the performance of lane tracking sensors. The differences seen between the three matched pair baselines (one per interface condition; e.g., Table 19) reflect the differences in driving conditions encountered in the study.

Issues related to the roadway lane line quality, lane-tracking devices, and weather or environmental conditions also posed problems. The lane deviation is a channel derived from lane tracking devices detecting patterns such as edge lines on the roadway. On many roads, lane-marking lines either do not exist or are in poor condition, such as during construction on highways. Thus, the lane trackers will either flag the data as unavailable or detect some other parallel edge to track (such as a curb, road edge, snow plow line, and so on). For example, the minimum mean lane position value in Table 15 is -4.86 feet, signifying that the vehicle was on average 4.86 feet to the left of center during one particular call, for the duration of 30 seconds. Upon looking at the video, it was seen the driver was in a construction area atop a difference between two paved surfaces (the adjoining of the old and new surface), which was the focus of lane tracker detection. The driver, however, did not vary from center as was seen by both the video and the standard deviation value of the segment (0.08 feet). Thus, the data is correct but could be misinterpreted if collection methods were not understood.

5.3. EYE GLANCE BEHAVIOR DURING PHONE USE

In regards to dialing, the assumption was tested that when dialing using a voice dialing-capable, hands-free wireless phone interface, drivers can keep their eyes on the road more than they can while dialing a hand-held phone. However, anecdotal observations had led to the belief that drivers might still be looking at the hands-free wireless phone interface during conversation. While it is true in this study that participants looked at the forward roadway a larger percentage of the time when dialing with the EHF (voice dialing) interface (49 percent) than with the HH interface (39 percent), participants using the EHF interface glanced nearly an equal amount (46 percent) at the AutoPC / phone location. This phenomenon results in essentially no net benefit in terms of visual behavior. The opportunity that drivers using the EHF interface could take advantage of to improve their awareness of the surrounding environment was wasted making unnecessary glances at the phone interface. Voice dialing exhibited a modest benefit relative to manual dialing, but still involved a 20 percent reduction in the time spent looking at the forward roadway, relative to the baseline samples. Not surprisingly, participants looked away from the forward roadway location more during dialing episodes than during phone conversation.

A number of observations were made regarding the initial 30 seconds of conversation. In general, participants were observed making fewer and longer glances during conversation then they did during baseline driving. Mean glance durations were longer during initial conversation than during baseline driving, ranging from approximately 46 percent longer when using a hands-free interface to 120 percent longer when talking using a hand-held phone interface. Glances to the forward roadway were 150 percent longer during hand-held conversation than during baseline driving, while the durations of glances to other locations were generally similar. Compared to baseline driving, participants made 62 percent fewer glances during hand-held conversation 39 percent few glances when talking using the CHF interface and 35 percent fewer glances when talking using the EHF interface. Decreased visual scanning behavior can be interpreted as a sign of cognitive distraction, or possibly biomechanical interference, in the case of the hand-held phone interface.

This study also tested the hypothesis that drivers will spend more time looking away from the forward roadway while talking on a hands-free phone than while talking on a hand-held wireless phone. Specifically, drivers may have a tendency to glance at a hands-free wireless phone during a call. This hypothesis was supported by observations during the first 30 seconds of conversation, in which participants spent 24 percent of the time glancing at the forward roadway when conversing using the CHF interface and 22 percent of the time when using the EHF interface, compared to only 12 percent for the hand-held phone interface. Participants spent more time looking away from the forward roadway during baseline driving (30 percent) than during any of the three wireless phone interface conditions.

Glances to other locations were also affected during conversation as compared to baseline driving. The HH interface was also associated with fewer glances to the left and to the right as compared to the hands-free interfaces, suggesting a decrease in lateral situational awareness when conversing with a hand-held phone. Participants were less attentive when using hands-free interfaces than during the baseline driving samples, since 10 percent of the time involved looking at the AutoPC / phone. Participants also glanced at the rear-view mirror slightly less when conversing with an enhanced hands-free (6.8 percent) or conventional hands-free (5.5 percent) phone interface than when conversing with a hand-held phone (8.9 percent).

5.3.1. Eye Glance Behavior During Conversations of Duration 2 Minutes or Longer

Examination of eye glance behavior for conversations of 2 minutes or longer showed a clear trend toward increasing time spent looking at the forward roadway as the phone conversations progress. Associated with this trend is a corresponding decrease in time spent looking inside the vehicle, which may suggest a gradual increase in vigilance as the driver becomes settled into the phone conversation. However, there was also a slight decrease in the proportion of time spent looking left and right as time progresses, which may be an indication of a slight decrease in active scanning of the roadway.

The trend toward increasing percentage of time spent looking at the forward roadway as the phone conversation progresses was evident for all three phone interface conditions. In addition, there were several striking differences between the interface conditions. Specifically the CHF condition was associated with a higher percentage of time spent looking inside the vehicle than the other two interface conditions. Secondly, the EHF interface condition was associated with a higher percentage of time spent looking right or left during phone conversation than is seen for the other two interface conditions. Thirdly, when using the HH interface, the drivers spent the least amount of time looking inside the vehicle during the phone conversation.

It is not possible to interpret these data with certainty due to the uncontrolled differences in driving conditions. As a result, the comparisons across time within the same set of phone calls are probably more informative than comparisons between different groups of calls (i.e. between interface conditions). Moreover, it is not prudent to perform statistical tests on these data as the inclusion of multiple calls from a small sample of drivers violates the underlying assumption of independent observations. The combination of glances from different calls with those from the same call creates a similar problem. However, the consistent pattern of increasing percentage of time spent looking at the forward roadway is provocative and worthy of further consideration in experimental studies. Whereas an increase in the percentage of time spent looking forward would seem to indicate an increase in attention to the immediate driving situation, the associated decrease in glances to either side suggest that caution is necessary in making this interpretation. Rather, it might be the case that the increased percentage of time spent looking straight ahead corresponds with a decrease in overall attention to the driving scene as drivers become more cognitively involved in their phone calls. This possibility recalls the common category on police accident reports of "looked but did not see."

5.3.2. Eye Glance Data Validity

Consistencies in the eye glance data showed that glance location differences were more robust than other driver behavior measures. Glance behaviors associated with wireless phone use appear to be independent of the driving situation. The validity of the eye glance data is supported by similarities between the hand-held and hands-free wireless phone interface conditions for dialing, and between the hands-free and enhanced hands-free wireless phone interface conditions for conversation. Specifically, the respective percentages of time spent looking at the forward roadway and AutoPC / phone are essentially identical for the hand-held and hands-free conditions for dialing manually. Similarly, the percentages during conversation are essentially identical for hands-free and enhanced hands-free, both of which involve hands-free talking.

5.4. ADDITIONAL OBSERVATIONS REGARDING WIRELESS PHONE AND AUTOPC USE

Some qualitative observations regarding wireless phone and AutoPC use were obtained from review of video data, post-participation interviews, and a debriefing questionnaire.

Some participants exhibited a regard for safety by making calls while the vehicle was stationary, having passengers dial the phone for them, dialing on approach to a red light, and programming phone numbers into the phone to avoid lengthy dialing episodes. The number of participants who programmed phone numbers into the AutoPC phone book is unknown.

When participants used unfamiliar numbers in moderate or high traffic workload, they were observed taking extremely long times to find the number on paper by performing numerous short glances back and forth from the road scene. Thus, they were dialing parts of a phone number after each subsequent delay in an effort to maintain attention on the forward roadway.

In response to an item in the debriefing questionnaire, 7 participants stated that voice commands would be the most suitable method of interacting with a wireless phone. However, review of video data showed participants using the EHF interface incorrectly, abandoning the voice interface in favor of the manual interface. This may be attributable, in part, to difficulties using the AutoPC interface, which were observed. Although the AutoPC system had been trained to recognize each participant's voice, some were not easily recognized by it. This was noticed for certain participants, and pertained to voice interaction in general (radio, address book, etc.), not just while using the phone. However, some drivers also noted problems with the AutoPC design that were unrelated to the voice interface. Specific comments noting unhappiness included that the AutoPC buttons were too small for manual manipulation (indicated by two participants), the display was too plain for the price of the system (1), the display should be angled toward the driver for better visibility (1), a display brightness control was needed so it could be adjusted for day and night time conditions (i.e., it was too bright at night)(1), and the faceplate was difficult to remove at night (1).

Other participants had little or no problems and utilized the AutoPC voice interface freely. In fact, one participant was very interested in the AutoPC, read the entire manual, and learned how to use it in detail, even to the point of customizing the voice commands to his own personal choice of key words. In response to the debriefing questionnaire, six of the participants stated they preferred the voice control mode, while the other four preferred the manual control mode. Those who preferred voice control stated that they found it easier and less distracting to drive, use the stereo, and use the phone when they could control the AutoPC by voice commands. Those who preferred manual control stated that the AutoPC had significant difficulty in interpreting their voice commands resulting in driver frustration and increased task times.

5.5. ADDITIONAL ANALYSES TO PERFORM

Additional analyses of interest were identified during the course of this research, however the time did not permit their completion. One such analysis involves examining eye glance data over the entire duration of each of the 519 calls and later (30-second) time frames within long calls. Another analysis involves classifying and analyzing instances in which participants became frustrated when using the wireless phone interfaces. Phone conversation characteristics and their relationships to driving behavior are also of interest. A separate effort is underway to review video data and transcribe audio data with the intent of classifying conversation data. This effort seeks to determine a relationship between conversation classifications, driving behavior, and eye glance behavior.

Data generated by this research might be combined with databases that are being compiled by the Crashworthiness Data System (CDS) in the U.S. and by the Japan Police Agency in Japan. For a given period of time, the number of wireless-phone-related crashes can be estimated from these databases, as well as the conditions of their occurrence. For example, the distribution of wireless-phone-related tasks ongoing when the crash occurred could be examined, as well as, the type of equipment (hand-held, hands-free) used. From these statistics, baseline figures for number of crashes can be derived. By comparing the current study's driving performance results associated with hand-held phone use to that with hands-free phone use while driving, and associating hand-held phone use with the baseline crash statistics from the noted prior research, the number of crashes that might be avoided (or caused) by the requirement of hands-free wireless phone operation while driving could be estimated.

5.6. COMMENTS ON NATURALISTIC DATA COLLECTION

As was seen in this study, naturalistic data contains a wealth of detail about individual actions and incidents. Phone usage rates and conditions in which wireless phone calls are made are real and unique to naturalistic studies. Glance location results acquired in this study appear more robust than those for driving measures, suggesting eye glance patterns associated with wireless phone use are more consistent than differences in measures of driving behavior and appear to be independent of the driving situation. However, naturalistic data are most useful for studying driver behaviors that are not situation dependent. One cannot assume that situational details will wash out over a period time. Inherent variability among driving conditions in this study caused significant limitations upon the usefulness of the data for making comparisons between wireless phone interface conditions, particularly in regards to vehicle-based measures of driving performance. The first 30 seconds of a wireless phone conversation do not affect driving behavior enough to overcome the differences inherent in the varied driving situations.

The high degree of variability in the driving conditions that participants' experienced during this study led to the thought that it may not be fair to compare conditions. Lack of homogeneity in driving conditions leads to the question of whether data are good enough for hypothesis testing or whether should they just be mined for phenomena that can be more rigorously tested in a controlled experiment. An attempt was made to explore different variations of dependent measures in an effort to find out which one might show a provocative result. However, in most cases the variability in the data was too large for an effect to be distinguishable. Furthermore, the repeated sampling from a small number of participants caused limitations upon the validity of statistical testing and generalization of the results.

As stated previously pertaining to Phase 1 data, it is important to obtain some data for all of the driving that occurs, such that incidence of events can be related to factors such as miles driven, time of day, and traffic conditions. To address this variability in driving conditions, a defined-route component could be integrated into future naturalistic studies to provide some portion of consistent driving conditions across experimental conditions. Constraints should be incorporated to ensure that a certain amount of data contain comparable driving situations. For example, it may be beneficial to require participants to drive a defined route each day, at times when similar traffic conditions exist. This would help to reduce some of the variability attributed to the driving environment. Any correlations obtained between naturalistic and defined-route data collection using this method could provide important and useful insights regarding driver behavior, driving performance, and their measurement.

6.0 CONCLUSIONS

This study was carried out to gather information useful for assessing the effects of wireless phone interface type on driving performance and wireless phone use characteristics. All driving was fully discretionary, and presumably would have taken place regardless of involvement in this study. This, together with the absence of an in-vehicle experimenter and the unobtrusive nature of MicroDAS, represent a comprehensive effort to gather naturalistic driving data with a minimum of experimental artifacts. Observation over a period of time during normal driving provided insights into frequency of use, duration of use (e.g., conversation), and driving situations during use as a function of the technology. However, this unrestricted driving led to highly variable driving conditions that complicated data analysis.

One important question this research sought to answer was whether drivers would make more calls and longer calls with a hands-free phone than with a hand-held phone due to presumed increased ease of use. Drivers in this study did not make more calls or longer calls with hands-free wireless phones than with hand-held wireless phones. In fact, the hand-held wireless phone interface used in this study was associated with more calls and calls of longer duration. This could be attributable to increased familiarity with hand-held phones, as well as poor performance of the voice recognition system use for the EHF interface. Anecdotal evidence based on video data suggests that some drivers had considerable difficulty in dialing using the enhanced hands-free wireless phone (voice) interface supported by the AutoPC. More than half of calls made in the EHF condition were dialed manually. Drivers ignored instructions to use hands-free (voice) dialing, suggesting drivers found voice dialing difficult to use. The hand-held wireless phone was associated with shorter dialing periods.

Drivers engaged in fewer wireless phone calls when driving in conditions of high traffic density, particularly when using the hands-free phone interfaces. Ninety-two percent of calls were made when there were less than 10 vehicles present in the vicinity of the participant's vehicle. Seventy-five percent of calls were conducted in the presence of five or fewer surrounding vehicles. The mean number of surrounding vehicles was highest during HH calls (4.5) and lowest during EHF calls (3.2), suggesting drivers may have felt more comfortable engaging in calls using the HH phone interface.

Significant trends that would distinguish the effects on driving performance of hands-free wireless phone use from hand-held wireless phone use were not found. However, some interesting findings were obtained relating to glance behavior during wireless phone use:

- While hands-free (voice) dialing showed a modest benefit in terms of glances to the phone relative to manual dialing, it still involved a 20 percent reduction in time spent looking ahead, relative to baseline driving.

- Hands-free (voice) dialing methods allow the driver to look at the road more during dialing episodes, however, the distraction level is still significant relative to conversation on a wireless phone.

- Drivers look away from the forward roadway more during dialing episodes than during conversation on a wireless phone.

- Enhanced hands-free conversation was associated with more time spent looking left and right as compared to hand-held or conventional hands-free conversation, suggesting a slight benefit over the other phone interfaces in terms of lateral situational awareness.

● Drivers made more glances away from the forward roadway while talking on a hands-free wireless phone than while talking on a hand-held wireless phone.

● Drivers glanced frequently at the hands-free wireless phone equipment during a hands-free call, despite that there is no functional need to direct their glance or head toward the equipment.

● Drivers spent more time looking at the road ahead during phone conversation (all interfaces) than during baseline driving.

● During longer conversations (2 minutes duration or greater), the amount of time spent looking at the forward roadway increased steadily. This may indicate that drivers become more cognitively engrossed in the conversation as it progresses, which could lead to a "looked but did not see" situation.

● Although it is true that 99.9 percent of the time participants spent conversing using a Hand-Held phone in this study they drove with only one hand on the steering wheel, this number only rose to 12.7 percent for the Conventional Hands-Free (headset) interface and 16 percent for the Enhanced Hands-Free (voice dialing) interface. Thus, arguments which state that "hands-free lets you keep your hands on the wheel" are defeated by these results that suggest that driving with two hands on the wheel is a rarity, regardless of the type of wireless phone interface a driver might be using.

In summary, while some differences were found between phone interfaces for dialing duration and conversation durations, significant differences in driving performance were not found. Significant differences in driving performance during conversation versus driving performance during baseline driving were also not distinguishable based on data collected in this study. This lack of significant results is attributed to large variation in driving conditions encountered by participants in this study. However, the robustness of eye glance data provided useful information regarding drivers' glance behavior during conversations and how this glance behavior can change as the conversation progresses in time. Research to examine whether the observed increase in percent of time spent glancing at the forward roadway may be attributable to increased attention to the driving task or increased cognitive complacency would provide helpful insight into the safety implications of these findings.

7.0 REFERENCES

1. CTIA's World of Wireless Communications (home page), Retrieved April, 8, 2004 4:50:02 PM EST. http://www.wow-com.com/. Cellular Telecommunications & Internet Association. "162,168,994 Current US Wireless Subscribers."

2. J2396 Visual Demand Measurement Standard Safety & Human Factors (G. Farber, L. Tijerina) Defines procedures for measuring the visual demand placed on the driver by certain ITS systems. Under Development.

3. Barickman, F. (1998). Intelligent data acquisition for intelligent transportation research (SAE Technical Paper No. 981198). Warrendale, PA: Society of Automotive Engineers.

4. Barickman, F. S., Goodman, M. J. "MicroDAS: In-Vehicle Portable Data Acquisition System." Transportation Research Record No. 1689, TRB, National Research Council, Washington, D.C., 1999, pp. 1 - 8.

5. National Highway Traffic Safety Administration (1997). An Investigation of the Safety Implications of Wireless Communications in Vehicles. Technical Report No. DOT HS 808 635. Washington, D.C: U.S. Department of Transportation.

6. Mazzae, E. N., Baldwin, G. H. S., Barickman, F. S., Forkenbrock, G. J. (2003). NHTSA Light Vehicle Antilock Brake Systems Research Program, Task 5.2/5.3: Examination of driver crash avoidance behavior using conventional and antilock brake systems. (DOT HS 809 561). Washington, DC: National Highway Traffic Safety Administration.

8.0 APPENDIX A: TEST PARTICIPANT INFORMATION SUMMARY

TEST PARTICIPANT INFORMATION SUMMARY

Project Title: In-Vehicle High-Tech Device Evaluation

Principal Investigator: If you have questions at any time regarding this study please contact the principal investigator at the address and/or telephone number given below:

Liz Mazzae (or Scott Baldwin)
NHTSA Vehicle Research and Test Center
10820 SR 347
East Liberty, OH 43319
Phone:(800) 262-8309 or (937) 666-4511

We do not anticipate that any changes to procedures will take place during this study, however, any new information developed during the course of the research that may affect a subject's willingness to participate will be provided to you.

Study Description: You have been invited to participate in an effort to assess a state-of-the-art automotive data acquisition system called the Micro Data Acquisition System, or "MicroDAS." The United States Government's National Highway Traffic Safety Administration (NHTSA) has developed the MicroDAS instrumentation for collecting information to describe how average people drive. MicroDAS is being used in this study to collect data on various vehicle parameters and to assess the performance of sensor components of the data acquisition system.

The vehicle which we will provide you with will be instrumented with a MicroDAS. The MicroDAS contains sensors which measure certain aspects of vehicle operation, vehicle motion, and driver actions. The system also contains video cameras which capture images of driver actions and the environment in which the vehicle is being driven (e.g., driver's hand position on the steering wheel, forward road scene). These sensors and video cameras are located in such a manner that they will not affect your driving, the vehicle's performance, or obstruct your view while driving. The information collected using these sensors and video cameras is recorded onto data storage media for subsequent analysis by research staff.

We are also interested in your opinions regarding some new in-vehicle technologies which have been developed. Upon completion of the study, you will be asked to complete a brief questionnaire to obtain your opinions regarding the in-vehicle systems provided for your use in this study. This information is important for the design of safer automobiles and automotive safety systems.

During the study, you will drive an instrumented research vehicle for a total of 6 weeks. This will be divided into three 2-week periods. During each 2-week period, you will have available for your use up to three high-tech in-vehicle technologies. These technologies will be modified or changed at the end of each 2-week period so that you can be exposed to a variety of technologies and system features.

For your convenience, we have made a wireless phone available in the vehicle so that you can contact the principal investigator in the event that you experience problems with the vehicle or one of the in-vehicle devices. You may also use the phone for your own personal or business calls. We require that you DO NOT use your own personal wireless phone inside the vehicle. It is important that you do not use your own personal wireless phone while in the vehicle since that may actually cause damage to our data collection system. We request that you turn off your personal wireless phone each time you enter the vehicle to begin driving. So that you do not miss any important calls, you should program your personal wireless phone to forward your calls (under "no answer" conditions) to our phone in the test vehicle.

Use of the wireless phone provided in the vehicle is subject to the following constraints. You may use the phone for local and in-state long distance calls as you wish (no limit to number of calls or minutes per month) and at no cost to you. You may also use the phone to place out-of-state long distance calls to the extent that you reported you normally make per month. You may not use the phone to place international calls. We request that calls not be made any more so than you would normally make, just because the phone is available. Abuse of phone privileges or failure to comply with these constraints may result in a reduction in your final compensation for participating in the study comparable to the phone charges incurred. Any use of the in-vehicle devices including the wireless phone should be conducted in a safe manner.

In order to allocate appropriate funds for your use of our wireless phone while you are participating in this study, we need to get some sense of whether you typically use the phone while you drive and, if so, some idea of how much you might use it. Again, we request that calls not be made any more so than you would normally make, just because the phone is available. During your trips we will be recording data based on your driving, including video and audio data. Any audio data recorded during personal conversations including wireless communications will be destroyed upon the completion of data analysis.

Driving Requirements: Participation in this study will involve driving an instrumented research vehicle during your normal daily activities for a period of approximately six weeks. This vehicle will be provided to you by NHTSA for use over this period upon signing of the informed consent and information disclosure statements contained in this form. You have informed NHTSA that your normal daily, weekday routine includes driving an automobile for a total of at least 1 hour per day for at least 5 days per week. By agreeing to participate in this study, you agree to drive the research vehicle for a period of approximately 6 weeks as you wish, wherever you wish, subject to the following limitation. By signing the informed consent statement below, you agree that you will not drive the research vehicle outside the geographical boundaries of the State of Ohio. You are not permitted to allow any other person to operate the vehicle during the time it is in your possession. You will be responsible for purchasing the fuel required to operate the vehicle as you would your own vehicle.

Use of the Research Vehicle: Please drive as you normally would while participating in this study. You remain responsible for your driving during this testing. When on public roads, you are not exempt from any laws. Be aware that crashes can happen at any time when driving. Crashes that occur on public roads must be reported to law enforcement officials. You must notify the principal investigator in the event of a crash. We will contact law enforcement officials if you have been unable to do so. *It is very important to always remember that you, as the driver, are in control of the vehicle and are fully responsible for driving safely at all times.*

The contractor responsible for conducting this testing, the Transportation Research Center Inc. (TRC), will maintain insurance that will cover you in the event of a crash. This insurance will provide coverage for injuries to yourself up to a limit of $10,000.00. Coverage will also be provided for injuries to others, including passengers in the research vehicle and the driver and any passengers of other vehicles involved in the crash, as well as damages resulting from any crashes occurring during your participation in this study, up to a $1,000,000 limit. Except to the extent covered by such insurance policy, neither the TRC nor NHTSA will be responsible for your actions during this study nor will they indemnify you or otherwise compensate you for any problems arising out of your actions or the normal risks associated with driving. However, you will not be liable for loss or damage to the MicroDAS equipment, the research vehicle, or other test equipment during the test unless there is gross negligence on your part.

Risks: During your participation in this study, you will be subject to all risks normally associated with driving on public roadways while using the commercially available in-vehicle technologies provided. There will be no risks involved in this testing beyond those which are normally associated with driving on public roadways. All driving which you will do in this study will be of your own volition. Your use of the in-vehicle technologies provided is fully discretionary and should be conducted with safety in mind. You will not be instructed to drive any particular route at any particular time. You will not be asked to perform any specific tasks while driving for this study. While driving for this study you will not be asked to perform any unsafe driving acts. In the event of an unforseen incident, you should contact the authorities immediately and then contact the Principal Investigator at your earliest convenience. There are no known physical or psychological risks associated with participation in this study beyond those normally found in driving while using commercially available in-vehicle technologies.

Vehicle Checkups and Data Retrieval: At regular intervals, possibly as frequently as twice per week, the vehicle must be made available to NHTSA in order to allow data to be downloaded from the on-board data acquisition system. These data retrieval activities are expected to be brief in duration. In addition, you may at some point during your participation be required to bring the vehicle to a location specified by the Principal Investigator to allow the vehicle to undergo a brief checkup to ensure it is running properly and all instrumentation is functioning as expected. These meetings will be arranged to take place at a time and place which is convenient both for you and for NHTSA. If possible, for your convenience NHTSA will dispatch a technician to your home or workplace to perform these tasks. Depending on the condition of the vehicle and/or the nature of the tasks which need to be performed, it may be necessary for you to bring the vehicle to NHTSA at 10820 SR 347 in East Liberty, OH.

Vehicle Maintenance and/or Service: The vehicle will be provided to you in good condition. All routine maintenance will be completed before you receive the vehicle such that none will be necessary during the time that the vehicle is in your possession. In addition, if you are not already personally enrolled in such a program, Roadside Assistance coverage has been acquired for you for the duration of your participation in this study through the American Automobile Association. When necessary, you may contact AAA by phone at the following number:

AAA 24-Hour Roadside Assistance: (614) 431-3388

In the event of an unexpected vehicular failure, you should react to remedy the failure in the following manner according to the nature of the problem:

> **Minor failure**: If at any time the vehicle experiences a minor failure (e.g., flat tire, battery problems, locked key in the car), you should use the mobile phone located in the vehicle, or a public phone, to contact AAA at (614) 431-3388 for roadside assistance in resolving the problem.
>
> **Moderate or serious failure**: During business hours (nominally 7:30 am to 5 pm, if you detect any sign of vehicular malfunction other than a minor failure, you must contact the Principal Investigator at (800) 262-8309 ***immediately*** to report the trouble.

When calling, you should ask for the Principal Investigator by name, Liz Mazzae, and identify yourself as a ***participant in the "In-Vehicle Technology and Instrumentation" Study***. Upon contacting the Principal Investigator, you may be instructed to contact AAA at (614) 431-3388 for service, or arrangements may be made by the Principal Investigator to retrieve the vehicle from you for a brief period of time for servicing by NHTSA.

Note: At any time when contacting the Principal Investigator by phone, in the event that Ms. Mazzae is unavailable, please ask to speak to Scott Baldwin for assistance.

Severe failure: If the vehicle becomes ***undrivable*** for any reason *during normal business hours*, you must use the mobile phone located in the vehicle to notify the Principal Investigator of this condition and then contact AAA at (614) 431-3388 and have the vehicle towed to NHTSA at 10820 SR 347 in East Liberty, OH in order for repairs to be made. If the vehicle becomes undrivable *outside of normal business hours*, simply contact AAA at (614) 431-3388 and have the vehicle towed to NHTSA for repair.

Collision: If the vehicle is involved in any type of ***minor collision*** and sustains *little or no damage (even a minor "fender bender")*, you must use the mobile phone located in the vehicle to notify the Principal Investigator of this condition and make arrangements for the vehicle to be temporarily returned to NHTSA to ensure that all instrumentation is functioning properly.

If the vehicle is involved in a more ***severe collision*** and sustains damage and/or is ***undrivable***, you must use the mobile phone provided to notify the Principal Investigator of this condition and then contact AAA at (614) 431-3388 and have the vehicle towed to NHTSA at 10820 SR 347 in East Liberty, OH in order for repairs to be made.

You should not under any circumstances take the vehicle to any commercial automotive maintenance facility to be serviced without prior consent of the Principal Investigator. All repairs shall be performed by NHTSA or at their discretion. Upon repair, the vehicle will be returned to you as soon as possible to continue participation in the study.

Study Completion: At the end of the study period, you will be asked to complete a questionnaire asking your opinions regarding such issues as driving automobiles, trends in in-vehicle technologies, and your experiences in this data collection effort. Your assistance will help NHTSA understand the relationship between driver behavior and automotive safety. If you agree to participate, you will be asked to sign the attached Informed Consent Form indicating that you have read and understand the procedures of this study.

Return of the Research Vehicle: At the end of the six week period, you will be required to return the research vehicle to NHTSA. The anticipated return date for you to return the research vehicle to NHTSA is: _____________.

Use of Information Collected: In the course of this study certain **engineering data,** video recorded image data, or **video data,** will be collected.

The **engineering data** collected and recorded in this study will be analyzed along with data gathered from other test participants. NHTSA may publicly release this data in final reports or other publications or media for educational, outreach, and research purposes. However, your name and other personal identifying information will not be included in any of these public releases.

The **video data** recorded in this study includes your video-recorded likeness and all in-vehicle audio including your voice. Video and in-vehicle sounds will be used to examine your driving performance and use of in-vehicle systems. NHTSA may publicly release video image data (in continuous video or still formats) and associated in-vehicle audio data, either separately or in association with the appropriate engineering data. However, your name and other personal identifying information (except your videotaped likeness) will not be included in any of these public releases. For privacy reasons, any in-vehicle audio data containing conversations of a personal nature will not be released and will be destroyed immediately upon completion of data analysis.

Please note that, should you be involved in a crash or other event during testing which results in legal action, NHTSA may be required to release personal identifying information and associated test data, in response to a court action.

Compensation: Your participation should take approximately six weeks and your compensation will be $200. Please note that additional compensation will not be provided in the event that the test lasts longer than six weeks. Understand that if you engage in illegal activities during your use of the vehicle or fail to meet the minimum "Driving Requirements" as outlined in this Information Summary, you may be disqualified from the study and may forfeit your eligibility to receive the payment of $200.

Informed Consent: By signing the informed consent statement contained in this document, you agree that participation is voluntary and you understand and accept all terms of this agreement. Also by signing the informed consent statement, you agree to the following conditions of participation regarding operation of the research vehicle:

1. You will drive the instrumented research vehicle provided to you by NHTSA for at least 1 hour per day for at least 5 days per week for a period of 6 weeks as specified by the Principal Investigator. You understand that if any circumstances would affect my ability to meet these minimum "Driving Requirements" as outlined in this Information Summary, you must notify the Principal Investigator immediately.

2. You, the participant, are the only person permitted to drive the research vehicle. The participant is defined as the one individual who agreed to participate in this study and signed the informed consent form.

3. The research vehicle cannot be used to tow any form of trailer, or haul any material greater than what the vehicle was designed to accommodate.

4. You may not remove, modify, tamper with, or otherwise hinder the operation of any components of the research vehicle or data collection system or allow others to do so. You must receive verbal permission from the experimenters prior to allowing any mechanical work to be performed on the research vehicle.

5. The research vehicle cannot be used to conduct illegal activities.

6. You must agree to operate the research vehicle in accordance with all traffic laws.

7. You cannot drive the research vehicle while impaired by alcohol or any controlled substances. You will not permit others to consume alcohol or use drugs or other controlled substances inside the research vehicle.

8. You are the sole individual responsible for your conduct while driving the research vehicle.

9. You are responsible for purchasing fuel for the research vehicle for the duration which it is assigned to you.

10. The research vehicle cannot be taken outside of the state of Ohio.

11. You are the sole individual responsible for all tickets and violations for the duration which the research vehicle is assigned to you.

12. You are responsible for reporting as early as possible to NHTSA any problems, mechanical malfunctions, or collisions involving the research vehicle.

13. If at any time, and for any reason, the experimenters deem it necessary that the research vehicle be returned to NHTSA, you must either return the vehicle or make it available for NHTSA personnel to retrieve it.

14. You must return the research vehicle at the specified date and time your assignment ends as specified by the Principal Investigator.

You may withdraw your consent and discontinue participation at any time without penalty or loss of benefits to which you are entitled.

Disposition of Informed Consent: NHTSA will retain a signed copy of this Informed Consent form. A copy of this form will also be provided to you at the time you receive the research vehicle for commencement of your participation in this study. A copy of this form will also be present in the research vehicle at all times so that you will have access to contact information in order to reach the Principal Investigator in the event that you have questions or vehicle problems.

Information Disclosure: By signing the information disclosure statement contained in this document, you agree that NHTSA and its authorized contractors and agents will have the right to use the engineering data and the videotape data and the wireless communications systems use data for educational, outreach, and research purposes, in perpetuity, including dissemination or publication of your likeness in videotape or still photo format, but that neither NHTSA nor its authorized contractors or agents shall release your name or other personal identifying information; and you understand that, in the event of court action, NHTSA may not be able to prevent release of your name or other personal identifying information.

INFORMED CONSENT STATEMENT:

I certify that all personal and vehicle information as well as information regarding my normal daily driving habits provided by me to NHTSA and TRC employees associated with this project during the pre-participation phone interview and the introductory briefing was true and accurate to the best of my knowledge. I understand that if I engage in illegal activities during my use of the vehicle or fail to meet the minimum "Driving Requirements" as outlined in this Information Summary I may be disqualified from the study and may forfeit my eligibility to receive the payment of $200.

I understand that the purpose of this study is to collect data on how people drive in an effort to assess a state-of-the-art automotive data acquisition system called the Micro Data Acquisition System, or "MicroDAS", and to provide my opinions regarding some new in-vehicle technologies being considered for use in automobiles.

I,__________________________, VOLUNTARILY CONSENT TO PARTICIPATE.

____

I UNDERSTAND THE TERMS OF THIS AGREEMENT AND AGREE TO THE FOLLOWING CONDITIONS:

1. I will drive the instrumented research vehicle provided to me by NHTSA for a period of 6 weeks during which I anticipate driving at least 1 hour per day for at least 5 days per week. If for some reason I experience a change which results in my normal daily driving no longer meeting the requirements for participation in the study, I will notify the Principal Investigator immediately. I will notify the Principal Investigator if any changes in my work hours occur to ensure that data may be collected properly and successfully retrieved at the required intervals explained to me.
2. I, the participant, am the only person permitted to drive the research vehicle. The participant is defined as the one individual who agreed to participate in this study and signed the informed consent form.
3. The research vehicle can not be used to tow any form of trailer, or haul any material greater than what the vehicle was designed to accommodate.
4. I will not, or allow others to, remove, modify, or tamper with, or otherwise hinder the operation of any components of the research vehicle or data collection system. I must receive verbal permission from the Principal Investigator prior to allowing any mechanical work to be performed on the research vehicle.
5. The research vehicle cannot be used to conduct illegal activities.
6. The research vehicle cannot be driven or otherwise taken outside of the state of Ohio.
7. I will not drive the research vehicle "off road", or on any form of test or race track, nor will I use the vehicle in the performance of any stunt.

8. I agree to operate the research vehicle in accordance with all traffic laws.
9. I will not drive the research vehicle while impaired by alcohol or any controlled substances. I will not, or allow others to, consume alcohol or consume or possess other controlled substances inside the research vehicle.
10. I am the sole individual responsible for his/her conduct while driving the research vehicle.
11. I am responsible for purchasing the 89 Octane fuel necessary for operation of the research vehicle for the duration which it is assigned to me. I understand that I will not be reimbursed for the fuel.
12. I am the sole individual responsible for all tickets and violations for the duration which the research vehicle is assigned to me.
13. I am responsible for reporting as early as possible to NHTSA any problems, mechanical malfunctions, or collisions involving the research vehicle.
14. If at any time, and for any reason, the Principal Investigator deems it necessary that the research vehicle be returned to NHTSA, I must either return the vehicle or make it available for NHTSA personnel to retrieve it.
15. I must return the research vehicle at the specified date and time my assignment ends as specified by the Principal Investigator and as indicated in this document.
16. I will familiarize myself with the characteristics of the research vehicle, its safety features, and the location of frequently used controls prior to driving the research vehicle for the first time.
17. I agree to allow my personal wireless telephone calls to be forwarded to the telephone systems which I will be using during this study for the duration of my participation.

18. I understand that the vehicle that I will be driving is equipped with the following features:

VEHICLE FEATURE	"X" IF PRESENT ON THIS VEHICLE
Remote Keyless Entry	
Vehicle Theft Security System	
In-Dash AM/FM Stereo with Cassette Player	
In-Dash Enhanced Multi-Function Stereo with LCD Display	
In-Vehicle Computer	
Personal Digital Assistant (PDA or electronic personal organizer)	
Wireless Telephone	
Hands-Free Wireless Telephone	
Voice Recorder	
In-Dash Route Navigation System	
Automatic Temperature Control	
Automatic Dimming Center-Mounted Rear-View Mirror	
Electronic Speed (Cruise) Control	
Power Brake System	
Antilock Brake System	
Power Assisted Steering	
Speed Proportional Steering	
Traction Control System	
Manual Seat Belt	
Automatic Seat Belt	
Daytime Running Lights	
Driver's Side Air Bag	
Passenger's Side Air Bag	
Ultrasonic Rear Parking Aid	
Radar-based Rear Parking Aid	

______________________________ ____________

Signature Date

INFORMATION DISCLOSURE STATEMENT:

I, ________________________, grant permission, in perpetuity, to the National Highway Traffic Safety Administration (NHTSA) to use, publish, or otherwise disseminate engineering data and video image data (including continuous video and still photo formats derived from the video recording) and associated in-vehicle audio data collected about me in this study, either separately or in association with the appropriate engineering data for educational, outreach, and research purposes. I understand that such use may involve widespread distribution to the public and may involve dissemination of my likeness in video or still photo formats, but will not result in release of my name or other identifying personal information by NHTSA or its authorized contractors or agents. For privacy reasons, any in-vehicle audio data containing conversations of a personal nature will not be released and will be destroyed immediately upon completion of data analysis.

______________________________ ____________

Signature Date

TEST PARTICIPANT INFORMATION SUMMARY - Addendum

Project Title: New Vehicle Instrumentation Validation Study and Data Collection - Addendum

Study Description and Participation Requirements: The purpose of this additional provision to the above referenced study is to determine the wireless phone usage patterns of drivers who participated in the on-road driving study. You are asked to provide your wireless phone bills covering the 3 months prior to your participation in the "New Vehicle Instrumentation Validation Study and Data Collection" experiment. You will provide copies of your wireless phone bills to NHTSA by mailing to the following address:

Liz Mazzae
NHTSA Vehicle Research and Test Center
10820 SR 347
East Liberty, OH 43319

You are requested to mark out any phone numbers and information relating to call origin and destination present on the phone bill, showing incoming and outgoing call frequency, call duration, the conditions of call occurrence (e.g., time of incoming, outgoing, and attempted calls). We are only interested in number of calls made, length of calls made, and time of calls made.

Use of the Wireless Phone Bill Data: Wireless phone bill data will be used to determine your average wireless phone usage patterns, including average calls made per month and average length of call, for comparison with usage patterns observed during your participation in the on-road driving study. The data contained in these records will be transferred to a record that is separate from your name and the copy of the phone bill which you provided will be destroyed.

Compensation: You will receive a payment of $50 upon submitting a copy of your wireless mobile telephone billing records covering the 3 months prior to your participation in the study.

Informed Consent: By signing the informed consent statement contained in this document, you agree that participation is voluntary and you understand and accept all terms of this agreement. Also, by signing the informed consent statement, you agree to provide to NHTSA your wireless phone bills covering the 3 months prior to your participation in this study.

Disposition of Informed Consent: NHTSA will retain a signed copy of this Informed Consent form. A copy of this form will also be provided to you.

Information Disclosure: By signing the information disclosure statement contained in this document, you agree that NHTSA and its authorized contractors and agents will have the right to use the wireless communications systems phone bill data for educational, outreach, and research purposes, in perpetuity, but that neither NHTSA nor its authorized contractors or agents shall release your name or other personal identifying information; and you understand that, in the event of court action, NHTSA may not be able to prevent release of your name or other personal identifying information.

INFORMED CONSENT STATEMENT:

I understand that the purpose of this effort is to determine the wireless phone usage patterns of average drivers and that my participation in this study will involve providing my wireless phone bills covering the 3 months prior to my participation in the “New Vehicle Instrumentation Validation Study and Data Collection” experiment. I understand that once calculations have been made to assess my normal wireless phone usage patterns, the copies of my wireless phone bill data which I provided will be destroyed, and the data contained in these records will be transferred to a record that is separate from your name.

INFORMATION DISCLOSURE STATEMENT:

I, ________________________, grant permission, in perpetuity, to the National Highway Traffic Safety Administration (NHTSA) to use, publish, or otherwise disseminate wireless phone bill data collected about me for educational, outreach, and research purposes. I understand that such use may involve widespread distribution to the public, but will not result in release of my name or other identifying personal information by NHTSA or its authorized contractors or agents. I understand, however, that in case of a crash or other event resulting in legal action, NHTSA may be required by subpoena or other court action to release identifying personal information.

______________________________ ____________

Signature Date

9.0 APPENDIX B: QUESTIONNAIRE

DATE: _______________

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

PERSONAL INFORMATION

1) What is your highest level of education completion?

- ❑ Primary School
- ❑ High School Diploma
- ❑ Technical School
- ❑ Associates Degree
- ❑ Some Undergraduate School
- ❑ Bachelors Degree
- ❑ Some Graduate or Professional School
- ❑ Graduate or Professional Degree

2) Approximately how many miles do you drive per year?

- ❑ Under 2,000
- ❑ 2,000 - 7,999
- ❑ 8,000 - 12,999
- ❑ 13,000 - 19,999
- ❑ 20,000 or more

3) Is any driving you do work-related? (This does not include traveling to and from work.)

- ❑ Yes
- ❑ No (skip to question 5)

4) If you answered yes to question 3, how many work-related miles do you drive per year?

- ❑ Under 2,000
- ❑ 2,000 - 7,999
- ❑ 8,000 - 12,999
- ❑ 13,000 - 19,999
- ❑ 20,000 or more

5) What speed do you typically drive at when the posted speed limit on a road is (e.g., @ **35mph: __41_**):

35mph: ________45mph:

55mph: ________65mph:

6) What type of automobile do you drive most often?

Make (e.g. Ford, Toyota) ....

Model (e.g. Escort, Celica) ....

Year...

....

7) Which of the following features does your automobile have? (Check all that apply)

- ❑ Air Bag
- ❑ Antilock Brakes
- ❑ Automatic Transmission
- ❑ CB Radio
- ❑ Cellular Phone
- ❑ Manual Transmission
- ❑ Power Brakes
- ❑ Power Steering
- ❑ Radar Detector
- ❑ Other technologies (e.g. trip computer, moving-map display). Please list these here:
- ❑ None of these

The following questions deal with your opinions about the vehicle which you were given to drive in this study. Circle the number corresponding to the most appropriate response:

OPINIONS OF VEHICLE / FEATURES

---

1) What is your opinion of the adequacy of the control / display systems layout and design of the car?

| __________________ | __________________ | __________________ | __________________ |

1 2 3 4 5

Very Unsatisfied Somewhat Unsatisfied Neutral Somewhat Satisfied Very Satisfied

1b) Do you have any suggestions for improvement of the control / display systems layout and design of the car?

____

____

____

2) What is your opinion of the adequacy of the vehicle's handling / maneuverability capabilities?

| __________________ | __________________ | __________________ | __________________ |

1 2 3 4 5

Very Unsatisfied Somewhat Unsatisfied Neutral Somewhat Satisfied Very Satisfied

2b) Do you have any comments about the vehicle's handling performance?

____

____

____

3) What is your opinion of the adequacy of the vehicle's braking performance?

| __________________ | __________________ | __________________ | __________________ |

1 2 3 4 5

Very Unsatisfied Somewhat Unsatisfied Neutral Somewhat Satisfied Very Satisfied

3b) Do you have any comments about the vehicle's braking performance?

____

____

____

4) What is your opinion of how comfortable the vehicle seemed to you?

| ________________ | ________________ | ________________ | ________________ |

1 2 3 4 5

Very Unsatisfied Somewhat Unsatisfied Neutral Somewhat Satisfied Very Satisfied

4b) Do you have any suggestions for improvement to make the vehicle more comfortable?

____

____

____

5) How did driving in the test vehicle compare to driving your vehicle?

| __________ | __________ | __________ | __________ | __________ | __________ |

1 2 3 4 5 6 7

Harder Same Easier

5b) How did the vehicle's handling and braking performance compare to your personal vehicle?

____

____

____

6) Would you consider purchasing a _Chrysler Concorde___ for your own personal vehicle?

- ❑ Yes
- ❑ No

7) Any other comments about the vehicle which you were asked to drive?

____

____

____

____

The following questions deal with your opinions, in particular, about the in-vehicle technology(ies) you were exposed to while driving in this study.

OPINIONS OF IN-VEHICLE TECHNOLOGIES

1) What is your opinion of the adequacy of the display system layout and design of the in-vehicle computer?

| ____________ | ____________ | ____________ | ____________ |

1	2	3	4	5
Very Unsatisfied	Somewhat Unsatisfied	Neutral	Somewhat Satisfied	Very Satisfied

2) Do you have any suggestions for improvement of the display system design of the in-vehicle computer?

____

____

____

3) During the duration of the participation, you experienced two modes of in-vehicle computer operation which we have termed *Voice Control* and *Manual Control*. Which did you like better or find more user friendly for navigating to desired functions? (Circle One.)

1) Voice Commands 2) Manual Commands

3b) What is the reasoning behind your answer to question 3?

____

____

____

4) How would you compare the in-vehicle computer to your normal car's setup (radio, CD Player, phone, computer, etc.) (for example, what are the trade-offs, benefits, likes / dislikes associated with having either one as opposed to the other)?

____

____

____

5) In-vehicle computer systems have the capability to control various tasks and interaction features of the automobile. The following is a list of potential capabilities. Please check the method of interaction you would deem most suitable for each of the following features.

Feature List	Manual Commands Interaction	Voice Commands Interaction
Radio		
CD Player		
Directions / Navigation		
Wireless Phones		
E-mail		
Internet Access		
Address Book		

6) Would you consider purchasing an AutoPC or a similar system for your own personal vehicle?

- ❑ Yes
- ❑ No

7) Any other comments or suggestions about the in-vehicle features you were exposed to while driving our vehicle?

____

____

____

8) If you would be interested in knowing more information about this study once it is finished, or would like to receive a copy of the finished report, please insert a mailing address below:

____

____

____

Thanks again for your participation!

10.0 APPENDIX C: SELECTED POST-DRIVING QUESTIONNAIRE RESULTS

Each participant completed a questionnaire during a debriefing session following the 6-week driving period. The purpose of the questionnaire was to gather information regarding the participants' demographics, driving habits, opinions of the performance and handling of the test vehicle, and driver perceptions about the wireless phone interfaces used in the study. A copy of the actual questionnaire is located in Appendix B. Select results relating to driver demographics and habits, and opinions about manual vs voice control of the in-vehicle computer, are described below.

<u>10.1.1. What speed do you typically drive at when the posted speed limit is…</u>

Participants were asked what speed they typically drove when the posted speed limit was 35, 45, 55, and 65 miles per hour. This question helped researchers to assess the participants' driving style. All participants responded fully to this question and a majority responded that they would typically drive above each of the listed speed limits. No participants responded that they would typically drive below any speed limit.

<u>10.1.2. Features on Personal Vehicle</u>

Participants were asked to complete a checklist of personal vehicle features to create a better understanding of what type of vehicles they drive. The checklist included air bags, antilock brakes, automatic transmission, CB radio, cellular phone, manual transmission, power brakes, power steering, radar detector, and a fill in the blank space for other technologies. Of particular interest was the presence of electronic devices in the participants' vehicles. Five participants stated that they had a cellular phone in their personal vehicle, while the other five carried a phone on their person and thus did not consider the phone to be part of their vehicle's features. Two participants had radar detectors. One participant had a CB radio. No other technologies were reported.

<u>10.1.3. What is your opinion of the adequacy of the display system layout and design of the in-vehicle computer? Do you have any suggestions for improvement?</u>

Three participants were very satisfied with the layout and design of the in-vehicle computer, and four were somewhat satisfied. One participant was somewhat unsatisfied with the layout and design of the in-vehicle computer. Two participants remained neutral on the issue.

Specific comments included that the AutoPC buttons were too small for manual manipulation (indicated by two participants), the display was too plain for the price of the system (1), the display should be angled toward the driver for better visibility (1), a display brightness control was needed so it could be adjusted for day and night time conditions (i.e., it was too bright at night)(1), and the removable faceplate was difficult to remove at night (1).

<u>10.1.4. During the duration of the participation, you experienced two modes of in-vehicle computer operation, which we have termed *Voice Control* and *Manual Control*. Which did you like better or find more user friendly for navigating to desired functions? What is the reasoning behind your answer?</u>

Six of the participants preferred the voice control mode, while the other four preferred the manual control mode. To better clarify their reasoning, each participant's response is listed below in his or her own words:

Preferred voice control:

- "Had to take my eyes off the road to look for the right button; had a little trouble with phone base not opening when asked or ending when asked."

- "At first it was awkward to talk to the computer; when I went back to manual mode I wish I had voice command again."

- "Able to use Voice Controls without taking eyes off road or hands off wheel."

- "This made it easy to use the phone and stereo while focusing on the road."

- "Easier to command by voice while operating vehicle."

- "Voice commands made it much easier to use. Manual was much more distracting to driving. Voice allows driver to stay more focused. Especially when using the phone."

Preferred manual control:

- "The computer doesn't like my voice!"

- "Recognize voices!"

- "I felt like I had to scream to get the voice command to do anything and most of the time I couldn't get it to do anything."

- "The voice control didn't always receive the commands accurately, which meant going through the process again or getting stuck in a mode where I didn't want to be."

<u>10.1.5. How would you compare the in-vehicle computer to your normal car's setup (radio, CD player, phone, computer, etc.)(For example, what are the trade-offs, benefits, likes / dislikes associated with having either one as opposed to the other)?</u>

This was an open-ended question to solicit participants' personal opinions comparing their car features to the in-vehicle computer's features of the test vehicle. One participant did not respond. The remaining responses are listed below.

- "A lot better." (Referring to in-vehicle computer being better.)

- "Manual operation was much harder with the in-vehicle computer only because there was a lot of options to choose from; with time the system would become more user friendly."

- "I just have an AM-FM cassette player in mine and for me that's really all I need. I tried to get the address book with the manual command and I could not get it to come up so I suppose it might be beneficial to someone who doesn't have a hard time comprehending it.”

● “I liked the voice commands but the buttons on my car are larger and easier to read. Sometimes it was hard to find the right button on the in-vehicle computer because they are so small.”

● “Preferred test vehicle's equipment due to ease of operation.”

● “I liked the hands free phone system but liked dialing myself - it was quicker than the voice control function - I was told that I wasn't always heard well by whoever I was talking to.”

● “My normal setup lacks voice command – voice command would be very convenient and much safer.”

● “The 'test' vehicle was equipped w/ the in-vehicle computer feature which I loved. The vehicle also had the directions / address book feature which could prove highly useful.”

● “Current car has controls on steering wheel, which are convenient to use. However, voice commands make using phone much easier and less distracting. The CD player is somewhat difficult to use i.e. putting CD in player - having to swivel to insert was a hassle.”

10.1.6. In-vehicle computer systems have the capability to control various tasks and interaction features of the automobile. The following is a list of potential capabilities. Please check the method of interaction you would deem most suitable for each of the following features (radio, CD player, directions / navigation, wireless phones, e-mail, internet access, address book).

For the radio, 7 participants felt voice commands would be the most suitable interaction method, whereas, three participants felt manual commands would be better suited.

For an in-dash CD Player, six participants felt voice commands would be the most suitable interaction method, whereas, three participants felt manual commands would be better suited. One participant thought a combination of voice / manual would be good, depending on the task (i.e., this participant thought changing the track would be best done manually).

For use of a navigational aid, 9 participants felt voice control would be most suitable interaction method, whereas, one participant preferred manual input methods.

For wireless phone use, 7 participants felt voice commands would be the most suitable interaction method, whereas, two participants felt manual commands would be better suited. One participant thought a combination of voice / manual would be good, depending on the task (i.e., dialing the phone would be best done verbally).

For both in-vehicle e-mail retrieval and in-vehicle Internet access, a majority of participants preferred voice input methods. Six participants felt voice commands would be the most suitable interaction method and one preferred manual methods. Three participants did not respond on this potential feature since they had no hands-on experience with such features in a vehicle.

For use of an address book feature, 8 participants felt voice commands would be the most suitable interaction method and two preferred manual control.

10.1.7. Would you consider purchasing such an in-vehicle device or similar system for your own personal vehicle?

Eight participants stated that they would consider purchasing an in-vehicle computer, whereas, two participants would not consider such a purchase.

10.1.8. Other comments of interest provided in the questionnaire.

The following is a list of in-vehicle device related comments made by the participants:

- "Voice commands did not work all of the time (don't know if it was me or the in-vehicle computer; had trouble with address book and phone base)."

- "I enjoyed driving this car very much but I prefer the regular radio over the in-vehicle computer."

- "Having used both manual and voice, I think voice was much easier and safer to use. Voice also eliminated the need to visually look at the display."