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Examination of the Distraction Effects of Wireless Phone Interfaces Using the National Advanced Driving Simulator - Final Report on a Freeway Study

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16. Abstract

The report describes research to investigate the effects of wireless phone use on driving performance and behavior. The main objectives were to assess: 1) the distraction potential of wireless phone use while driving, and 2) the difference in distraction caused by the use of a Hands-Free wireless phone interface versus that associated with use of a Hand-Held interface. This research was conducted by NHTSA using the National Advanced Driving Simulator (NADS) in collaboration with NADS staff.

Driving performance was examined in four events, including: (1) car-following, (2) lead-vehicle braking, (3) lead-vehicle cut in, and (4) merging. Phone conversation impaired performance most consistently during car following, resulting in an increase of approximately 0.3 to 0.4 seconds in drivers' delay in responding to lead-vehicle speed changes, relative to performance without phone conversation. Steering entropy (error) also increased during phone conversation in car-following events, reflecting an increase in high-frequency steering corrections. Increased steering reversal rates indicated increased workload during phone conversation. There was little evidence of performance impairment due to phone conversation for the other three events. Neither the lead-vehicle braking nor lead-vehicle cut-in events exhibited the predicted slowing in accelerator release and brake response times. The merge event also did not provide consistent evidence of degraded performance due to phone use generally, with the notable exception based on analysis of eye glance data, that while engaged in phone conversation, drivers devoted less visual attention to planning for an upcoming merge event. Older and younger drivers did not exhibit consistently degraded driving performance due to phone conversation than middle-aged drivers.

There were modest differences among interface conditions. Specifically: (1) Hand-Held phone use interfered with steering and lane control more than the Voice Digit Dialing with Speaker Kit Hands-Free interface, and (2) the Voice Digit Dialing with Speaker Kit Hands-Free interface was associated with faster travel speeds than the Hand-Held interface. Differences between interface conditions were stronger for dialing and answering than for conversation. The Hand-Held interface was associated with fastest dialing times and fewest dialing errors while voice dialing was associated with fastest answering and hang-up times. No differences among interface conditions in phone conversation task performance were found. Post-drive questionnaire results showed that in most cases participants overestimated the ease of use afforded by Hands-Free phone interfaces. In general, participants considered the Hand-Held interface to be most difficult to use, followed by the Headset Hands-Free and Voice Digit Dialing with Speaker Kit Hands-Free interfaces, respectively.

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EXECUTIVE SUMMARY

In recent years, studies have shown that use of wireless phones while driving contributes to crashes. Numerous efforts are under way to pass legislation that makes it illegal to use hand-held wireless phones while driving. The assumption behind this move 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, research has not supported this assumption.

This report describes research by the National Highway Traffic Safety Administration to investigate the effects of wireless phone use on driving performance and behavior. The study had two primary objectives: (1) to assess the distraction potential associated with the use of wireless phones while driving, and (2) to determine whether distraction potential was related to the specific phone interface used. In particular, the experiment addressed the question of whether Hands-Free operation substantively affected the distraction potential associated with wireless phone use while driving. In addition, the experiment investigated whether voice-activated dialing affected the distraction potential associated with using a phone while driving. The secondary objective was to determine whether the distraction potential associated with phone use varies with driver age.

This research was conducted by NHTSA using the National Advanced Driving Simulator (NADS) in collaboration with NADS staff. The experiment was one of the first to use the NADS' capabilities for developing complex driving scenarios.

Fifty-four subjects drove a freeway route scenario on the NADS with each of three different wireless phone interface types: Hand-Held (HH), Hands-Free with headset (HSHF), and Hands-Free speaker kit with voice dialing (VSHF). Phone conversations consisted of performance of a verbal interactive task involving judging whether sentences made sense and later recalling words from each sentence.

Each participant completed a single session lasting 3 hours. During this session, the participant drove the same scenario route three times, once for each phone interface. The order of presentation of phone interface conditions was varied systematically. Each traversal of the route involved one incoming and one outgoing call. The order of presentation of incoming and outgoing calls was balanced.

The route consisted of a four-lane divided freeway with a 65-mph speed limit with traffic present. The route generally consisted of four straight segments of nearly equal length joined by right-side interchanges requiring exiting and merging behavior. The treatment drives were approximately 15 minutes in length and required participants to drive three segments of the divided freeway route. The route segments corresponded, respectively, to the incoming phone call, outgoing phone call, and baseline (no call) periods. Each route segment involved a series of interactions between the driver and the scenario vehicles (i.e., events). Events included a sudden lead-vehicle (LV) cut-in, sudden braking by the lead vehicle (LV brake), a car following event, and a merge. Each traversal of the route was associated with a different order of events. The intention of the scenario design was to overlap the events with the 3.5-minute conversation task periods. Each participant also experienced a brief final event involving a more critical lead vehicle braking event.

Results showed that the simulated phone conversations used in this experiment impaired aspects of driving performance. The car-following events provided the strongest demonstration of performance impairment effects due to phone conversation. Phone conversation was associated with increased delay in responding to lead-vehicle speed changes, which indicates significant cognitive impairment due to phone conversation. Steering entropy (error) was also found to increase during phone conversation in car-following events, reflecting an increase in high-frequency steering corrections. Phone use was associated with elevated steering reversal rates during car following, which reflect the increased workload associated with the combination of car following and phone conversation.

The results provided some support for the hypothesis that hand-held phone use would degrade driving performance more than the Hands-Free interface conditions during car-following events. Specifically, lane position variability was greater in the Hand-Held condition than in the other interface conditions, presumably reflecting the physical conflict between Hand-Held phone use and steering. However, the interpretation of this result is complicated by the overall finding that phone use generally was associated with *decreased* lane position variability during car-following events, which suggests improved lane tracking performance while drivers were engaged in phone conversation. Steering entropy was highest in the Hand-Held condition, presumably reflecting the conflict between holding the phone and steering, both of which require use of the hands.

The results for steering holds, which represent periods of steering inactivity and are assumed to reflect increasing neglect of steering due to the demands of other tasks, were contrary to predictions, reflecting better performance during the simulated phone conversation. Specifically, the baseline condition was associated with higher steering hold rates than the Hands-Free or Hand-Held conditions. Finally, the observed decrease in modulus (gain) during car following indicates more conservative responses when drivers were engaged in conversation, and may be interpreted as an attempt to compensate for the increased demands of car following and phone conversation.

Beyond the car-following events, there was only modest evidence consistent with predictions of performance impairment due to phone conversation. Neither the lead-vehicle braking nor lead-vehicle cut-in events exhibited the predicted slowing in accelerator release and brake response times. The merge event provided one piece of evidence of impairment due to phone use. Specifically, while engaged in the phone conversation task, drivers devoted less visual attention to planning for an upcoming merge event. They made fewer glances toward the traffic stream and spent proportionately less total time looking in that direction relative to the baseline condition. This suggests that drivers diverted attentional resources from merge planning to manage the phone conversation task.

Results suggested that the drivers may have compensated for phone conversation by increasing their time headways, but at the same time, they were likely to have diverted attention away from speed monitoring, which led, unintentionally to increased average speeds.

There were modest differences between interface conditions during conversation for the other scenario events. First, there was some evidence that the HH interface interfered with steering and lane control, as would be expected since both tasks require use of the hands. Second, there was some evidence that the VSHF interface was associated with faster speeds, relative to the other interfaces. In particular, speeds for the VSHF interface were fastest at the beginning of the cut-in events and also at the end of the merge events. VSHF calls were associated with more slowing at the very beginning of the merge and more increase in speed at the end of the merge. One interpretation is that while engaged in VSHF calls, drivers felt safer and thus paid less attention to speed control.

Differences among interfaces conditions were stronger for dialing and answering than those associated with conversation. Specifically, the HH interface was associated with consistently faster dialing times and fewer dialing errors (i.e. repeated attempts) than the other interface conditions. Voice dialing times exceeded hand-held dialing times by 84 percent for VSHF and by 51 percent for HSHF. The VSHF interface was associated with significantly faster answering and hang-up (call termination) times than the other interfaces.

Several differences among age groups were found. Young drivers were more aggressive in their car following, as reflected by higher modulus scores. Older drivers exhibited more steering reversals during car following, indicative of higher workload for this group. Drivers in the middle age group were faster than younger drivers at the beginning of the LV cut-in event. In the merge event, relative to the other age groups, older drivers made proportionately more glances leftward before the merge event and spent more time looking left to plan the merge. Older drivers also maintained greater following distances than younger drivers.

Analysis of the final event scenario revealed significant differences for some dependent measures. Hypothesized effects related to phone interface were complicated by significant interactions between phone interface and age. For first response to the final brake event, participants in the Hand-Held condition responded significantly faster than those in the Hands-Free and no-phone conditions, contrary to hypothesis.

Although participants rated the Hand-Held interface to be most difficult to use, this interface was associated with the fewest dialing errors (in terms of the number of attempts per dialing trial). Participants' feelings that the Hand-Held interface was the most difficult to use were also not supported by dialing time results, which showed that the Hand-Held interface was associated with significantly faster dialing times than the other two interfaces for all three age groups. Shorter dialing times for the Hand-Held interface may be attributable to participants' prior experience with Hand-Held wireless phones, which was approximately 6 years on average. However, it should be noted that the length of time required to perform voice digit dialing depends on the interface being used. This study used the Sprint PCS Voice Command system, since it was assumed that a system-based voice dialing interface would be more likely to have better voice recognition capability than phone-based voice dialing. Some newer model phones feature integrated voice digit dialing capability which may allow shorter dialing times. Use of voice "tags" for dialing may also afford shorter dialing times; however, voice digit dialing was chosen for implementation in this study since it provided the most direct comparison between manual and voice dialing.

Conversation task performance did not differ as a function of phone interface. Age was the only examined variable significantly related to phone task performance, with younger individuals performing better than older individuals.

Based on these findings, we concluded that:

1. Phone use while driving degraded driving performance particularly during car following. The simulated phone conversation was associated with a significant delay in responding to lead vehicle speed changes. Phone conversation also degraded vehicle control, as reflected by increased steering error and increased one measure of driver workload. Drivers spent less time planning for merge events while engaged in the phone task.
2. Overall, there were modest differences among interface conditions during the conversation task. The hand-held phone interfered with steering and lane position more than the hands-free interfaces.
3. Differences among interface conditions were strongest for dialing and answering. Specifically, the hand-held interface was associated with fastest dialing times and fewest dialing errors. Drivers rated this interface most difficult to use while driving.
4. Neither older nor younger drivers exhibited consistently worse performance due to simulated phone conversation.

1.0 INTRODUCTION

This document outlines research to examine driver distraction and performance issues relating to the use of wireless phones while driving. The research was conducted by the National Highway Traffic Safety Administration (NHTSA) using the National Advanced Driving Simulator (NADS) located at the University of Iowa. A prior, preliminary report described the rationale for performance of the research, the development of experimental methods, the development of driving scenarios and associated events, and a description of a small-scale pilot study. This report summarizes results of the main experiment and discussed inferences drawn from these results.

1.1 <u>Background</u>

As of September, 2004 there were over 169 million wireless subscribers (CTIA, 2004) in the U.S. This number is constantly growing. 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. Studies have shown that use of wireless phones while driving contributes to crashes. Researchers in Japan have gone further to investigate what aspects of phone use contribute most to crashes. The Japanese results indicated that the majority of wireless phone-related crashes were associated with dialing or answering, while data from the U.S. suggest that a majority of wireless phone-related crashes occur during conversation (NHTSA, 1997). Identifying which aspect(s) of the task of engaging in a wireless phone call while driving would assist in the determination of whether or not changes to the phone interface design might decrease distraction. Thus NHTSA undertook research, described in this report, to examine: a) the effects on driver distraction of wireless phone use while driving and b) driving performance as a function of wireless phone interface type (i.e., Hand-Held, headset Hands-Free, and Hands-Free with voice digit dialing).

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.

Recently, NHTSA conducted an on-road, naturalistic study that provided detailed information about the frequency, duration, and content of a selected set of phone calls made while driving, as well as the effects of phone use on driving behavior (report in progress). Useful information was also obtained regarding difficulties which drivers can encounter in using wireless phones while driving (e.g., poor voice recognition performance for the system used to provide voice dialing). However, one inherent limitation of naturalistic studies is their inability to control the situational (e.g., driver motives, roadway geometry), environmental (e.g., visibility, weather) and operational (e.g., traffic) conditions in which drivers use phones. As a result it is not possible to address specific questions about the extent to which different phone interface conditions and phone-task components interfere with driving in truly comparable conditions. The current work includes the experimental controls necessary to obtain relevant data to address such questions.

The NADS provides the computational capabilities and fidelity necessary to create complex driving situations with varying task demands. This research complements and extends ongoing test-track and on-road experimentation by examining the effects of wireless phone use in a variety of common driving situations in which the task demands are increased systematically. Participants are placed in situations in which they are using wireless communications devices in situations of varying driving demand that would create unacceptable risk if performed on real roadways. The use of the NADS also allows the inclusion of conflict situations that cannot safely be created in on-road experiments. The research thus utilizes the unique capabilities of the NADS to address questions that cannot be addressed with on-road or test-track experimentation.

1.2 Study Objectives

The study had two primary objectives: (1) to assess the distraction potential associated with the use of wireless phones while driving, and (2) to determine whether distraction potential was related to the specific phone interface used. In particular, the experiment addressed the question of whether Hands-Free operation substantively affected the distraction potential associated with wireless phone use while driving. In addition, the experiment investigated whether voice-activated dialing affected the distraction potential associated with using a phone while driving. The secondary objective was to determine whether the distraction potential associated with phone use varies with driver age.

1.3 Research Hypotheses and Approach

The experiment was designed to address the following hypotheses:

1. Phone conversation degrades driving performance and/or diverts attentional resources away from driving.
2. Hand-Held conversation degrades driving performance more and/or diverts more attentional resources away from driving than Hands-Free conversation.
3. Manual dialing requires more effort and/or takes more time than voice-activated dialing.
4. Answering a Hand-Held phone requires more effort and/or takes more time than answering with a Hands-Free interface.
5. Phone use while driving will degrade the driving performance of older and younger drivers more than middle-aged drivers.

The experiment was conducted using the National Advanced Driving Simulator (NADS), which allowed presentation of complex events with realistic motion cues. The approach required drivers of different ages to drive several iterations of a divided highway scenario while engaged in simulated phone conversations with different phone interfaces. Wireless phone use was scheduled to coincide with selected common driving situations to ensure that all participants used the phones under comparable driving conditions. Monetary incentives were used to establish priorities with respect to primary (driving) and secondary (phone communication) task performance. Research hypotheses were addressed by examining measures of driving performance, phone performance, and eye glance behavior.

2.0 SCENARIO DEVELOPMENT

This section describes the development of the freeway driving scenario. Using knowledge gained in the pilot study, the scenario was improved for use in the main experiment.

2.1 Rationale for Road Type

A number of issues were considered in determining the type of roadway environment in which to examine driver performance while using a wireless phone. Anecdotally, some people report that when driving they wait until they get on the freeway to make calls. Possible reasons for this might include the beliefs that the freeway environment involves more space between vehicles than in an urban environment and fewer objects and potential conflicts to respond to in the forward visual field. Considering this presumed propensity of drivers to use wireless phones on freeways, one might decide that this is the most appropriate environment in which to study driver distraction due to wireless phone use. However, if the rationale for waiting to make calls on the freeway stems from the drivers anticipating conflicts relating to the multitasking of driving while talking on the phone, then an urban arterial environment may more readily provide data useful for drawing conclusions about the effects of wireless phone use on driving performance. After much consideration, it was decided that both freeway and urban arterial roadway types provide the opportunity for examining interesting, but different, driving performance measures since these environments may result in very different phone utilization and consequences for safety. Thus, both types of environments were included in this initial research, but as separate experiments. Subsequent planned research, that will involve the examination of conversation content effects on driver distraction, could then draw from the results of the current research in determining the types of roadway scenarios most likely to reveal distraction effects.

The freeway experiment and associated route were developed first. The development of the freeway driving scenarios, experimental design, and experimental protocol were the main focus for a preliminary report (NHTSA, 2004). For the convenience of the reader, this information is summarized in the following sections. Discussion of development of the urban arterial driving scenarios and associated experimental methods will be presented in a subsequent report.

2.2 Freeway Scenario

The freeway scenario for this study used a four-lane divided roadway with a 65-mph speed limit. The route generally consisted of four straight segments of nearly equal length joined by right-side sweeping curved exit lanes, as shown in Figure 1. The large loops at each corner of the route were provided to keep the participant on course in the event that an exit was missed. The two smaller loops (part of the interchange) at each corner of the route were not used. The scenario involved the participant's vehicle starting on the right berm of a straight portion of the roadway and then merging to the left into the traffic lanes to begin the drive.

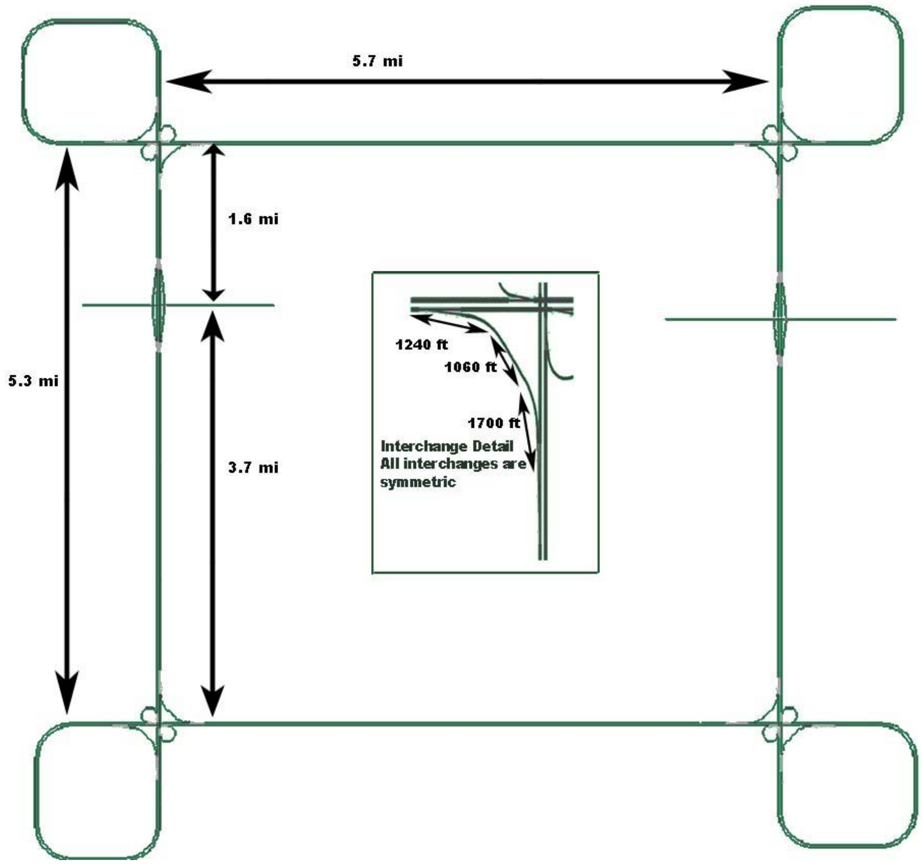

Figure 1. Freeway scenario route layout and dimensions.

The freeway treatment drives required participants to drive three segments of the divided freeway route with traffic present and events occurring at specified times. Each freeway drive consisted of three distinct phases. Each phase of the scenario involved a series of interactions between the driver and the scenario vehicles (i.e., events). Events included a sudden lead-vehicle cut-in (LV cut-in), sudden braking by the lead vehicle (LV brake), merging into a lane with traffic present, and a car following event. Detailed descriptions of the events are provided later in this section. The intention of the scenario design was to overlap the scenario events with conversation task periods, as illustrated in Table 1. This table shows the components and durations of the two phone call tasks. The conversation task components were 3.5 minutes in duration for all calls. Although the conversation task component of each call was presented continuously, the conversation task period was separated into three consecutive intervals based on the associated driving tasks. Specifically, each conversation task included a continuous car-following segment of 60 seconds (during which measures of the participant's ability to accurately follow the speed changes of the lead vehicle were obtained), a 30-second segment during which a discrete event such as a LV cut-in or LV brake event occurred, and a merging segment which required approximately 45 seconds to traverse at speed. Overall, 40 percent of the scenario involved phone task performance coupled with scenario events while 18.3 percent of the scenario consisted of baseline driving in which participants experienced scenario events while they were not using the phone. The remaining 41.7 percent of the scenario involved uneventful driving.

Table 1. Relation of phone tasks to freeway scenario events for one 15-minute drive (uneventful driving time not noted)

Phone task	Phone Task Duration (s)	No Phone Task Duration (s)	Coinciding Event
Dialing	30		Car following
Converse (1)	60		LV cut in
Converse (1)	60		Car following
Converse (1)	45		Merge
Answering	30		Car following
Converse (2)	60		Car following
Converse (2)	30		LV brake
Converse (2)	45		Merge
Baseline		30	LV cut in
Baseline		30	LV brake
Baseline		60	Car following
Baseline		45	Merge
TOTAL TASK TIME (s)	360	165	

The order of the associated driving tasks was varied so that the discrete event occurred first in approximately half the calls and the continuous car-following task occurred first in the remaining half.

The baseline phase included the same events as did the treatment drives, with the addition of one additional discrete event (i.e., both the lead vehicle brake event and the cut-in were presented in each baseline phase). Baseline events occurred without a phone task. A participant's performance in these baseline events was compared to his or her performance when using a wireless phone.

Each scenario drive lasted approximately 15 minutes. Note that this is much longer than the sum of the individual scenario events and included the time to startup, the time to perform transitions between phases and the time it took to come to a complete stop at the end of the scenario. Transition periods were present between events and came about as a result of trying to construct a visual database that would accommodate varying order for events in each segment. These transition periods also allowed the scenario vehicles to be gradually placed at specific locations relative to the driver before the next event occurred. Transition periods resulted in "uneventful driving time" when the participant was not performing a task or responding to an event. This uneventful driving time total 41.7 percent of the 15-minute freeway scenario.

Three treatments were designed to eliminate learning and anticipation of events from the participant. Each treatment varied the order of the baseline, incoming call, and outgoing call segments. In addition, the order of the scenario events within each segment varied across treatments as well. Table 2 shows the segment order and the sequence of events within each segment for each of the three treatments. Each scenario event is labeled with a B or C prefix indicating baseline or a call segment. Following the prefix, one or more letter codes are used to indicate the actual event. The last numeric component of the label is an indication of the intended duration of the event, in seconds. When no letter code exists after the prefix B or C (as in the third event of Treatment 1), then the participant is meant to drive freely with no specific events with the scenario vehicles. Figures 2 through 4 illustrate these same three treatments.

Table 2. Treatment order matrix

KEY:	B = Baseline C = Call (phone call)	CF = Car following M = Merge	LVB = Lead vehicle braking LVC = Lead vehicle cut-in

Treatment 1	**Treatment 2**	**Treatment 3**
Start	Start	Start
B-LVC B-LVB B (no event) B-CF B-M	C (no event) C-CF C-LVC C-M	C (no event) C-M C-LVB C-CF
C (no event) C-LVB C-CF C-M	B (no event) B-LVC B-CF B-M B-LVB	C (no event) C-M C-CF C-LVC
C (no event) C-LVC C-CF C-M	C (no event) C-CF C-M C-LVB	B-CF B-LVB B-M B-LVC B (no event)
End	End	End

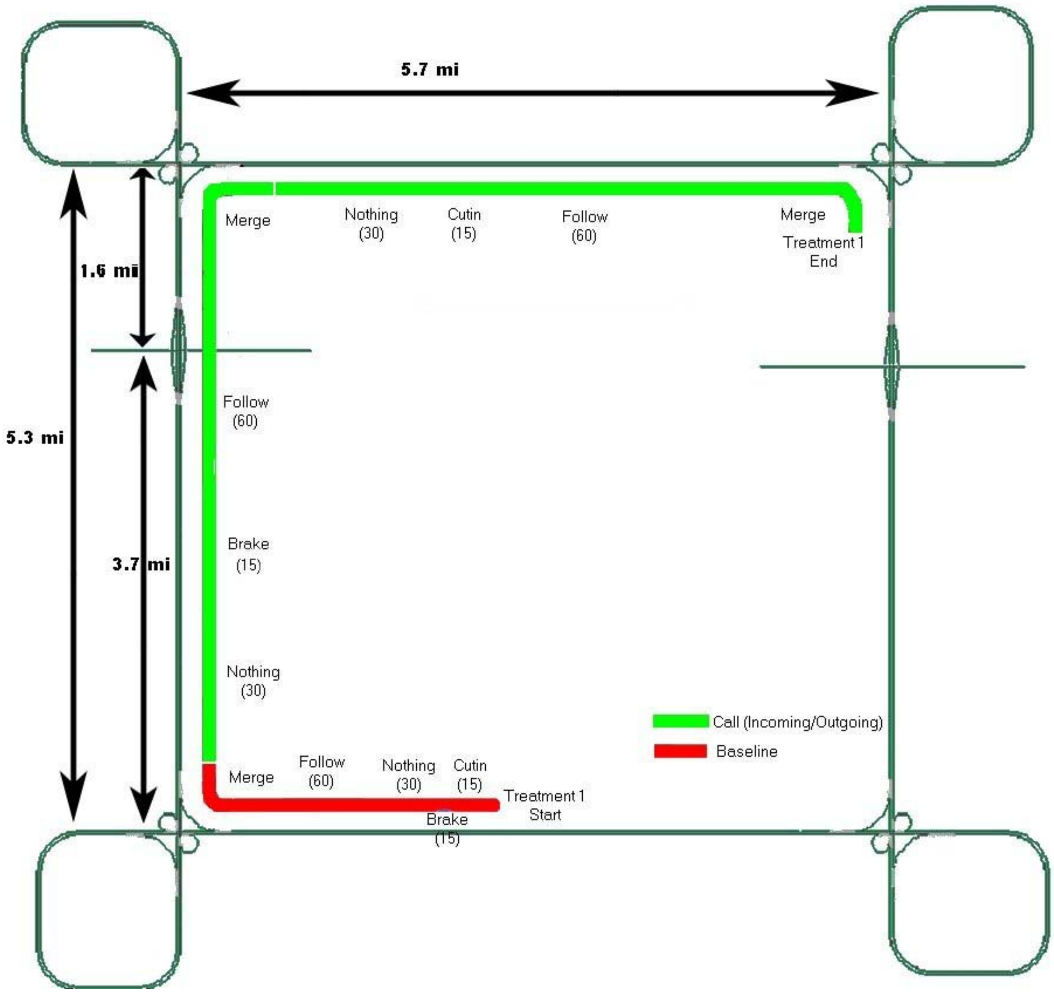

Figure 2. Treatment 1 illustration (numbers in parentheses are in units of seconds).

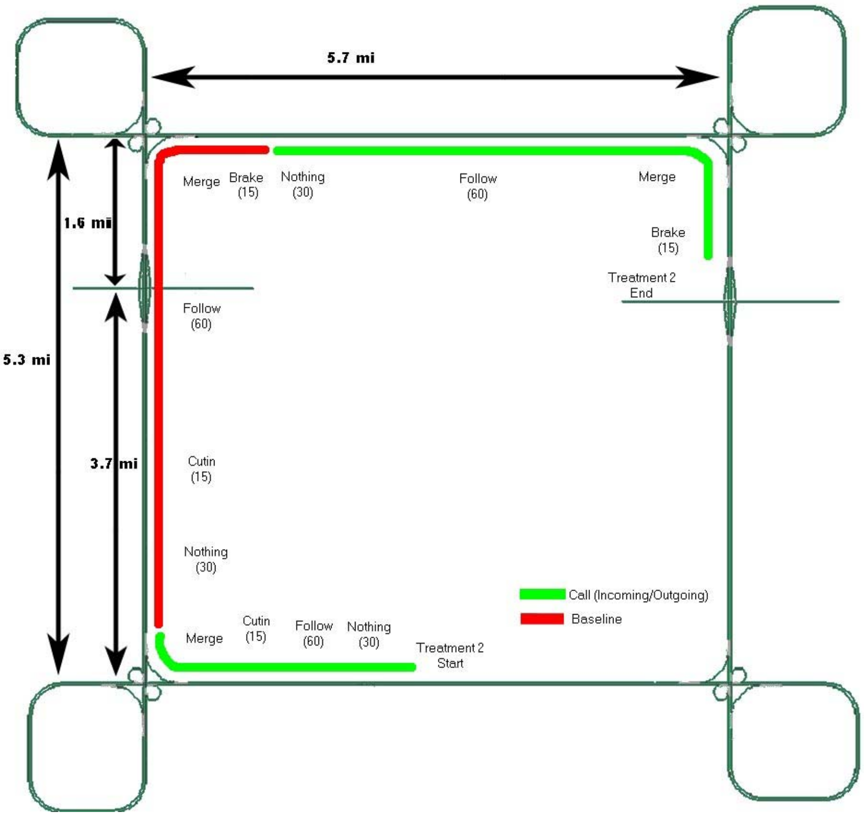

Figure 3. Treatment 2 illustration (numbers in parentheses are in units of seconds).

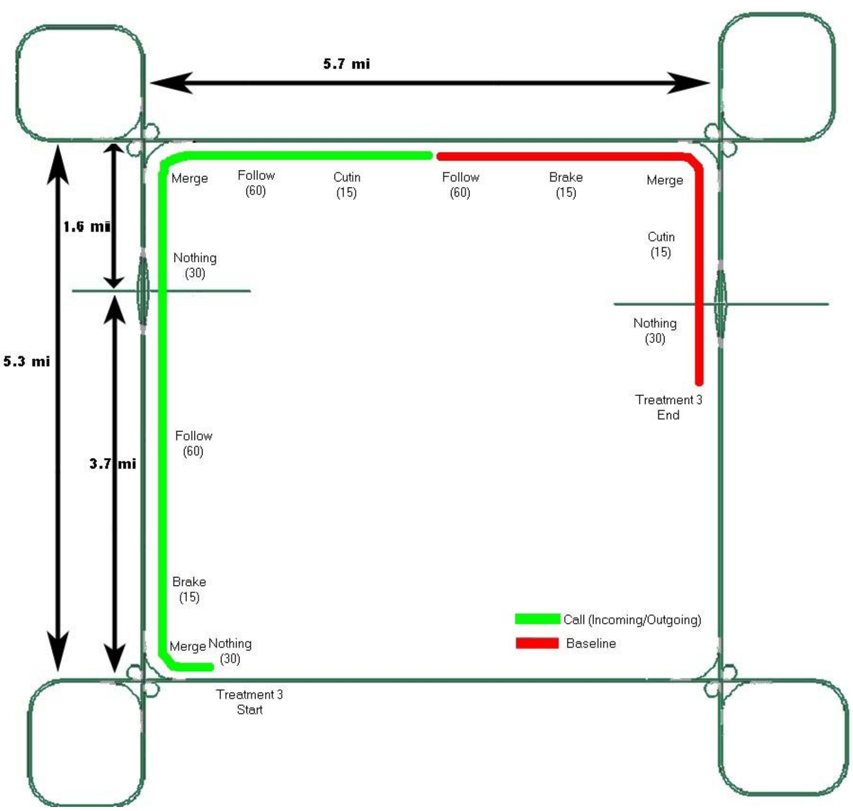

Figure 4. Treatment 3 illustration (numbers in parentheses are in units of seconds).

2.2.1.1 Lead Vehicle Braking Event (LV Brake)

This event involved a scenario vehicle (LV, for "lead vehicle") ahead of the participant's vehicle (P) in the right lane, braking suddenly, eliciting a braking input from the subject. The parameters associated with the event (time and location of occurrence relative to the position and speed of the participant's vehicle, i.e., Time-To-Collision (TTC) were selected to require an immediate response that was not critical or near critical. The intention of setting the parameters in this manner was to allow repeated trials without alarming participants to the point that they unnaturally divert their attention in anticipation of additional discrete events. Figure 5 illustrates this event.

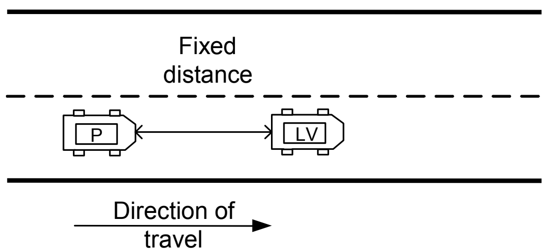

Figure 5. Illustration of initial condition for the lead vehicle braking event.

2.2.1.2 Lead Vehicle Cut-in Event (LV Cut-In)

This event involved a lead scenario vehicle (LV) in the left lane cutting in front of the participant's vehicle (P) in a non-threatening way. As with the lead vehicle braking event, this event also involved setting the parameters associated with the event (time and location of occurrence relative to the position and speed of the participant's vehicle, i.e., TTC) to require an immediate response that was not critical or near critical. The intention of setting the parameters in this manner was to allow repeated trials without alarming participants to the point that they unnaturally divert their attention in anticipation of additional discrete events. A graphical representation of this event is shown in Figure 6.

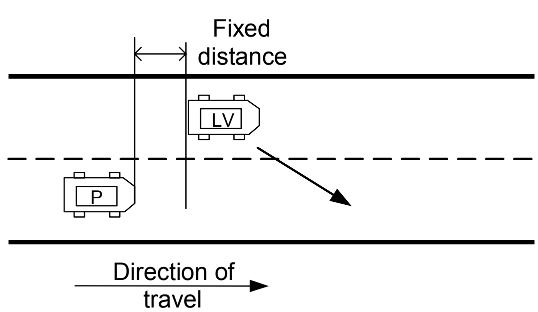

Figure 6. Illustration of initial conditions for the lead vehicle cut-in event.

2.2.1.3 Car Following Event

The car following event was based on a method developed by Brookhuis, de Waard and Mulder, (1994). The method utilized a car-following task in which the speed of the lead vehicle was varied systematically and the speeds of the lead and following vehicles were subjected to a transfer function analysis using lead vehicle speed as the input and following vehicle speed as the output.

The car following scenario event required the explicit cooperation of the participant who was instructed to follow a specific vehicle within a fixed range of following distance, despite any changes in the lead vehicle's velocity. Figure 7 illustrates the initial condition for this event, with "FV" indicating the vehicle that the participant should follow. This vehicle was unique and did not appear in any other place in any of the scenarios. The vehicle was a gold mini-van with a black and white "bulls eye" target on the rear (approximately where a spare tire might be mounted on a sport utility vehicle). A generic scenario vehicle (SV) was placed between the participant and the FV to hide the FV from the participant until the event began. The setup for this event involved the slight slowdown of the SV in order to leave room for creating the FV ahead of it. In addition, creating the FV ahead of another SV ensured that the "pop-up" (instantaneous appearance) of the FV was not easily visible to the participant.

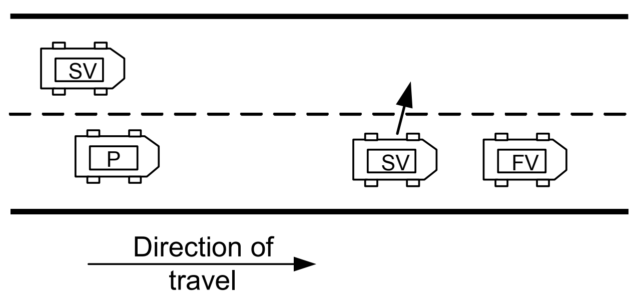

Figure 7. Illustration of initial conditions for the car following event.

Once the FV had been created, the event began when the SV between the participant and the FV made a lane change to the left, exposing the FV. The driver at that point was supposed to recognize the FV and commence the following task. The participant was required to accelerate in order to position his/her vehicle within the requested following distance range from the FV. After the FV was revealed, approximately 30 seconds are provided for the participant to "catch up" to the FV. During the 30 seconds, the FV maintained a fixed velocity thus allowing the driver to bring the following distance within the requested following distance range. At the end of this 30 seconds, the car following period of interest (for which data would be reduced) began with the FV entering the velocity variation phase. During this phase, which lasted exactly 60 seconds, the FV varied its speed according to the formula:

vel (in mph) = $60 + 7 * \sin(f*t + ph)$

In the above equation, 't' represents time. The variables 'f' and 'ph' were selected to provide a 30 second period with a 15 second negative phase. The period was selected so that the driver was exposed to two full cycles of speed variation. The phase was set to ensure that the LV would initially decelerate, providing one more opportunity for the participant to catch up.

Once the two cycles of speed variations were completed, the FV performed a lane change to the left. For the cases where this was not directly followed by a merge event, the FV slows down significantly and then performs a lane change to the right, in effect hiding behind any of the scenario vehicles that are following the participant.

2.2.1.4 Merge Event

This event took place when the driver was forced to negotiate a continuous stream of traffic while merging onto the freeway. Figure 8 illustrates a typical situation as a participant neared the merge point.

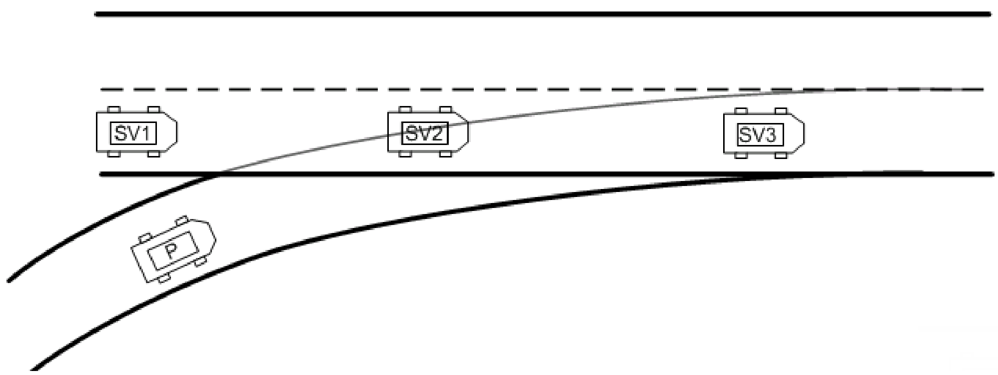

Figure 8. Illustration of the merge event.

The scenario was designed so that while approaching the merge point, the participant encounters a continuous stream of traffic requiring the participant to select and attempt to enter a gap between two successive scenario vehicles. The stream was created using a platoon of vehicles traveling with specified of inter-vehicle distances and travel speed. The scenario vehicles did not accommodate the participant by yielding or modifying their behaviors in any way except to slow down to avoid a collision once the participant's vehicle (P) had merged into the right lane of the freeway.

Note that even though the incident angle between the merge lane and the freeway was rather shallow, the freeway does not have a dedicated merge lane, thus requiring the participant to merge rapidly.

The setup for this scenario simply involved creating enough vehicles at the appropriate time so that the stream of scenario vehicles reached the end of the merge lane at approximately the same time as the participant.

2.3 Critical Event Scenario

A brief scenario involving a critical event was driven last, after all three treatment drives had been completed. The purpose of this scenario was to examine the effects of wireless phone use on the participant's ability to avoid a crash. Participants were assigned to one of three conditions for this drive: Hand-Held, Hands-Free speaker kit with voice digit dialing (VSHF), and baseline (HSHF with no call).

The final event was similar to the lead vehicle braking event, but involved a higher deceleration rate of the lead vehicle. The event was triggered by the participant driving over a particular spot on the road (i.e., a geographical trigger). The event consisted of a series of vehicles that made lane changes in front of the participant followed by a final vehicle that signaled, cut in, and ly performed an aggressive braking maneuver. This maneuver forced the participant to respond to avoid rear-ending the scenario vehicle.

3.0 METHOD

This section describes the method used for the examination of wireless phone interface effects on driving performance and behavior in a freeway environment. The urban arterial scenario study will be covered in a subsequent report.

3.1 <u>Experimental Design</u>

The freeway experiment had three factors: wireless phone interface (3 levels), phone call status (3 levels) and driver age group (3 levels). The first two factors were manipulated within subjects.

<u>3.1.1 Independent Variables</u>

3.1.1.1 Wireless Phone Interface

There were three interface conditions, Hand-Held (HH), Headset Hands-Free (HSHF), and Voice Digit Dialing with Hands-Free Speaker Kit (VSHF). The different interfaces required different numbers of steps to perform the phone tasks of dialing, answering, hanging up, and conversing. These steps and other details are presented in Table 3.

Table 3. Wireless phone interface conditions and phone task steps

<table>
<tr><th>Phone Task</th><th>Hand-Held
(HH)</th><th>Headset Hands-Free
(HSHF)</th><th>Voice Digit Dialing with Speaker Kit Hands-Free
(VSHF)</th></tr>
<tr><td>Physical Location of Phone and Accessories</td><td>Phone stowed in drink holder</td><td>Participants wears headset throughout drive, phone stowed in drink holder</td><td>Phone stowed in cradle, visor-mounted microphone provided for Hands-Free voice input</td></tr>
<tr><td>Dialing</td><td>1. Flip phone open in hand
2. Extend antenna
3. Dial 10-digit number
4. Press ‘talk’)</td><td>1. Flip phone open in hand
2. Extend antenna
3. Press ‘*’ then ‘TALK’
4. Say “Call 319-335-xxxx”
5. System repeats number back, then says “correct?”
6. If number is correctly repeated back, say “yes”
7. System says “Dialing!”</td><td>1. Reach toward phone in cradle
2. Press ‘*’ then ‘TALK’
3. Say “Call 319-335-xxxx”
4. System repeats number back, then says “correct?”
5. If number is correctly repeated back, say “yes”)
6. System says “Dialing!”</td></tr>
<tr><td>Answering</td><td colspan="2">1. Flip phone open in hand
2. Extend antenna
3. Press ‘talk’
4. Raise phone to ear
5. Say “hello”</td><td>1. Reach toward phone in cradle
2. Press ‘TALK’
3. Say “hello”</td></tr>
<tr><td>Conversing (Talking)</td><td>Phone in hand</td><td>Phone in hand or resting on lap/seat</td><td>Phone fixed in cradle</td></tr>
<tr><td>Hanging Up</td><td colspan="2">1. Press “END”
2. Flip phone closed in hand
3. Stow antenna
4. Place phone in drink holder</td><td>1. Reach toward phone in cradle
2. Press ‘END’</td></tr>
<tr><td>Baseline</td><td colspan="3">Same for all interfaces</td></tr>
</table>

3.1.1.2 Phone Call Status

Each drive had three comparable road segments, allowing for two phone calls and one baseline segment. The levels for this variable were therefore (Incoming, Outgoing, No Call).

3.1.1.3 Age

Three age groups were examined: Younger (18-25), Middle (30-45), and Older (50-60).

3.1.2 Conversation Task

The conversation task was a modification of the Baddeley working memory span task (Baddeley, Logie, and Nimmo-Smith, 1985). Participants were required to listen to sentences and determine whether or not they made sense (decision-making/judgment component). All sentences were of the following construction: Subject - action verb – object, and used common English words. Sentences were constructed so that the judgment task (sensical/nonsensical) could not be made until the object was heard. This required the participant to pay attention to the entire sentence before answering and also forced a consistent start to the response period (i.e., the completion of the last word of a sentence was the beginning of the response period.). After each group of four sentences, participants were required to recall either the subject or object of each sentence in the group (memory recall component). The recall components (subject/object) were balanced across calls such that half requested recall of the sentence subjects and half requested recall of the sentence objects.

Before each group of sentences, participants were told to recall either the subjects or objects of the sentences. Each group of four sentences comprised one Baddeley task trial. To ensure that phone calls spanned the desired events, calls were constructed to last approximately 3.5 minutes. Thus, each call had six groups of four for a total of 24 sentences (12 meaningful + 12 nonsensical sentences).

Additional details on this task and its development are presented in the NHTSA report titled, "Examination of the Distraction Effects of Wireless Phone Interfaces Using the National Advanced Driving Simulator - Preliminary Report on a Freeway Pilot Study" [NHTSA, 2004].

3.1.3 Dependent Variables

Driving performance measures are summarized in the table below for each of the scenario events presented. Additional details on each event follow the table. Computation of the metrics listed in Table 4 is discussed in Appendix A.

Table 4. Scenario event stimuli and related dependent measures

STIMULUS	DEPENDENT MEASURE
Car Following	Coherence Phase shift (delay) (s) Modulus (gain) Time headway (s) Lane position variability Steering reversals Steering holds Steering entropy
Lead-Vehicle Braking Event	Accelerator drop reaction time (s) Brake reaction time (s) Maximum deceleration (g) minimum bumper-to-bumper distance between vehicles (ft)
Lead Vehicle Cut-In Event	Speed before the event (mph) Accelerator drop reaction time (s) Brake reaction time (s) Maximum deceleration (g)
Merging	Speed change during exit Lane position variability during exit Percentage of time glancing left during planning Time required to merge Speed at merge
Phone Task Performance	Dialing time (s) Answering time (s) Hang up time (s) Conversation task number of correct judgments Conversation task number of recalled words

3.1.3.1 Lead Vehicle Braking Event

Two primary dependent measures were the accelerator release and brake reaction times, each measured from the time at which the lead vehicle brake lights were activated. We also measured the maximum deceleration and the minimum bumper-to-bumper distance between the vehicles.

3.1.3.2 Lead Vehicle Cut-In Event

Participants experienced two cut-in events during each drive, one while involved in a phone call, one while not in a phone call. There were four performance measures associated with the cut-in events: speed before the event (mph), brake reaction time (seconds), accelerator release time (seconds), and maximum deceleration (g). All measures are timed from the beginning of the event, defined as the time at which the encroaching vehicle first turns on its turn signals.

3.1.3.3 Car Following Performance

Dependent variables for the car following event included coherence, phase shift (delay), and modulus (gain). The coherence between the speeds of the two vehicles is a measure of squared correlation, reflecting the accuracy of the following driver's adaptation to changes in the lead vehicle speed. When coherence is relatively high (e.g., ≥.70), the driver is adequately following the lead vehicle's speed changes. Brookhuis, de Waard and Mulder (1994) have shown that distraction due to wireless phone use while driving increased the phase shift of the two speed signals, reflecting an increase in the lag or response time in the car following task, which they refer to as delay.

Modulus was the third parameter in the car following paradigm, reflecting the gain associated with the following vehicle speed, relative to the lead vehicle speed. A modulus value of 1 indicates that the amplitude of the following vehicle speed trace was equivalent to that of the lead vehicle. The magnitude of the deviation from 1 corresponds to the amount of error in car following. Values greater than 1 represent over-correction, typically resulting from aggressing following. Values less than 1 represent under-correction, typically resulting from conservative following.

Time headway, in seconds, was examined during car following. Time headway was calculated by dividing the range (distance) from the participant's vehicle to a forward vehicle by the speed of the participant's vehicle.

Lane position variability, calculated as the standard deviation of lane position (SDLP), was examined during car following as well as during non-event driving.

Several measures of steering performance were also examined including steering entropy, steering reversals, steering hold rates.

3.1.3.4 Merging Performance

Each merge event required the driver to exit the freeway to the right, follow an exit ramp and then re-enter the traffic stream that ran on a freeway perpendicular to the original freeway. All merges were geometrically identical. To facilitate analysis, a behavioral model was developed, according to which merge behavior was separated into the following components: Exit ramp behavior, transition, merge planning and merge execution. Performance measures were developed in accordance with this model. Specifically, the change in speed and maintenance of lane position were used to characterize behavior on the exit ramp. Lane maintenance was examined for the transition. Measures of when drivers began planning and how intensively they planned, primarily measures of glance behavior, were used to characterize behavior in advance of the merge. Finally, the time required to merge, the position of the vehicle on the roadway, and the speed of the vehicle at the end of the merge were examined. Additional details of the behavioral model and performance measures are presented in Section 4.5 of this report.

3.1.3.5 Glance Behavior

Glance behavior was examined only for the planning component of merge events. Dependent measures included frequency of glances to the left, glance duration, and the percentage of time spent looking left in preparation for the merge.

3.1.3.6 Phone Task Performance

Measures of phone task performance included dialing speed and answering speed, both measured in seconds. Measures of conversation (Baddeley task) performance include accuracy of judgment and recall, both measured in terms of number correct.

3.1.4 Incentives

Participants were paid a base pay amount of $30, plus incentive pay. The monetary incentives were used to establish priorities for participants and to promote a balance between primary (driving) and secondary (phone communication) task performance. The incentive scheme was intended as a method of reliably rewarding participants for performance; it was not intended or designed for use as a dependent measure.

The monetary rewards and penalties were based on a total number of points allocated for each task during each drive. Money was earned for driving safely and attentively and for completing phone tasks accurately and quickly. Unsafe driving, including speeding, reckless driving, and collisions that could have been avoided, resulted in monetary penalties. For example, extreme steering responses or excessively hard braking were considered unsafe responses. Participants started with a specified number of points and then lost points for not performing well and/or gained points for performing above expectations. It was not possible for participants to "lose" money beyond what was allocated for incentives (i.e., no pay was taken away from the base pay). Incentive pay ranged between $0 and $8.00 per drive.

3.2 Participants

A total of 54 licensed drivers (27 males and 27 females) participated. The participants were equally divided among three age groups: Younger (18-25), Middle (30-45), and Older (50-60). Persons eligible to participate had owned a wireless phone for a minimum of six months and reported using a wireless phone while driving at least once per day.

3.3 Wireless Phone Equipment

The same wireless phone model was used to implement all three wireless phone interface conditions. The phone selected for use in the experiment (Samsung A460) is pictured in Figure 9. The phone ring tone was set to ringer #6, since this tone was judged to sound most like a typical phone ring tone. Figure 10 shows the headset selected for use in the study (Plantronics M175). This headset was selected because it fit securely about the head and had a noise-canceling boom microphone.

Figure 9. Wireless phone model used in the experiment (Samsung A460).

Figure 10. Phone headset used in the “Headset Hands-Free” condition (Plantronics M175).

Figure 11 shows the location of the phone cradle used in the VSHF condition as it was positioned for testing mounted to the right side of the center console. A pad of paper containing names and related phone numbers was mounted to the dashboard. These numbers were used for outgoing calls. Figure 12 shows another view of the phone cradle configuration (attached to the right side of the console) along with the location of the pad of paper.

Figure 11. Photograph showing VSHF Hands-Free Speaker Kit setup and phone cradle location.

Figure 12. Photograph showing location of phone cradle and phone number pad location.

3.4 Simulator Apparatus

The National Advanced Driving Simulator (NADS), located at the University of Iowa's Oakdale Research Park in Coralville, was used for this study. The NADS consists of a large dome in which entire vehicle cabs (e.g., cars, trucks, and buses) can be mounted. The dome is mounted on a 6 degree of freedom hexapod, which is mounted on a motion system, providing 65.62 feet (20 meters) of both lateral and longitudinal travel and 330 degrees of yaw rotation. The resulting effect is that the driver feels acceleration, braking and steering cues as if he or she were actually in a real car, truck or bus. The vehicle cabs are equipped electronically and mechanically using instrumentation specific to their makes and models. A Chevrolet Malibu sedan cab was used for this experiment.

The Visual System provides the driver with a realistic field-of-view, including the rearview mirror images. The driving scene is three-dimensional, photo-realistic, and correlated with other sensory stimuli. The Visual System database includes representations of highway traffic control devices (signs, signals and delineation), three-dimensional objects that vehicles encounter (animals, potholes, concrete joints, pillars, etc.), common intersection types (including railroad crossings, overpasses, bridge structures, tunnels, etc.), and various weather conditions. In addition, high density, multiple lane traffic can be made to interact with the driver's vehicle.

The Control Feel System (CFS) for steering, brakes, clutch, transmissions, and throttle, realistically controls reactions in response to driver inputs, vehicle motions and road/tire interactions over the vehicle maneuvering and operating ranges. The CFS is capable of representing automatic and manual control characteristics such as power steering, existing and experimental drive trains, Antilock Brake Systems (ABS), and cruise control. The control feel cuing feedback has high bandwidth and no discernible delay or distortion associated with driver control actions or vehicle dynamics. An automatic transmission and conventional (non-ABS) brake system were used for this study.

The Motion System provides a combination of translational and angular motion that duplicates scaled vehicle motion kinematics and dynamics with nine degrees of freedom. The Motion System is coordinated with the CFS to provide the driver with realistic motion and haptic cuing during normal driving and pre-crash scenarios. The motion system is configured and sized to correctly represent the specific forces and angular rates associated with vehicle motions for the full range of driving maneuvers. In addition, four actuators located at each wheel of the vehicle, provide vertical vibrations that simulate the feel of a real road.

The Auditory System provides motion-correlated, three dimensional, realistic sound sources, that are coordinated with the full ranges of the other sensory systems' databases. The Auditory System also generates vibrations to simulate vehicle/roadway interaction. The auditory database includes sounds emanating from current and new design highway surfaces, from contact with three-dimensional objects that vehicles encounter (potholes, concrete/tar joints, pillars, etc.), from other traffic, and from the vehicle during operation, as well as sounds that reflect roadway changes due to changing weather conditions.

The Vehicle Dynamics (NADSdyna) System determines vehicle motions and control feel conditions in response to driver control actions, road surface conditions and aerodynamic disturbances. Vehicle responses are computed for commanding the Visual, Motion, Control Feel, and Auditory Systems. Available vehicle dynamics models include passenger cars, light trucks, and heavy trucks. The models encompass normal driving conditions and limit performance maneuvering that might be encountered during crash avoidance situations, including spinout and incipient rollover.

For this study, the NADS was configured with a Chevrolet Malibu cab and related vehicle dynamics model with an automatic transmission.

Additional detailed information about the NADS can be found in the form of a downloadable brochure on NHTSA's Internet web site at http://www-nrd.nhtsa.dot.gov/pdf/nrd-12/nads/NADSBrochure.pdf. Information is also provided on the University of Iowa's NADS web site at http://www.nads-sc.uiowa.edu/.

3.4.1 Wireless Phone Service Implementation in the NADS

This study used actual digital wireless phone service, rather than simulating the phone calls. Using actual wireless phone service allowed the use of an unmodified, commercially available wireless phone and required only adding a digital signal repeater to transmit the signal into the NADS dome. Actual wireless phone service was thought to give the most realistic experience and be relatively easy to implement, but introduced variability in terms of connect time. Simulating the calls would have involved "tapping" into the phone itself to permit the conversation to be presented through the phone without using a wireless phone service, as well as allow the phone to ring at the appropriate time. This would have involved a time intensive process to determine the appropriate circuits and then figure out how to connect to them in order to emulate the various functions. Additionally, many of the functions are implemented without discrete circuitry possibly requiring proprietary knowledge of the custom, single-chip designs. Lastly, to accomplish this wired manual control of the phone, wires would have to be run to the phone, essentially making it a "corded" phone thus losing the wireless aspect. For these reasons, use of an actual phone handset with digital wireless service was chosen.

3.5 Experimental Procedures

Fifty-four individuals participated in the study. Procedures for each segment of the experiment are presented below.

3.5.1 Screening

Experimental staff completed a standard telephone screening procedure, augmented with questions regarding wireless phone use. The screening procedure addressed issues such as driving habits, demographics information, health issues, and medications that have the potential to affect driving performance.

3.5.2 Briefing and Informed Consent

Experimental staff greeted each participant upon arrival at the NADS facility. He or she was given a verbal overview of the material covered in the Informed Consent Document (see Appendix B) and was then asked to read and sign the document before continuing participation in the study. Next, the participant was asked to complete the NADS Driving Survey (see Appendix C). The participant preparation period concluded when the participant was instructed as to how the incentive scheme for driving performance was applied.

3.5.3 Prep Room Pre-Drive Instruction and Training

3.5.3.1 Phone Interface Training

In the prep room, the participant was introduced to the wireless phone and its features, as well as the accessory equipment used in different interface modes. Experimental staff then explained the three modes of operation for the phone and instructed him or her on how to place and receive calls in each mode. The participant was instructed to use 10-digit dialing (i.e., the area code and 7-digit phone number). The participant was asked to demonstrate placing and receiving calls in each mode.

The participant was told that during driving they would be required to place and receive phone calls. The participant was instructed to answer the phone by saying, "hello." The participant was instructed that during driving the experiment would occasionally ask them to call a person by saying, "Please call (person's first name) now." When asked to place the call, the participant was instructed to refer to a list of several names and phone numbers that was mounted on the dashboard of the vehicle. An opportunity was provided for the participant to ask questions.

3.5.3.2 Conversation Task Training

The participant was next presented with printed (see Appendix D) and pre-recorded audio instructions for the conversation (Baddeley working memory span) task. The participant was encouraged to complete the interactive training segments at the end of the instruction phase. Each conversation task was integrated with each wireless phone interface, allowing the participant to make and receive calls and complete the task with each interface. An opportunity was again provided for the participant to ask questions.

3.5.3.3 Driving Overview

The participant was given verbal descriptions of the various driving events he or she would experience (i.e., car following, merge/exit ramp, lead vehicle cut-in, and lead vehicle brake) by experimental staff and were shown a brief video clip of the car following event. An example of the desired distance at which to follow the lead vehicle in the car following event was shown to the subject by video. An opportunity was again provided for the participant to ask questions.

3.5.4 Driving

The participant was introduced to the in-vehicle experimenter. The in-vehicle experimenter escorted the participant to the vehicle and seated, then gave him or her instructions on how to adjust the driver's side mirror and how to move the steering wheel up and down. The in-vehicle experimenter pointed out the speedometer and gear lever, emphasizing that it is to stay in DRIVE once the drive begins. Next, the participant was directed to the wireless phone and encouraged to practice putting the wireless phone in the cradle and hooking up the accessory equipment. He or she was then asked to set the equipment up for the first interface condition. The participant was instructed to keep the seatbelt on until instructed to remove it, or the simulator will shut down. An opportunity was then given for the participant to ask questions.

The in-vehicle experimenter then briefed the participant on the scenario: "In this driving scenario, you need to stay in the right lane at all times and adjust your speed to a comfortable and appropriate distance behind the vehicle in front of you. You will take the exits for BREMEN; do not take any other exits or make any other route deviations. Do you have any questions?"

3.5.4.1 Familiarization Drive

The participant was asked to drive the freeway route in its entirety to become familiarized with driving the simulator and the roadway scenarios. This familiarization drive consisted of the freeway route without any traffic or events present. The participant experienced the car following scenario and was provided with guidance regarding the appropriate following distance to maintain.

3.5.4.2 Practice Drive

The participant completed three short practice drives, one before each treatment drive. Each practice drive consisted of one segment of the freeway route along with one of the merge portions of the route. Both traffic and scenario events were presented. The purpose of this drive was to give the participant the opportunity to practice making an outgoing phone call (dialing) and to perform the phone conversation task.

3.5.4.3 Treatment Drives

The participant completed three 15-minute treatment drives, answering one call and placing one call during each drive. The participant completed the conversation task during all phone calls. The experimenter explained the performance incentive results from each drive after it was completed. Between drives, the participant was instructed as to which phone interface to hook up and use in the next drive. Following the third treatment drive, the participant experienced a brief final scenario involving a conflict situation that required him or her to maneuver the vehicle to avoid a crash.

The intention of the scenario design was to overlap the scenario events with conversation task periods, as illustrated in Table 1. This table shows the components and durations of the two phone call tasks. The conversation task components were 3.5 minutes in duration for all calls. Although the conversation task component of each call was presented continuously, the conversation task period was separated into three consecutive intervals based on the associated driving tasks. Specifically, each conversation task included a continuous car-following segment of 60 seconds (during which measures of the participant's ability to accurately follow the speed changes of the lead vehicle were obtained), a 30-second segment during which a discrete event such as a LV cut-in or LV brake event occurred, and a merging segment of approximately 45 seconds in length. Overall, 40 percent of the scenario involved phone task performance coupled with scenario events while 18.3 percent of the scenario consisted of baseline driving in which participants experienced scenario events while they were not using the phone. The remaining 41.7 percent of the scenario involved uneventful driving.

The order of phone events was varied so that the incoming call, outgoing call, and baseline period each occurred an equal number of times at the beginning, middle, and end of the treatment drive.

3.5.4.4 Final Event Scenario Drive

In the final, critical scenario, participants used the same wireless phone interface as had been used in their third treatment drive. Those who drove with the HSHF interface last experienced this event while they were not engaged in a call to facilitate collection of baseline data for this event. Thus, the conditions for which the critical event was presented were Hand-Held, Hands-Free speaker kit with voice digit dialing (VSHF), and baseline. This drive was approximately 5 minutes in length.

3.5.4.5 End of Driving

After the driving trial was complete and the vehicle shifted into PARK, the Simulator Sickness Questionnaire (see Appendix E) was administered. When the simulator was docked, the participant was escorted to the participant prep area and the prep area experimenter was notified of his/her arrival.

3.5.5 Post-Drive Questionnaires and Wrap-Up

The participant was offered a snack or beverage and given an opportunity to ask questions. If the Simulator Sickness Questionnaire was not finished in the vehicle, the participant was allowed to complete it. Next the Realism Survey (see Appendix F), and NADS Wireless Phone Post-Drive Survey (see Appendix G) were administered.

The NADS Wireless Phone Post-Drive Survey consisted of a 24-item post-drive questionnaire was administered to collect participant attitudes, preferences, and previous experience with each wireless phone interface and their opinions toward the safety and legislation of wireless phone use. Specific questions focused on perceived ease or difficulty in dialing, conversing, and driving with each interface, preference for each interface method, and overall preference for a manual vs. voice dialing method. Additional questions dealt with the perceived safety of using a wireless phone in various driving situations.

Next, a structured interview was conducted to gain additional information regarding drivers' awareness of changes in their driving behavior during wireless phone use. The format for this interview is presented in Appendix H.

Finally, the experimenter described how compensation was related to driving performance and paid the participant. The participant was then escorted to the exit.

4.0 RESULTS

4.1 Data Analysis Approach

Analyses were computed using the Proc Mixed in SAS V8.2. Separate analyses were computed for each dependent variable associated with a particular data set. Separate data sets were created for each scenario event, which included car following, lead-vehicle braking, lead-vehicle cut-in, and merges. Specific hypotheses and dependent variables associated with each event are discussed in the following sections.

Several preliminary analyses were conducted for each performance measure. Specifically, data from incoming and outgoing phone trials were first compared to test the hypothesis that there should be no difference between these trials. This hypothesis is based on the fact that when any of the events occurred, the subjects had already either initiated or received the call and were engaged in performance of the phone conversation task. For all measures, no differences were found between the incoming and outgoing calls and therefore were combined these data for subsequent analyses.

Next, the hypotheses were tested that there were no differences between the different baseline events. This is based on the fact that during baseline driving, subjects were encountering the exact same events under the exact same conditions without the phone task. Consequently, there was no reason to expect the interface condition to influence performance during the baseline segments. For all measures, no differences were found between the baseline events and therefore they were combined. A single phone interface variable was created, which had four levels (Baseline, Hand-Held interface, Voice Digit Dialing with Speaker Kit Hands-Free interface, Headset Hands-Free interface). This simplified the analysis model by allowing the use of a single baseline condition, however it created an unbalanced design in which the baseline condition had one and one-half or three times as many observations as in each interface condition. To compensate for this lack of balance, the comparisons between means were made using estimated least-square means, rather than arithmetic means. Comparisons between means presented in the following sections will therefore utilize the least-square means.

The resulting statistical model had two independent variables, including Interface (4 levels) and Age Group (3 levels). Interface was varied within subjects and subjects were nested within Age groups. The SAS protocol for Proc Mixed requires analyses to be conducted using the covariance structure that best models the correlation among the repeated factors in the design. Thus the initial step in each analysis was to test a number of covariance structures. SAS computes several log-likelihood indices of model fit, including a corrected version of Akaike's Information Criterion (AICC) and Schwarz's Bayesian Information Criterion, both of which are discussed by Littell and colleagues (Littell, Milliken, Stroup, & Wolfinger, 1996; Littell, Stroup, & Freund, 2002). Specifically, for each dependent measure, a model was selected that had the smallest AICC and BIC values, giving priority to AICC. If two or more covariance structures provided an approximately equal fit, the simpler covariance structure was selected. One important strength of the SAS Proc Mixed is that it allows for planned contrasts and post hoc analyses to be conducted without consideration of the appropriateness of the error term. Traditionally, it has been impossible to conduct post hoc tests for random effects in repeated-measures designs with other analysis of variance procedures (ANOVA, GLM) due to the inability to specify the correct error term. The use of a specially fitted covariance structure in

Proc Mixed eliminates the need to modify the error term for post hoc testing in repeated-measures analysis of variance.

A note of caution is appropriate for interpretation of comparisons between pairs of means. Specifically, the probabilities associated with the *t* tests have not been adjusted to account for experimentwise error, because such adjustments tend to be overly conservative. Alternatively, we have selected $p < .01$ as the cutoff for post hoc tests only and treat results with p values between .01 and .05 with caution. For omnibus test results, we use $p < .05$ as our criterion.

4.2 Car-Following Events

This event was designed to provide 1 minute of close car following behavior in which the participant followed a designated lead vehicle that was changing speed according to a predefined sine wave pattern. The speeds of the lead and following drivers were used to compute coherence and the associated measures (phase shift and modulus). The scenario control program incorporated a delay of approximately 10-15 seconds following the creation of the lead vehicle to allow the driver to attain a close following distance before data collection was initiated. Preliminary review of the car-following data revealed that on some trials the participant had not positioned the simulated vehicle at a close following position at the beginning of the data collection interval. On these trials, rather than following the speed changes in the lead vehicle, the driver was accelerating to catch up to the lead vehicle during the initial part of the data collection interval. This problem was observed in 183 (39 percent) of 472 trials for which data were available. [Note: the design called for 54 subjects x 3 interfaces x 3 phone conditions = 486 car-following samples. Data were unavailable for 14 (2.9 percent) of the trials.]

After examining the data, the decision was made to trim the affected files to eliminate data that was clearly not car following behavior. Since the data collection interval was designed to provide two full cycles of speed data, it was decided not to use trials that had less than 50 percent remaining after trimming. This ensured that a minimum of one full cycle of speed data was available. Previous experience indicated that one cycle was necessary to obtain a relatively stable coherence measure.

For 27 trials (5.7 percent of 472 available trials) less than 50 percent of the data were available and these trials were therefore eliminated. For the remaining 156 catch-up trials, the point at which the subject had coupled speed with the lead vehicle was determined by examining speed and distance channels. This was found to be easier to do visually than by attempting to develop objective criteria that could be applied automatically. The mean percentage of data trimmed was 28.2 (SD = 12.4).

With several exceptions, the effect of the trimming on the coherence values was relatively minor. The average difference in coherence was an increase of 0.04 (SD = 0.068). The changes ranged from a decrease of 0.21 to an increase of 0.29. The degree of change in coherence was generally correlated with the percentage of data trimmed. In particular, changes in coherence of more than 0.2 were almost always associated with samples for which more than 40 percent of the data were removed.

The effect of the trimming was to increase the homogeneity of the data set by eliminating trials that were a mixture of catch- up and following behavior. The resulting data set comprised samples of following behavior only. The analysis results for car-following coherence and its associated measures of phase shift and modulus are presented in Table 5.

Table 5. Summary of ANOVA results for coherence and associated measures

Dependent measure	Effect	DF	F value	Pr > F
Coherence	Interface	3,51	1.18	0.3300
	Age group	3,51	0.19	0.8300
	Interface x Age group	6,51	1.00	0.4400
Phase shift (delay)	Interface	3,148	9.15	<0.0001
	Age group	2,51	0.12	0.8900
	Interface x Age group	6,148	1.28	0.2700
Modulus (gain)	Interface	3,148	6.36	0.0004
	Age group	2,51	7.89	0.0010
	Interface x Age group	6,148	1.02	0.4100

None of the model factors influenced coherence, which indicated that drivers were able to perform car-following equally well while they were engaged in conversation task, relative to the baseline condition. There were significant differences in the observed phase shift as a function of interface condition, as shown in the following figure.

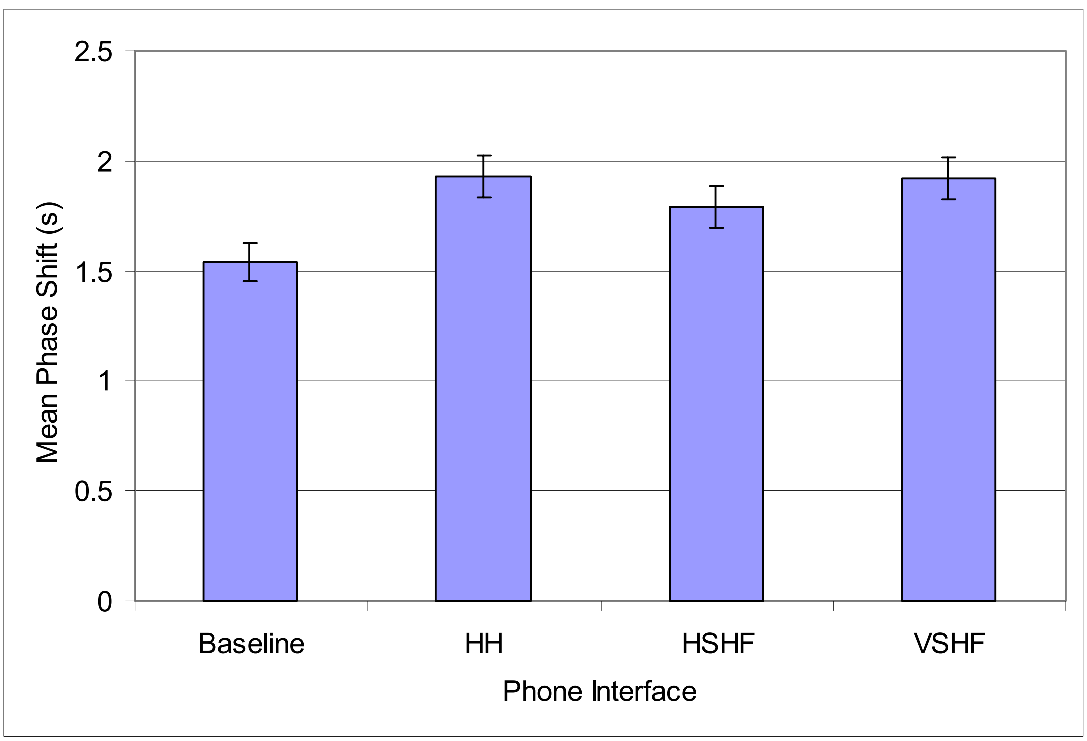

Figure 13. Means and standard errors for phase shift during car-following

Pairwise comparisons among means are shown in the following table.

Table 6. Individual comparisons for Phone Interface main effect on phase shift (delay)

Comparison	DF	T value	Pr > |t|
Baseline – VSHF	148	- 4.21	< .0001
Baseline – HH	148	- 4.19	< .0001
Baseline – HSHF	148	- 2.71	0.0075
VSHF – HH	148	-0.08	0.9403
VSHF – HSHF	148	1.32	0.1885
HH – HSHF	148	1.36	0.1745

The results indicate quite clearly that the conversation task was associated with a significant increase in car-following phase shift. As shown in Figure 13, the average increase in car-following phase shift was between 0.3 and 0.4 seconds, which represents an increase of approximately 20-25 percent. As shown in Table 6, the car following phase shifts for all three interface conditions were significantly different from the baseline condition. There were no statistically significant differences among the three interface conditions for this measure, although the headset condition was generally associated with a smaller increase in average phase shift, relative to the other two interface conditions.

This pattern of results is consistent with that found by Brookhuis, et al., (1994) in a study of the effects of mobile phone use during car following. Specifically, they found no effect of phone use on coherence, indicating that drivers were not impaired in their ability to adapt to the speed changes of the lead vehicle. This was combined with an increase in phase shift of approximately 20 percent. This increase in car following phase shift indicates a consistent delay occurring over the entire car-following interval. Thus, being engaged in performance of the phone conversation delayed task drivers' responses generally by approximately 20 percent.

Modulus values represent a ratio of the amplitude of the speed signals for the following and lead vehicle, respectively. Modulus values close to one indicate accurate following at the extreme values (i.e. minimum and maximum speeds). Modulus values under one reflect under-correction in response to changes in lead-vehicle speed, while modulus values over one reflect a tendency to over-correct. Under-correction can be considered to be a conservative response, while over-correction can be considered to be an aggressive car-following response to speed changes. Both behaviors can lead to unsafe following distances.

Mean values for car-following modulus (gain) are shown along with standard errors for the four interface conditions in Figure 14. Pairwise comparisons among means are shown in Table 7.

Table 7. Individual comparisons for Phone Interface main effect on modulus (gain)

Comparison	DF	T value	Pr > |t|
Baseline – VSHF	148	3.49	0.0006
Baseline – HH	148	3.76	0.0002
Baseline – HSHF	148	2.64	0.0091
VSHF – HH	148	0.32	0.7465
VSHF – HSHF	148	-0.73	0.4692
HH – HSHF	148	-1.03	0.3061

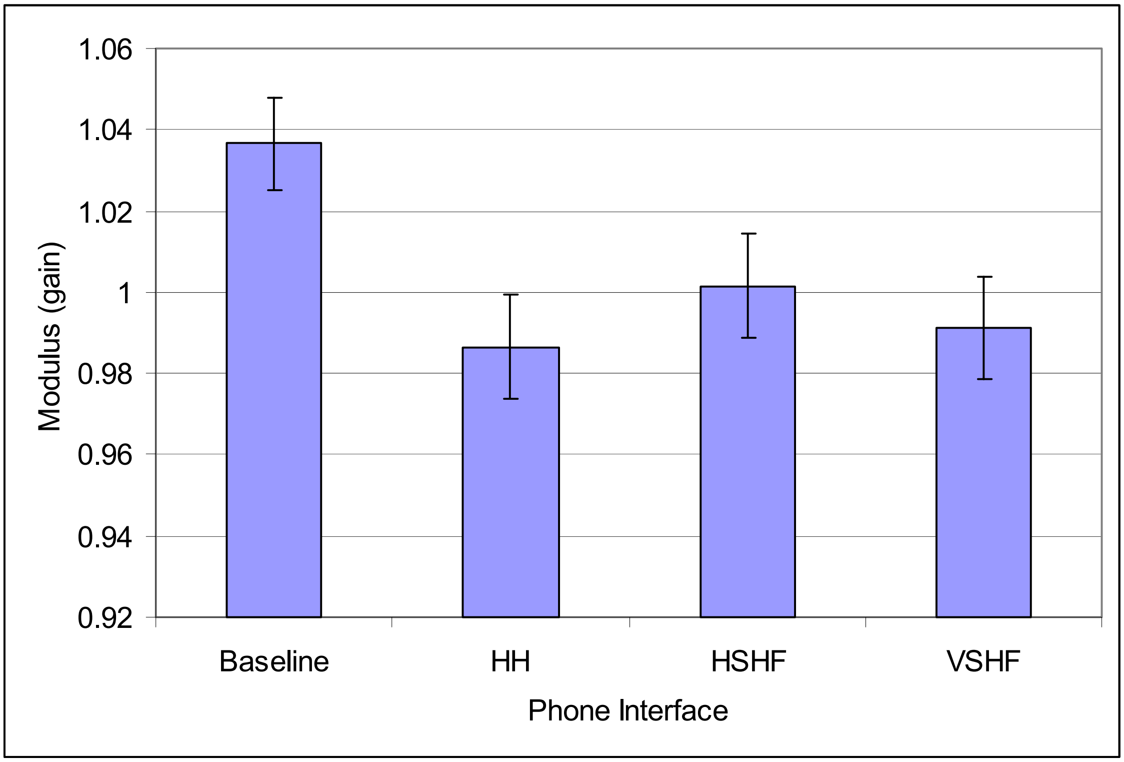

Figure 14. Means and standard errors for car-following modulus (gain) by Interface

The pattern of results indicates that while engaged in the conversation task, drivers tended to under correct slightly, particularly in comparison to the baseline trials, which on average, reveal a tendency toward modest over-correction. The results in Table 7 show that the baseline condition was significantly different from the three interface conditions and that the three interface conditions were not significantly different from one another.

Mean values for car-following modulus (gain) are shown along with standard errors for the three age groups in Figure 15. Pairwise comparisons among means are shown in the following table.

Table 8. Individual comparisons for Age Group main effect on modulus (gain)

Comparison	**DF**	**T value**	**Pr > |t|**
Middle – Old	51	0.33	0.7449
Middle – Young	51	-3.26	0.0020
Old – Young	51	-3.59	0.0007

The younger subjects tended on average to exhibit over-correction, which indicates a more aggressive following posture than the middle-aged and older drivers, who predictably were more conservative in their car-following. The young group was statistically different from the other two groups on this measure.

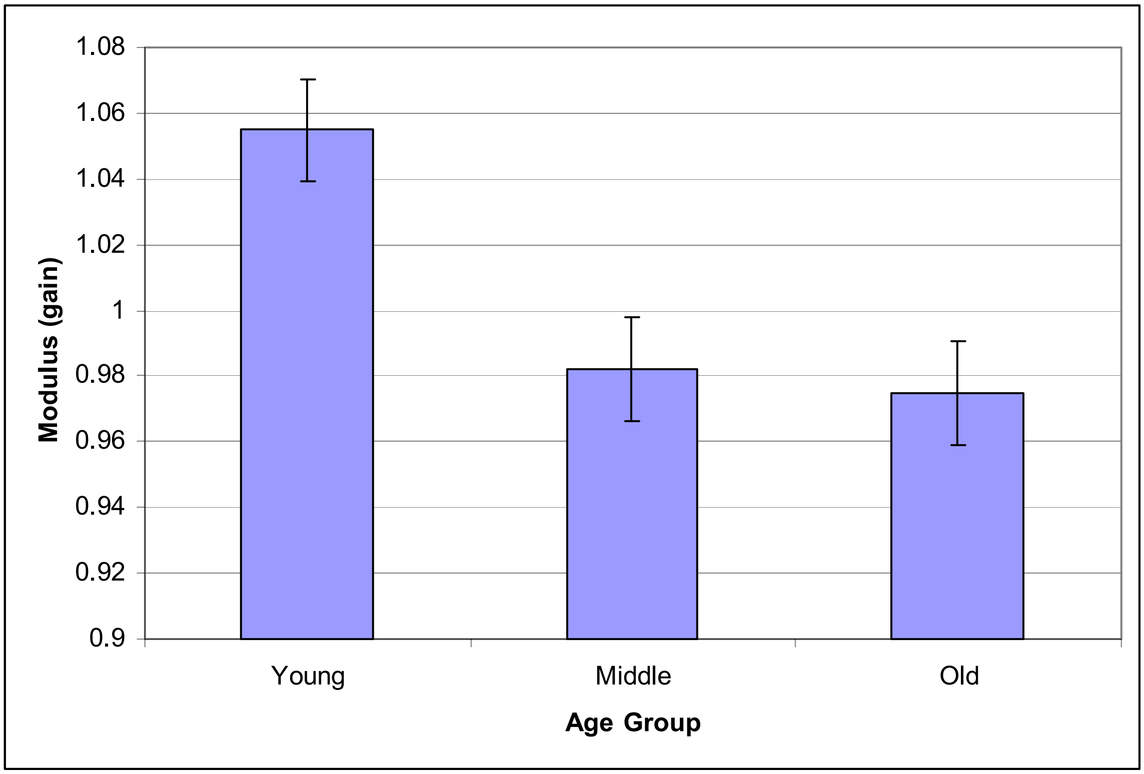

Figure 15. Means and standard errors for car-following modulus (gain) by Age Group

4.2.1 Other Measures of Driving Behavior in Car-Following Intervals

The one-minute car-following segments provided an opportunity to examine additional measures of driving behavior. It should be noted that these additional measures were not among our primary performance measures because subjects were given no specific instructions concerning steering and lane position behavior during car following. It was hypothesized that drivers' lane position and steering behavior would be fairly homogeneous during these data collection intervals because the car-following task imposed a modest level of demand on the drivers.

The two primary measures explored as part of this analysis were steering entropy and lane position variability. Steering entropy was based on the work of Boer (2000). Steering entropy is a measure of steering discontinuity. It is based on the assumption, according to Boer, that "attentive well-trained drivers exhibit smooth control behavior with minimal discontinuities, under non-taxing driving conditions." As drivers become distracted and divert their attention from low level vehicle control to, for example phone behavior, their steering traces begin to exhibit discontinuities, which reflect error corrections. The discontinuities result in increases in the entropy measure, which summarizes steering performance over an interval.

The use of steering entropy for statistical analysis creates some problems, as the computation of entropy requires use of parameters that have been derived from a matched baseline for each subject. Accordingly, the baseline and phone conditions are not fully independent, since the baseline behavior was used to create model parameters that are used for computation of entropy in the phone condition. To address this problem, a difference score was computed for each phone condition using its respective baseline, such that the difference score represents the increase in entropy associated with the phone task, relative to the baseline without the phone task. As a first step, a paired *t*-test was conducted using the difference scores to test the hypothesis that the effect of the phone task was significantly different from zero. The result was statistically significant, $t(485) = 14.71$, $p < .0001$, indicating a significant effect of phone conversation on steering behavior, as measured by the entropy difference score.

A mixed model analysis of variance was computed using Proc Mixed of SAS (V. 8.2). Entropy difference score was the dependent measure. Independent variables included interface (3 levels) and age group (3 levels). The results are summarized in the following table.

Table 9. Summary of ANOVA results for other measures of driving behavior during car-following events

Dependent measure	**Effect**	**DF**	**F value**	**Pr > F**
Entropy difference	Interface	2,51	3.51	0.0375
	Age group	2,51	1.07	0.3521
	Interface x Agegroup	4,51	1.59	0.1907
Std Lane Position	Interface	3,153	4.82	0.0031
	Age group	2,51	0.93	0.4019
	Interface x Agegroup	6,153	0.35	0.9076

Pairwise comparisons for the Interface main effect are shown in Table 10. Means for this effect, along with standard errors, are presented in Figure 16.

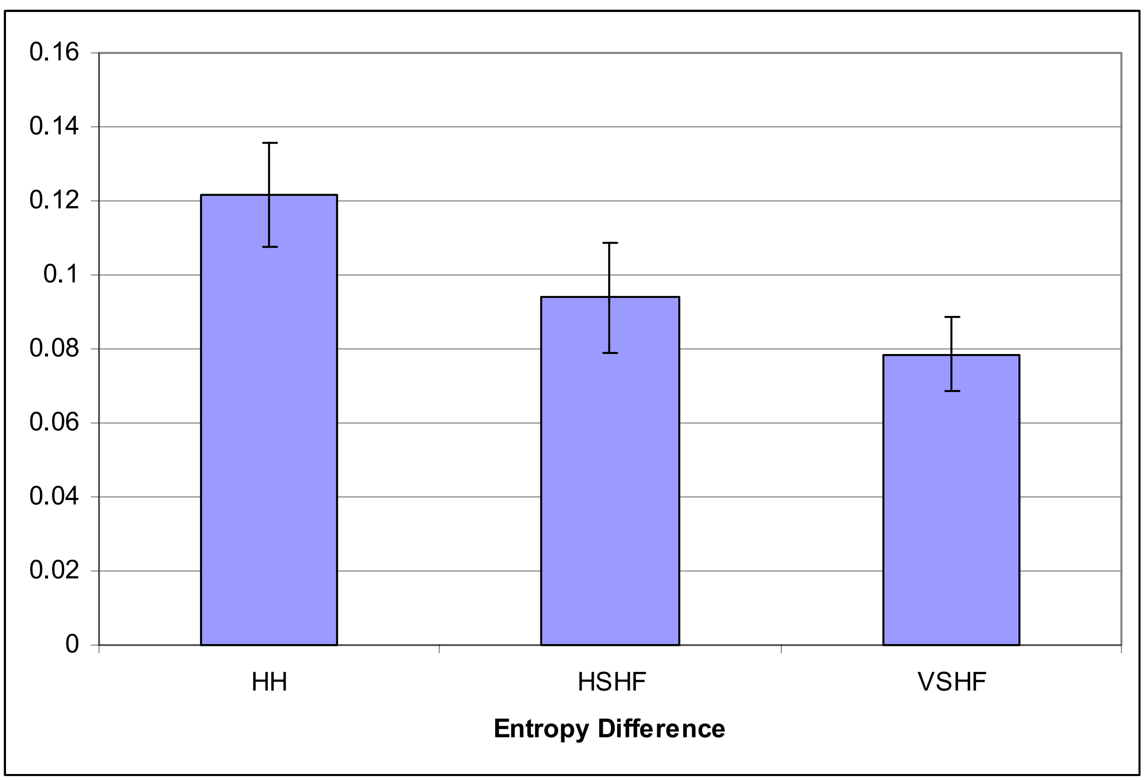

Figure 16. Entropy difference during car following by phone interface condition

Table 10. Individual comparisons for Phone Interface main effect on entropy difference

Comparison	DF	T value	Pr > |t|
VSHF – HH	51	- 2.64	0.0109
VSHF – HSHF	51	-1.01	0.3176
HH – HSHF	51	1.52	0.1346

The results of pairwise comparisons reveal that the only significant difference was between the HH and VSHF condition. Use of the HH phone interface was associated with a larger increase in steering entropy, relative to the individual subject Baseline scores than was the use of the VSHF interface. The headset condition was not significantly different from either of the other two conditions. This suggests a weak relationship, but the data indicate that HH phone use interferes more with steering than VSHF phone use.

The standard deviation of lane position was computed as a measure of how much lateral position variation was associated with each trial. The ANOVA results were summarized in Table 9. The post hoc comparisons of means for the significant main effect of interface are presented in Table 11. The means are shown in Figure 17.

Table 11. Individual comparisons for Phone Interface main effect on STD Lane Position

Comparison	DF	T value	Pr > |t|
Baseline – VSHF	153	3.04	0.0027
Baseline – HH	153	0.63	0.5266
Baseline – HSHF	153	2.97	0.0035
VSHF – HH	153	- 2.21	0.0284
VSHF – HSHF	153	-0.07	0.9451
HH – HSHF	153	2.14.	0.0336

Historically, with some exception, lane position variability has been shown to increase with increasing driver workload. In the present study, it was predicted that the increase in workload associated with the addition of the phone task to driving would lead drivers to divert attention from vehicle control resulting in increasing lane position variability. The results, as shown in Figure 17, are not consistent with this prediction. In particular, the highest lane position variability was associated with the Baseline condition, which ostensibly has less total workload than the other three conditions, which involve phone conversations. Interestingly, however, the differences among the three interface conditions, although marginal, are consistent with the prediction that the Hand-Held condition would interfere most with steering, due to the conflict in the use of the drivers' hands for steering and for phone use.

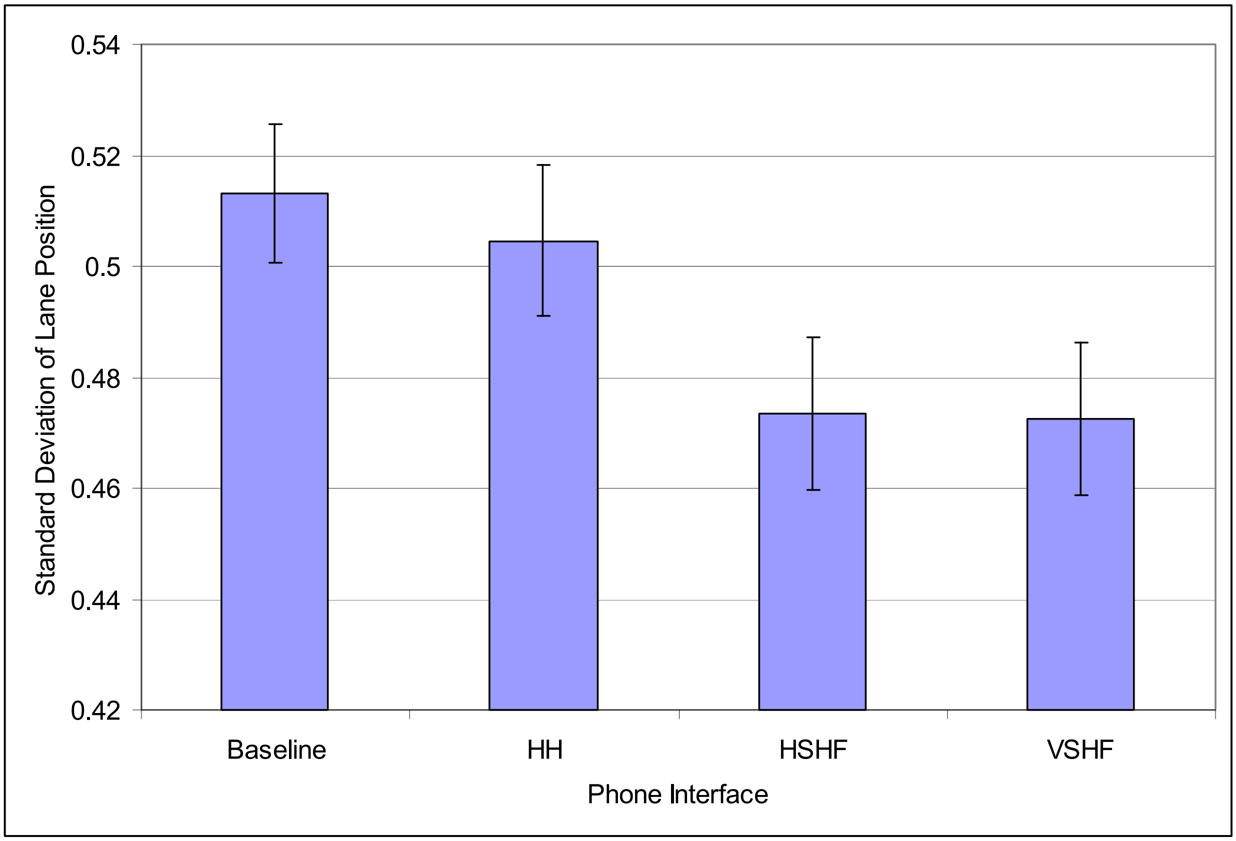

Figure 17. Effect of interface on STD lane position during car following

4.2.2 Steering Behavior During Car-Following Episodes

Two additional measures of steering during the car-following intervals were examined, including steering reversal rates and steering hold rates. Historically, steering reversals and holds have been interpreted as indications of elevated workload (MacDonald & Hoffman, 1980).

A steering reversal was defined to begin when the steering velocity left a zero-velocity dead band with the opposite sign than when it entered the zero-velocity deadband and ended when the steering velocity entered a zero-velocity dead band such that the magnitude of the reversal was 2 degrees or greater (Tijerina, Kiger, Rockwell, & Tornow, 1995).

Steering holds are defined as periods of at least 400 ms involving no steering activity. MacDonald and Hoffman (1980) have interpreted steering holds as evidence of withdrawal of attention from the steering task, presumably reflecting increased secondary task demands. The correlation between reversals/s and holds/s ($r = -.71$, $r^2 = 0.50$) indicates that the measures reflect overlapping behaviors. A summary of ANOVA results is presented in Table 12.

Table 12. Summary of ANOVA results for other measures of steering behavior during car-following events

Dependent measure	Effect	DF	F value	Pr > F
Steering Reversal Rate	Interface	3,153	49.74	<.0001
	Age group	2,51	4.52	0.0156
	Interface x Agegroup	6,153	1.43	0.2060
Steering Hold Rate	Interface	3,153	9.66	<.0001
	Age group	2,51	2.23	0.1177
	Interface x Agegroup	6,153	1.26	0.2781

The results indicate that the interface condition influenced both steering reversal rates and steering hold rates. The mean steering reversal rate for each interface condition is presented in Figure 18. Comparisons among pairs of means for steering reversal rates are presented in Table 13.

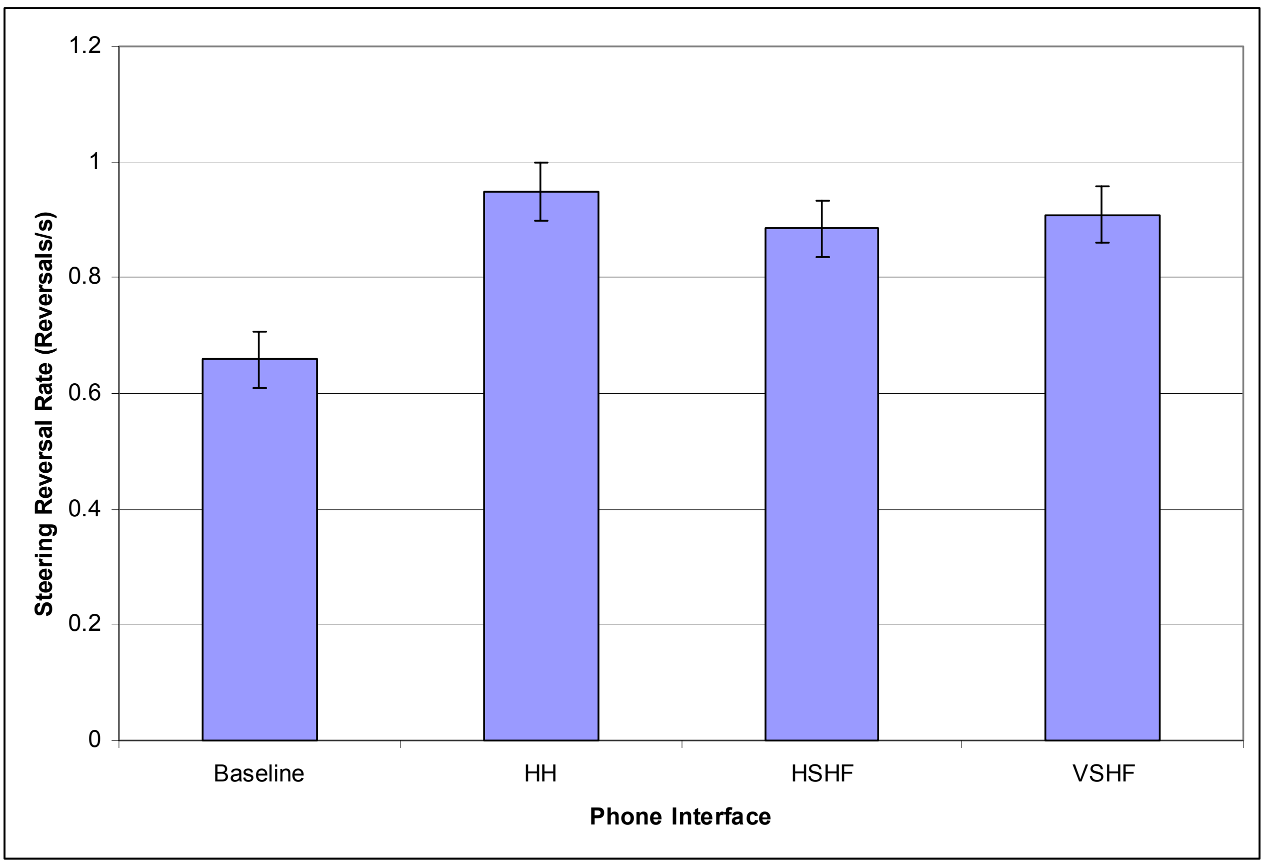

Figure 18. Effects of Phone Interface condition on steering reversal rate

Table 13. Individual comparisons for Phone Interface main effect on steering reversal rate

Comparison	**DF**	**t value**	**Pr > |t|**
Baseline – VSHF	153	-9.13	< .0001
Baseline – HH	153	-10.56	< .0001
Baseline – HSHF	153	-8.27	< .0001
VSHF – HH	153	-1.30	.1956
VSHF – HSHF	153	0.79	.4287
HH- HSHF	153	2.09	.0380

The Baseline condition was associated with significantly fewer steering reversals than the other three Interface conditions. The rate associated with the HH condition was marginally greater than the rate for the HSHF condition. This pattern of results is consistent with the model proposed by MacDonald and Hoffman (1980), according to which increased steering reversal rates reflect increased workload when the driver is not operating at peak capacity. The mean steering reversal rate for each age group is presented in Figure 19. Results of pair comparisons for these means are presented in Table 14.

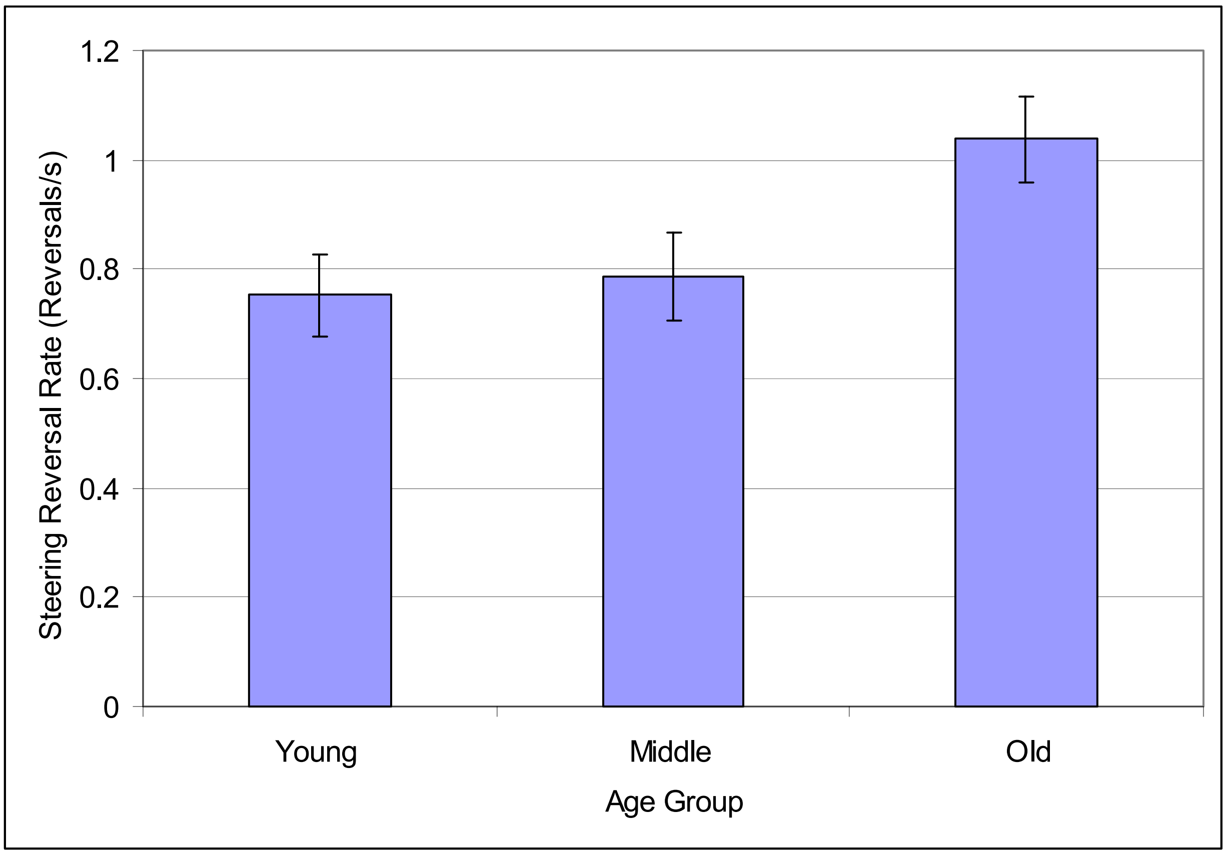

Figure 19. Effects of Age Group on steering reversal rate

Table 14. Individual comparisons for Age Group main effect on steering reversal rate

Comparison	DF	t value	Pr > |t|
Middle – Old	51	-2.23	0.0305
Middle - Young	51	0.57	0.5735
Old - Young	51	2.86	0.0061

The results indicate that older drivers generally had more steering reversals during the car following episodes than both middle-aged and younger drivers, whereas the difference between the young and middle age groups was not statistically significant. This suggests that the car-following task generally resulted in increased workload among the older drivers.

The mean steering hold rate for each interface condition is shown in Figure 20. Results of post hoc comparison of mean pairs are shown in Table 15. The results indicate significantly more steering holds in the Baseline condition. There were significantly fewer steering holds in the Hand-Held condition than in the headset condition. This pattern of results is counter to the prediction that when engaged in phone conversation, drivers would divert their attention from steering, thus exhibiting more holds during phone conversation than during the Baseline condition.

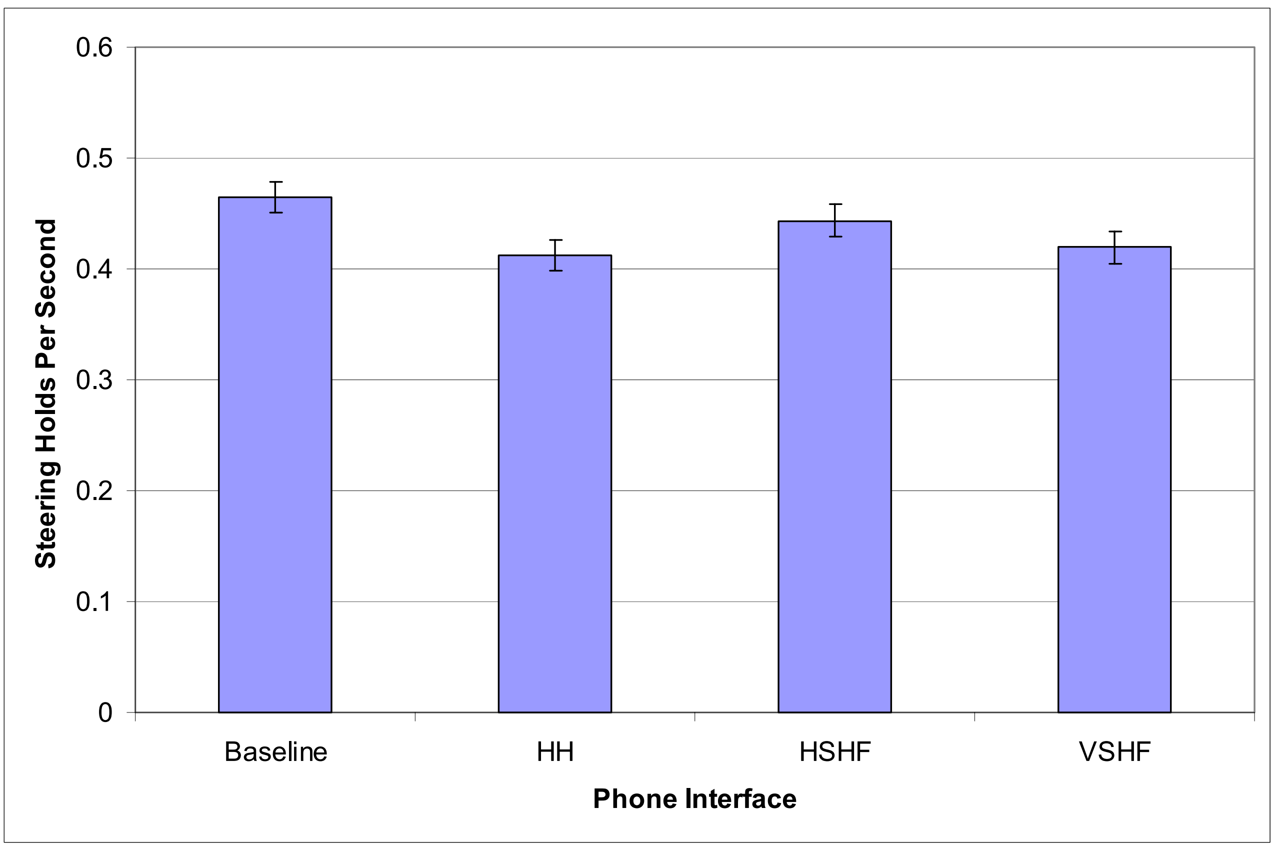

Figure 20. Effects of Phone Interface condition on steering hold rate

Table 15. Individual comparisons for Phone Interface main effect on steering hold rate

Comparison	DF	T value	Pr > |t|
Baseline – VSHF	153	4.12	< .0001
Baseline – HH	153	4.76	< .0001
Baseline – HSHF	153	1.90	0.0587
VSHF – HH	153	0.58	0.5595
VSHF – HSHF	153	-2.02	0.0452
HH- HSHF	153	-2.60	0.0101

4.2.3 Summary of Results for Car-Following Events

Consistently high coherence values indicated that drivers were able to perform the car-following task adequately. Increased phase shift values were associated with all phone interface conditions, indicating that the phone conversation task delayed drivers' responses. The performance impairment was consistent, as there were no statistically significant differences among the three interface conditions. The car-following modulus exhibited consistently lower values in the phone task conditions, indicating more conservative responses at the speed extremes. There were no significant differences among the interface conditions for modulus. Middle-aged and older drivers exhibited lower modulus values, again indicating more conservative responses at the speed extremes.

Analyses of steering entropy indicated increased steering error associated with all three phone interface conditions. The Hand-Held interface was associated with significantly higher entropy difference scores than the other two interfaces, which indicates increased steering error in the Hand-Held condition relative to the other interface conditions. The Hand-Held condition was also associated with increased standard deviation of lane position relative to the other interface conditions, indicative of greater error. However, the finding that all three interface conditions had smaller lane position error than baseline drives is counter to our predictions and indicates that phone use generally was associated with less degradation of lane position performance.

Drivers exhibited increased steering reversal rates in all three interface conditions relative to the baseline condition, which is indicative of increased workload while engaged in the phone conversation task. For this measure, the Hand-Held condition was marginally greater than the Headset Hands-Free condition. Overall, older drivers exhibited higher reversal rates than younger and (marginally) middle-aged drivers. The pattern of results for steering holds revealed increased values in the baseline condition relative to the phone conversation task conditions.

Performance impairment associated with the phone conversation task during car following was observed in multiple measures, including, increased phase shift (delay), steering entropy, and steering reversal rates. Two measures, including lane position variability and steering holds revealed patterns suggesting worse performance in the baseline condition than in any of the phone interface conditions.

There was evidence, although not strong, that the hand-held interface condition was associated with worse performance than the other two interface conditions on measures that isolate the conflict between steering and holding the phone, including steering entropy, steering reversal rates, and lane position variability. Otherwise, the results generally indicated that the performance impairment effects due to the phone conversation task were relatively consistent across interface conditions.

4.3 Lead Vehicle Braking Event

Preliminary examination of the data revealed significant variability in the position of the lead vehicle relative to the participant's vehicle at the beginning of this event. Specifically, the bumper-to-bumper distance between the vehicles at the beginning of the event varied between 48.6 and 533 feet (M= 115.0, SD = 86.5). This was converted to time headway by dividing this distance by the subject vehicle speed at the beginning of the event. The corresponding headways ranged from 0.51 to 6.47 seconds (M = 1.35, SD = 0.97). A subset of trials were selected that maintained homogeneity in the degree of challenge presented to the driver. Specifically, it was desirable to identify and eliminate all trials that did not require an immediate response. To do so, the correlation between headway and brake response time was examined for different subsets of trials. A significant correlation was found for the entire data set, reflecting drivers' general tendency to delay the brake response at larger headways. The largest subset was sought for which this correlation became negligible, based on the assumption that this would represent the set of trials for which the driver had to respond immediately independent of the headway. Trials were selected for which the initial headway was less than or equal to 1.5 seconds.

The experimental design included two LVB events in each drive, for a total of (54 x 3 x 2=) 324 trials. Restricting the time headway to 1.5 seconds eliminated 98 (30.3 percent) of the trials. Analyses were conducted on the remaining 226 (69.8 percent) of the trials. Four performance measures were considered, including brake response time, accelerator release time, the minimum bumper-to-bumper distance and the maximum level of deceleration during the event. The hypotheses tested were that if phone conversation impaired driving performance, it would lead to slower accelerator release and brake response times, necessitating more extreme levels of deceleration and resulting in smaller minimum bumper-to-bumper distances. Generally, as will be shown in the remainder of this section, none of these hypotheses was supported by the data. Brake response time and accelerator release time exhibited differences between interface conditions, however the differences were not in the direction predicted. A summary of the ANOVA results is presented in the following table.

Table 16. ANOVA summary table for measures of drivers' responses to LVB events

	Brake Response Time		**Accelerator Release Time**		**Min Bumper-to-Bumper Dist**		**Maximum Deceleration**	
Model Factor	**F**	**p>F**	**F**	**p>F**	**F**	**p>F**	**F**	**p>F**
Interface	5.36	.002	7.74	.0001	0.85	.47	0.31	.82
Age Group	0.26	.77	0.01	.99	3.03	.06	0.62	.54
Interface x Age Group	1.03	.41	1.24	.29	0.41	.87	0.74	.62

As shown in Table 16, both brake response time and accelerator release time were affected by the interface condition. Means for these significant main effects are shown in Figure 21. Pairwise comparisons are presented in Table 17.

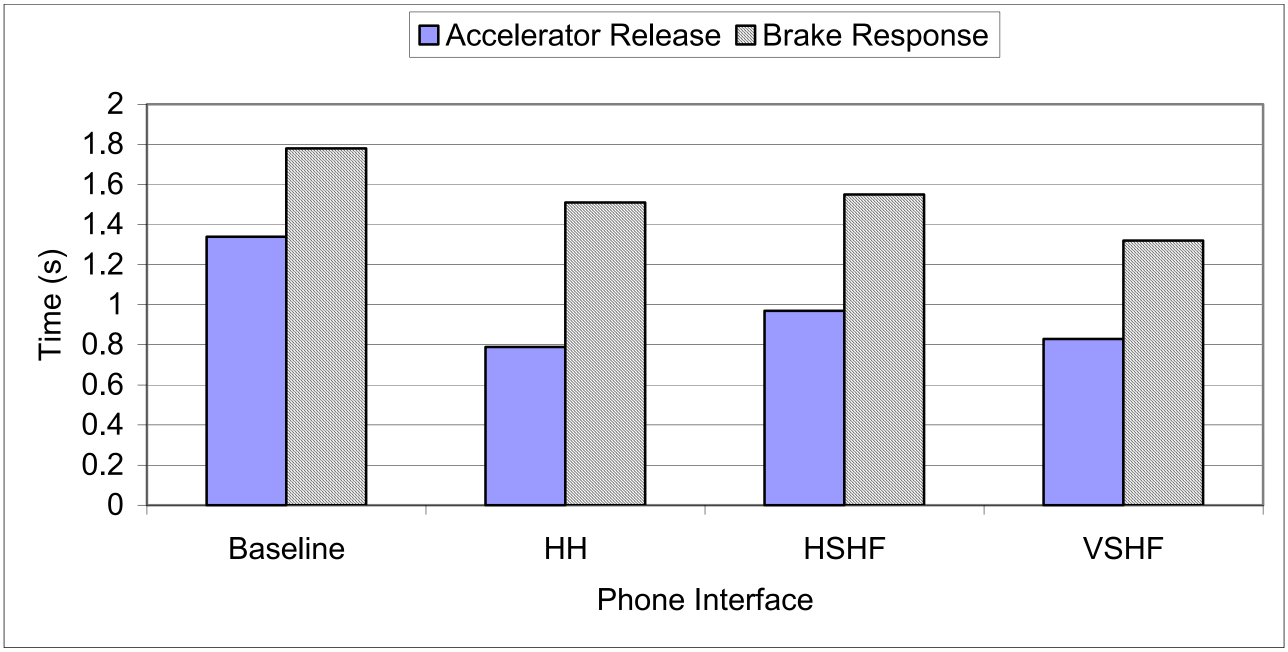

Figure 21. Means for accelerator release and brake response by Phone Interface condition

Table 17. Individual comparisons for Phone Interface main effects on accelerator release and brake response time during lead vehicle braking event

	Accelerator Release Time			Brake Response Time		
Comparison	**DF**	**T value**	**Pr > |t|**	**DF**	**T value**	**Pr > |t|**
Baseline – VSHF	82	3.45	.0009	83	3.59	.0006
Baseline – HH	82	3.58	.0006	83	2.11	.0378
Baseline – HSHF	82	2.52	.0136	83	1.83	.0711
VSHF – HH	82	0.22	.8301	83	-1.13	.2621
VSHF – HSHF	82	-.76	.4513	83	-1.41	.1637
HH- HSHF	82	-/95	.3429	83	-0.26	.7993

The results of post hoc analyses revealed that the accelerator release time associated with the Baseline condition was significantly different from those associated with other three conditions. The differences between conditions for brake response times revealed a similar pattern, however; they were smaller, resulting in generally weaker statistical test results.

This pattern of results is in the opposite direction of what would be predicted by the hypothesis that impairment due to distraction would delay responses leading to longer accelerator and brake response times. There are several possible interpretations. First, it is possible that efforts to eliminate all trials that did not require an immediate braking response had failed. This explanation was explored by repeating the analyses using a more restrictive subset of trials, namely those in which the simulator vehicle was no more than 1 second behind the target vehicle at the beginning of the event. This subset consisted of 161 (50 percent) of the trials. The pattern of results was identical to those presented above, suggesting that the lack of homogeneity with respect to the driver's accelerator and brake responses was not the explanation for the results observed.

The alternate explanation is that the drivers were hyper vigilant while on the phone and that there may have been some level of anticipation of an upcoming problem event, particularly while engaged in conversation. Clearly, the demands of the conversation task did not overwhelm the drivers to the point of interfering with their ability to manage the driving task.

As indicated in Table 16, the effect of age group on the minimum bumper-to-bumper distance during the event approached statistical significance. This effect reflects the finding that older drivers maintained greater following distances than younger drivers. Based on this finding, other possible indicators of compensation (behavioral adaptation) were explored, including speed and time headway at the beginning of the LVB event. It was hypothesized that if drivers were compensating for being engaged in phone conversation, this might be reflected in generally slower speeds and larger headways. The entire data set was used for these analyses, the results of which are summarized in the following table.

Table 18. ANOVA summary table for speed and time headway at the beginning of the LVB event

	Speed		**Time Headway**	
Model Factor	**F**	**p>F**	**F**	**p>F**
Interface	7.35	.0001	19.02	< .0001
Age Group	0.91	.4100	2.37	.1000
Interface x Age Group	0.20	.9800	1.08	.3800

Both speed and time headway at the beginning of the event were significantly influenced by interface condition. Examination of means revealed that drivers generally adopted longer headways while engaged in conversation relative to the Baseline condition. The consistency of this effect across interface conditions suggests that this may reflect compensation, presumably for the increased demands associated with the combination of driving and phone conversation. However, the pattern of differences among means for speed at the beginning of this event is not consistent with an interpretation of increased caution while on the phone. To the contrary, as shown in Figure 26, drivers exhibited higher speeds at the beginning of this event in each of the three phone conditions than in the Baseline condition.

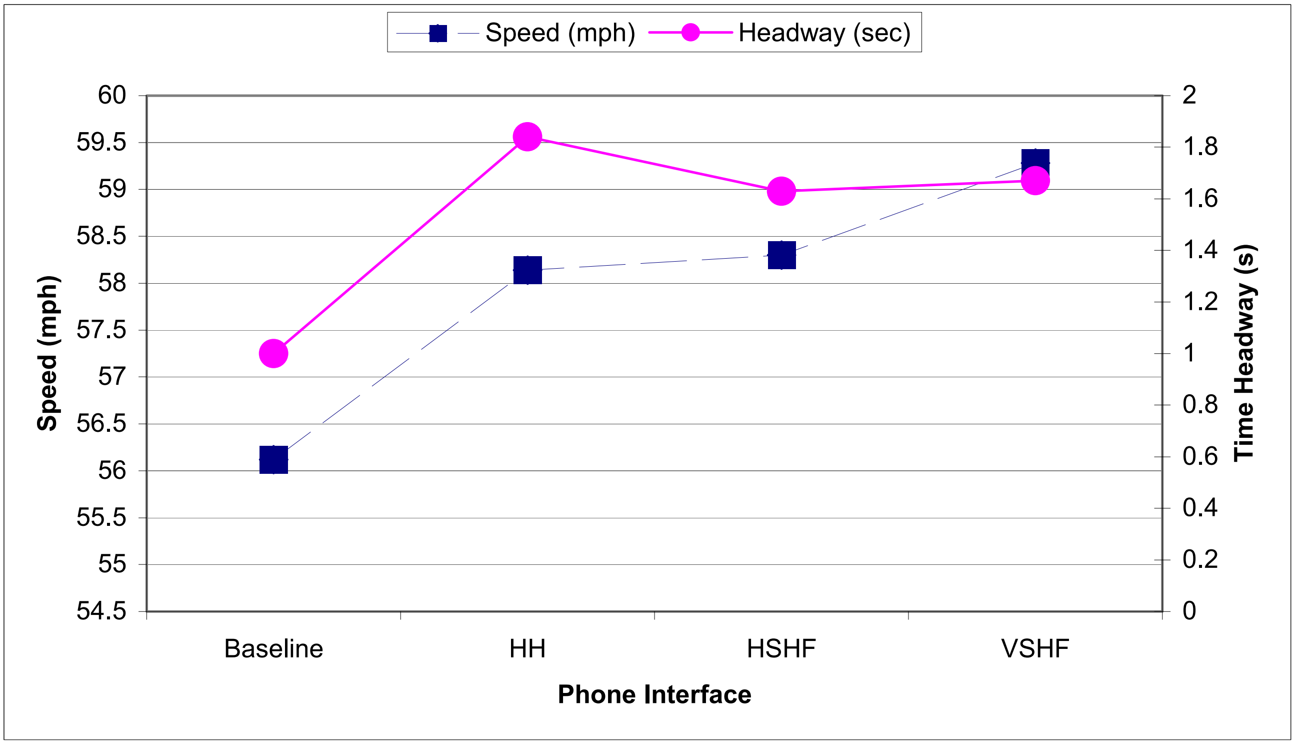

Figure 22. Speed and time headway at the beginning of the LVB event by interface condition

Post hoc comparisons between pairs of means, shown in Table 19, indicated significant differences between the three phone conditions and the Baseline for both measures, but no other significant differences. Together, these results suggest that the drivers may have compensated for phone conversation by increasing their time headway, but at the same time, they were likely to have diverted attention away from speed monitoring, which led, unintentionally to increased average speeds. One possible way to support this interpretation would be to demonstrate that drivers were less likely to monitor the speedometer while engaged in phone conversation.

Table 19. Individual comparisons for Phone Interface main effects on speed and time headway at the beginning of the lead vehicle braking event

	Speed			**Time Headway**		
Comparison	**DF**	**T value**	**Pr > |t|**	**DF**	**T value**	**Pr > |t|**
Baseline – VSHF	146	-4.13	<. 0001	146	-4.97	< .0001
Baseline – HH	146	-2.60	.0103	146	-6.16	< .0001
Baseline – HSHF	146	-2.81	.0057	146	-4.62	< .0001
VSHF – HH	146	1.21	.2293	146	-1.04	.2990
VSHF – HSHF	146	1.04	.3004	146	.22	.8251
HH- HSHF	146	-.17	.8680	146	1.25	.2129

4.3.1 Summary of Results for Lead Vehicle Braking Events

Drivers exhibited faster accelerator release times and faster brake response times in the three phone conversation task conditions than in the baseline condition. There were no effects of the phone task on the minimum bumper-to-bumper distance during the event or in the maximum deceleration required to respond to the lead vehicle braking. This pattern of results is not consistent with the prediction that drivers' responses would be slower during phone conversation, resulting in more near misses and/or higher deceleration rates required to avoid collisions.

Differences were found to be associated with the phone interface condition in the vehicle speed and time headways at the beginning of the event. Specifically, drivers exhibited faster speeds and longer time headways in all three phone interface conditions relative to the baseline condition. While not indicative of impaired performance due to distraction, these results suggest that drivers may have been less aware of their speed while engaged in the phone conversation task. They also suggest that drivers may have maintained longer initial following distances to compensate for the increased demands of being engaged in phone tasks while driving.

Overall, the results from the lead vehicle braking events indicate that their participation in the phone task did not significantly distract drivers from the threat posed by vehicles braking unexpectedly in the travel lane.

4.4 Lead Vehicle Cut-In Events

Twice during each drive, participants were confronted with a close cut-in event, in which a scenario vehicle pulled alongside the simulator vehicle, and then changed lanes in front of the driver. One cut-in occurred while the participant was involved in a phone call, one while occurred while he/she was not in a phone call. This event was intended to provide a stimulus that required an immediate response, but not of sufficient criticality as to require an emergency response. In addition, during each drive there were several vehicles that approached on the left in a similar manner, hesitated momentarily, and then accelerated straight ahead in the left lane. These events were "fake" cut-ins, intended to reduce the drivers' expectations that any vehicle approaching from the left would require a response.

Generally, due to the way in which this event was initiated, the initial conditions were considerably more consistent than for lead vehicle braking events. In particular, the bumper-to-bumper distance between the cut in and the driver's vehicle was greater than 40 feet in only 16 (5 percent) of 322 trials. The trials were eliminated from the analyses.

Using the statistical model described above, ANOVAs were computed for the following performance measures: accelerator release time, brake response time, and maximum deceleration. In addition, the simulator vehicle speed was analyzed at the beginning of the event as a measure of general travel speed, unrelated to the specific event. A summary of the analysis results is presented in the following table.

Table 20. ANOVA summary table for measures of drivers' responses to Cut-in events

	Accelerator Release Time		Brake Response Time		Maximum Deceleration		Speed before event	
Model Factor	**F**	**p>F**	**F**	**p>F**	**F**	**p>F**	**F**	**p>F**
Interface	0.37	.7765	0.74	.5308	2.23	.0876	6.01	.0007
Age Group	2.51	.0915	1.25	.2956	1.29	.2831	3.83	.0281
Interface x Age Group	1.12	.3519	0.76	.6043	1.33	.2458	0.26	.9555

Overall, the mean accelerator release time was 1.82 seconds (SD = 0.85) and the mean brake response time was 2.40 seconds (SD = 0.92). The mean level of maximum deceleration was –9.6 f/s/s (SD = 3.8). As shown in Table 20, none of these performance measures exhibited statistically significant differences due to the model factors. Only the drivers' speed before the event showed significant differences. Post hoc comparisons for the interface main effect are shown in Table 21.

Table 21. Individual comparisons for Phone Interface main effect on driver speed before the lead vehicle cut-in event

	Vehicle Speed		
Comparison	**DF**	**T value**	**Pr > |t|**
Baseline – VSHF	144	-3.87	.0002
Baseline – HH	144	.65	.5136
Baseline – HSHF	144	-1.24	.2169
VSHF – HH	144	3.64	.0004
VSHF – HSHF	144	2.17	.0317
HH- HSHF	144	-1.53	.1273

Drivers adopted fastest speeds in the VSHF condition (M = 66.1), followed by the HSHF (M = 64.6 mph), Baseline (M = 63.9 mph), and HH (M = 63.5 mph) conditions, respectively. The results of statistical tests shown in Table 21 indicate that the VSHF condition speeds were significantly faster than the Baseline and HH speeds. The difference between the VSHF and HSHF condition speeds was somewhat weaker. The VSHF condition stands out as the fastest, immediately before the cut-in event.

The results in Table 22 also show that the speed before the event was different among the various age groups. Post hoc comparisons, shown in Table 22, indicate that the middle age group (M = 65.4 mph) was significantly faster than the young drivers (M = 63.7 mph). The Older drivers mean speed was 64.6 mph.

Table 22. Individual comparisons for Age Group main effect on driver speed before the lead vehicle cut-in event

	Vehicle Speed (mph)		
Comparison	**DF**	**T value**	**Pr > |t|**
M – O	51	1.27	.2090
M – Y	51	2.77	.0079
O – Y	51	1.44	.1551

The absence of differences on the measures of drivers' responses to the cut-in events suggests that the drivers did not divert their attention away from vehicle control while engaged in the phone conversations. This pattern of results suggests that either the combination of phone conversation and response to the cut-in event was not demanding enough to cause impairment in the form of a slowed response, or that the drivers were able to anticipate the onset of these events. The latter explanation is plausible because the events were preceded by a brief period during which the cut-in vehicle moved alongside of and matched its speed to the simulator vehicle. Drivers may have learned to anticipate the cut-in event by the appearance of a "hovering" vehicle alongside the simulator vehicle. If so, then the "fake" events were not successful in eliminating drivers' anticipation of the beginning of the cut-in events.

4.4.1 Summary of results for lead vehicle cut in events

Drivers' accelerator release times, brake response times, and the maximum deceleration in response to the cut-in events were not affected by phone task participation. There were also no differences among the interface conditions in this regard. Drivers exhibited faster speeds at the beginning of the event in the VSHF condition relative to the baseline and the other interface conditions. Drivers in the middle age group drove slightly faster than drivers in the young group at the beginning of this event. The older drivers' speeds were in between, but not significantly different from either group.

Overall the results from the lead vehicle cut-in events indicate that their participation in the phone task did not significantly distract drivers from the threat posed by vehicles cutting into the travel lane unexpectedly.

4.5 Analysis of Merge Events

Each merge event requires the driver to exit the freeway to the right, follow an exit ramp and then re-enter the traffic stream that runs perpendicular to the original freeway. All merges are geometrically identical. To facilitate development of a behavior model and analysis, the following reference points were identified:

P0 – Beginning of exit ramp
P1 – End of curved segment of exit ramp, beginning of straight segment
P2 – End of straight segment, beginning of curve
P3 – Location of yield sign, at the end of the third curved segment
P4 – Point at which the entrance ramp intersects with freeway section
P5 – End of the entrance ramp

The physical dimensions associated with these points are depicted in Figure 23.

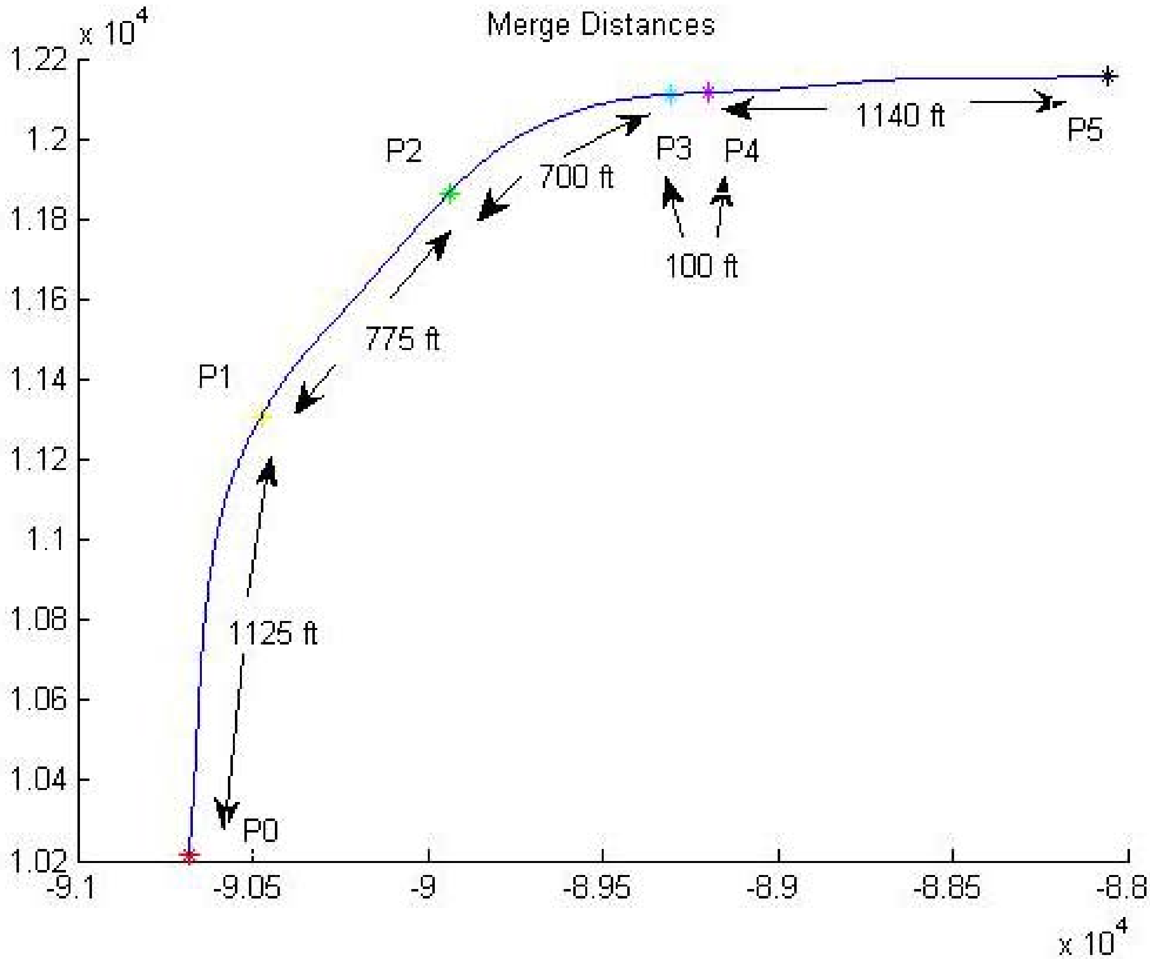

Figure 23. Merge geometry (Drivers move from P0 to P5)

A conceptual model was developed in an attempt to characterize driver behavior during the merge event. Specifically, merging behavior can be characterized as having the following components:

1. Exit ramp behavior – The driver exits from the freeway and adjusts vehicle speed and lane position. This occurs between P0 and somewhere between P1 and P2. Because of the narrow lane and initial curve, drivers were expected to reduce their speed during this component. Generally, smoothness of speed reduction and accuracy of lane tracking are considered to be good performance. Distraction due to phone conversation is hypothesized to reduce the smoothness of speed reduction and increase the lane position variability and possibly the steering entropy.
2. Transition – Once the driver has reduced speed and adjusted to the narrow single-lane roadway, there is a period during which the driver is simply in transition between the exiting and re-entering components of the merge. During this period it was hypothesized that the driver has completed the deceleration required following the exit. However, due to obstructed visibility, it is generally too early to begin planning for the merge. This component is expected to occur approximately between P1 and P2 (but following completion of the exit ramp behavior.

3. Merge Planning – In the vicinity of P2 or slightly thereafter, the driver must prepare to merge, typically by beginning to monitor the traffic stream into which s/he intends to merge and then accelerating to match the speed of the stream vehicles and position the vehicle appropriately to enter the traffic stream at the selected gap. The driver starts to identify the gap into which s/he intends to merge. This component ends when the driver either (1) attains a relatively steady (holding) speed near P4, waiting for a selected gap, or (2) begins to enter the traffic stream, when no waiting is required. Smoothness of acceleration and an approach speed that is close to the speed limit will be interpreted to reflect good behavior.
4. Merge – When the simulator vehicle reaches P4, the driver must confirm the decision about which gap is appropriate, adjust vehicle speed accordingly and then merge into the traffic stream. Timely entry into the traffic stream, minimal speed adjustments, location of entry nearer to P4 (vs. P5), entry at a non-critical TTC to the following vehicle and entry at a speed close to stream vehicle speed are considered indicators of good performance.

The main difficulty associated with testing this model is that while the geometric boundaries are well established, the boundaries between the various behavioral components are not readily identifiable. In addition, they are likely to vary among individuals. An additional complicating factor is that the merge events did not always present the same “degree of challenge” to the driver. This was due to differences in the positions of the stream vehicles at the time the driver completed the merge event.

The following table presents a list of performance measures that were examined to test the components of the behavioral model presented above. The results of analyses using these dependent measures are discussed in the remainder of this section.

Table 23. Possible performance measures for merge behavioral components

Merge Behavioral Component	Required Behavior	Performance Measure
Exit Ramp	Deceleration Lane maintenance	• Speed change during exit component • Number of brake applications • Maximum deceleration • STD lane deviation • Steering entropy
Transition	Lane maintenance	• STD lane deviation • Steering entropy
Merge Planning	Begin surveillance of traffic stream Accelerate to match speed of traffic stream	• Location of initiation of acceleration • Time from initiation of acceleration to steady (holding) speed, if any • Point at which driver begins eye glances to left • Number of glances to the left • Percent of time spent glancing to the left
Merge	Enter traffic stream	• Time from steady speed until entry into lane • Time from passing P3 until entry into lane • Speed at time of entry into lane • Position on road (point between P4 and P5) at time of entry into lane • TTC to following vehicle at time of entry into lane

4.5.1 Speed During Merge

Generally, drivers' speed behavior during the merge event corresponded to the behavioral model described above. During the first part of the merge, drivers generally slowed down from faster highway speeds. Drivers then gradually accelerated with the largest increase in speed occurring at the end of the merge (P4 to P5). The mean and standard deviations of speed, collapsed across all conditions, are presented in Figure 24.

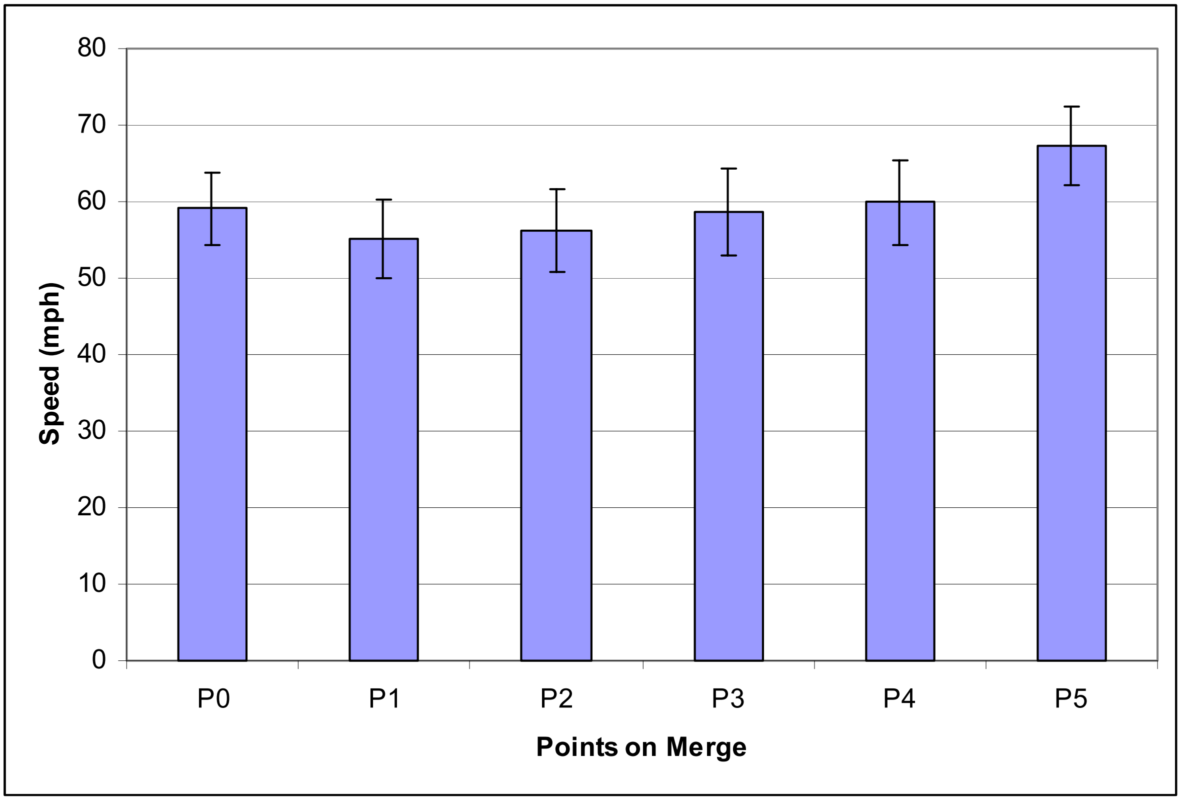

Figure 24. Mean and standard deviation speeds during merge events

The speeds at the individual points along the merge were examined, as well as the differences between successive speed pairs. Of primary interest was behavior during the initial and latter parts of the merge because speed behavior was relatively constrained at these points. Specifically, speed was constrained at the beginning of the merge due to the change in geometry associated with the transition from highway to exit ramp. Speed was also constrained toward the end of the merge because drivers were required to re-enter the high-speed traffic stream. The absence of geometric or task constraints at the intermediate points led us to expect less consistency in the speed behavior at these points.

Considering the speed at P0, older drivers were found to drive somewhat slower than the other two age groups, $F(2,49) = 4.03$, $p = .0240$, but there were no differences among the interface conditions, $F(3,131) = 1.54$, $p = .2079$. Next, the change in speed between points P0 and P1 was examined. Analyzing paired differences, a significant effect of interface was found, $F(3,131) = 5.71$, $p = .0010$. Drivers generally slowed less while in the Baseline condition (M = 3.2 mph), relative to the three interface conditions. Drivers exhibited the greatest slowing in the VSHF condition (M = 5.0), with intermediate values for HH (M = 4.8) and HSHF (M = 4.1) conditions. The results of pairwise comparisons of the means are shown in Table 24, according to which the differences between the Baseline and both the VSHF and HH conditions were significantly different. While entering the merge at approximately similar speeds, drivers in the VSHF and HH conditions were observed to decelerate more on average than when they were in the Baseline condition. There were no differences associated with the Age Groups for this measure, $F(2,49) = .01$, $p = .9857$.

Table 24. Individual comparisons for Phone Interface main effect on speed change between merge points P0 and P1

Comparison	DF	T value	Pr > |t|
Basline – VSHF	131	3.63	.0004
Baseline – HH	131	3.24	.0015
Baseline – HSHF	131	1.82	.0706
VSHF – HH	131	-.32	.7484
VSHF – HSHF	131	-1.62	.1087
HH – HSHF	131	-1.28	.2016

Considering the speed at the end of the merge (point P5), a significant main effect of Interface condition was found, $F(3,131) = 3.56$, $p = .0162$. Post hoc analyses revealed that the speeds associated with the Baseline and HH conditions were significantly slower than the speeds adopted by drivers in the VSHF condition. The significant effect of Age Group, $F(2,19) = 4.16$, $p = .0214$, reflected slower speeds among the older drivers, relative to the other two age groups at the end of the merge event. Finally, the changes in speed among drivers between merge points P4 and P5 were examined, which represent the final stages of merging. Drivers in the Baseline condition were found to increase speeds significantly less (M = 6.4 mph) than drivers in the VSHF condition (M = 8.7 mph), $t(131) = -3.40$, $p = .0009$. Intermediate values were associated with the HH and HSHF conditions but no other differences were statistically significant.

4.5.2 Other Measures of Merge Behavior

A variety of measures were considered at various points during the merge events, again focusing primarily on the beginning and end stages of the merge events. Specifically, differences attributable to interface were found in the steering entropy at the beginning of the merge event (P0 – P2). In addition to a significant main effect of interface, $F(3,149) = 59.08$, $p < .0001$, the interaction between interface and age group was statistically significant, $F(6, 149) = 2.83$, $p = 01$. This effect is shown in Figure 25. Post hoc tests revealed that all phone interface conditions were statistically different from their respective baselines. The Baseline condition was consistently associated with lower steering entropy. In addition, for the middle age drivers, the HH condition was associated with significantly higher entropy than the HSHF condition, $t(51) = 2.49$, $p = .0161$. For the older groups, the entropy in the VSHF condition was significantly greater than in the HSHF condition, $t(47) = 2.75$, $p = .0084$. For the younger drivers there were no differences between the three interface conditions.

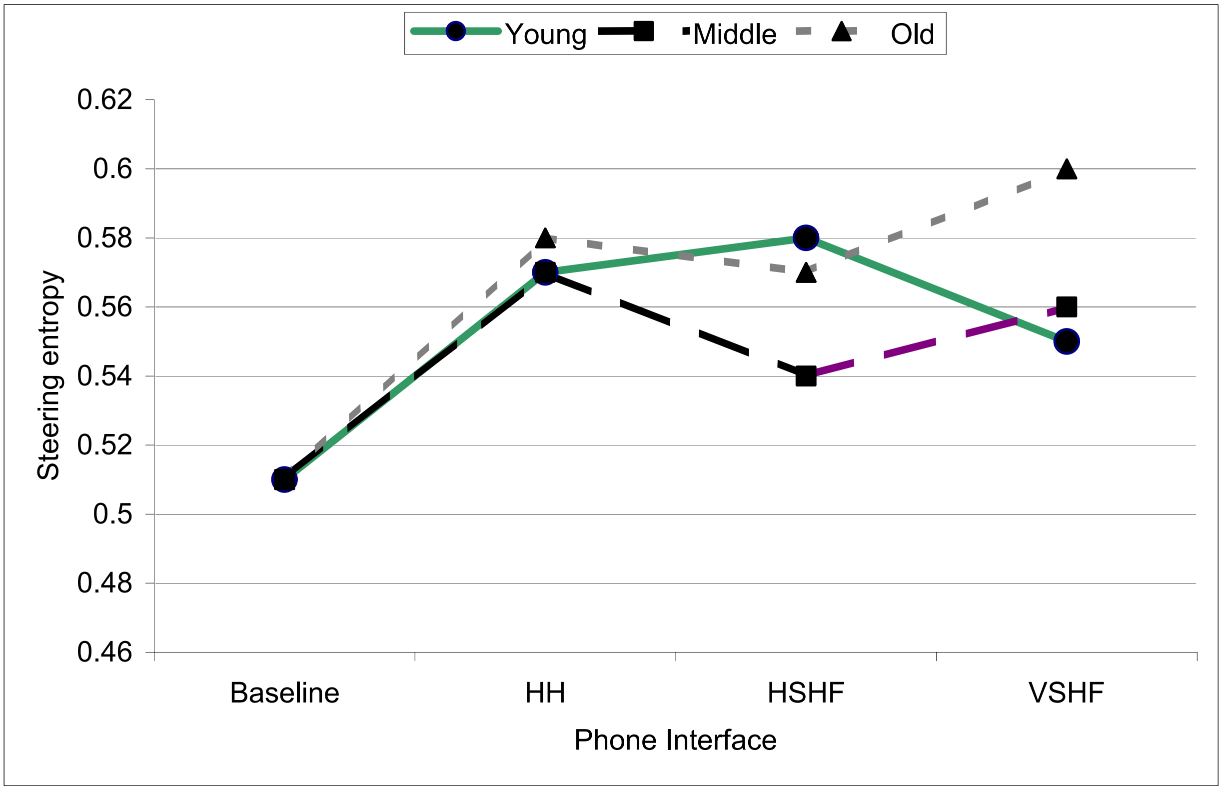

Figure 25. Interaction effect of Phone Interface on Age Group steering entropy on exit ramp (beginning of merge event)

It was also found that drivers exhibited increased standard deviations of lane position between P0 and P2 when involved in phone conversations, relative to the Baseline condition. Driver age group also was found to have a significant effect on lane position variability in this region of the merge. Older drivers exhibited greater lateral position variability than middle-aged drivers, who in turn exhibited greater differences than the younger drivers. During this portion of the merge, drivers exhibited significantly fewer brake applications in the Baseline condition than in the Hand-Held condition, however no other conditions were significantly different. No effects of model factors on the average time per brake application were found. However, drivers generally exhibited greater maximum brake pressure forces in the Hand-Held condition, relative to the Baseline condition. The other interface conditions had intermediate values.

In the final portion of the merge, drivers spent more time decelerating in the Baseline condition than in the three phone interface conditions. It had been hypothesized that this measure might reflect the degree of uncertainty experienced by drivers in the final portion of the merge such that this measure might be elevated in phone conditions relative to the Baseline condition. The observed difference was in the opposite direction, which led us to wonder whether this measure may have reflected increased caution in the Baseline condition. The results pertaining to eye glance behavior, which are presented below, tend to support this interpretation.

The time required to merge, defined as the time required to traverse the interval between P3 and P5, was examined. No differences attributable to phone use were found, but that the older subjects took slightly longer to traverse this segment than the younger and middle-aged drivers.

4.5.3 Planning to Merge

Drivers' glance behavior during the intermediate and final stages of the merge was examined. Specifically, as a potential indicator of how much advance planning drivers undertook before merging, the point at which drivers first looked left to assess the behavior of the traffic stream into which they were planning to merge was considered. This was difficult because it was not possible to separate meaningless occasional glances leftward from those that were actually involved with the beginning of planning. Several cut-off points were used in an attempt to eliminate spurious glances by assuming that any glance made before a certain point was not meaningful. The results were generally consistent with our predictions, however differences did not reach statistical significance. This non-significant trend indicated that in the Baseline condition, drivers began glancing left earlier than in any of the phone conditions.

Overall glance behavior was examined including the number of glances drivers made to the left during the latter portion of the merge, the percentage of time spent looking left, and the average duration of the left side glances. ANOVA results are summarized in the following table.

Table 25. Summary of ANOVA results for glance behavior during merge planning

Dependent measure	Effect	DF	F value	Pr > F
Number of Glances	Interface	3, 130	3.44	.0188
	Age group	2, 49	3.24	.0476
	Interface x Agegroup	6, 130	0.83	.5500
Percent time glancing left	Interface	3, 130	5.19	.0020
	Age group	2, 49	3.28	.0462
	Interface x Agegroup	6, 130	.71	.6429
Avg. Glance duration	Interface	3, 130	1.63	.1846
	Age group	2, 49	1.34	.2721
	Interface x Agegroup	6, 130	1.74	.1169

Overall, the average duration of glances to the left during merge planning was 0.85 seconds (SD = 0.27). This duration was consistent across experimental treatments, as evidenced by the absence of statistically significant effects. There were significant differences among the interface conditions for both the number of glances to the left during merge planning and the total percentage of time spent looking left during merge planning. Pairwise comparisons among means for the interface main effect on number of glances are shown in Table 26.

Table 26. Individual comparisons for Phone Interface main effect on number of glances to left during merge planning

Comparison	DF	T value	Pr > |t|
Baseline – VSHF	130	2.30	.0229
Baseline – HH	130	2.06	.0413
Baseline – HSHF	130	2.85	.0050
VSHF – HH	130	-.18	.8607
VSHF – HSHF	130	.52	.6032
HH – HSHF	130	.69	.4920

The means for number of glances by interface condition are shown in Figure 26. When not involved in a phone conversation, drivers generally made more glances to the left planning to merge than when on the phone. Although only one difference (Baseline vs. HSHF) reached our strict post hoc criterion, (P < .01), the apparent consistency of the effect across all three interface conditions gives the authors confidence that the differences between the other two interface conditions and the baseline are likely to reflect real differences, despite the earlier noted caution.

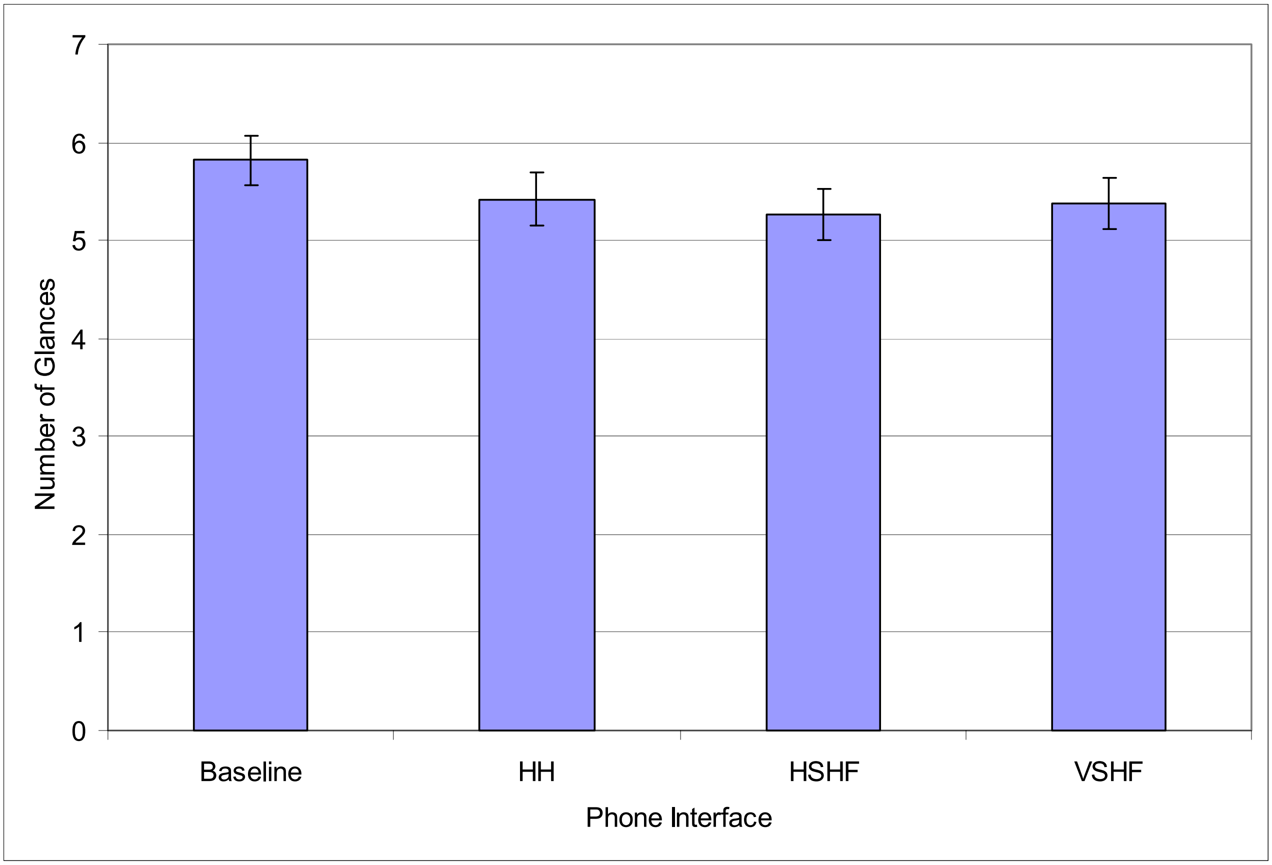

Figure 26. Effect of Phone Interface condition on the number of leftward glances made during merge planning

As shown in Table 25, there was a significant effect of Age group on the number of leftward glances during merge planning. Examination of the means revealed that drivers in the older group made more glances (M = 6.1) than younger drivers (M = 4.7), with middle-aged drivers in between (M = 5.5). Only the difference between the older and younger group was statistically significant.

The average percentage of time during planning that drivers looked to the left was 26.4 percent (SD = 10.9).

Pairwise comparisons among means for the interface main effect on the percentage of time spent glancing left are shown in Table 27. Means are presented in Figure 27.

Table 27. Individual comparisons for Phone Interface main effect on number of glances to left during merge planning

Comparison	DF	T value	Pr > |t|
Baseline – VSHF	130	2.16	.0329
Baseline – HH	130	3.87	.0002
Baseline – HSHF	130	1.93	.0552
VSHF – HH	130	1.60	.1124
VSHF – HSHF	130	-.18	.8550
HH – HSHF	130	-.1.78	.0781

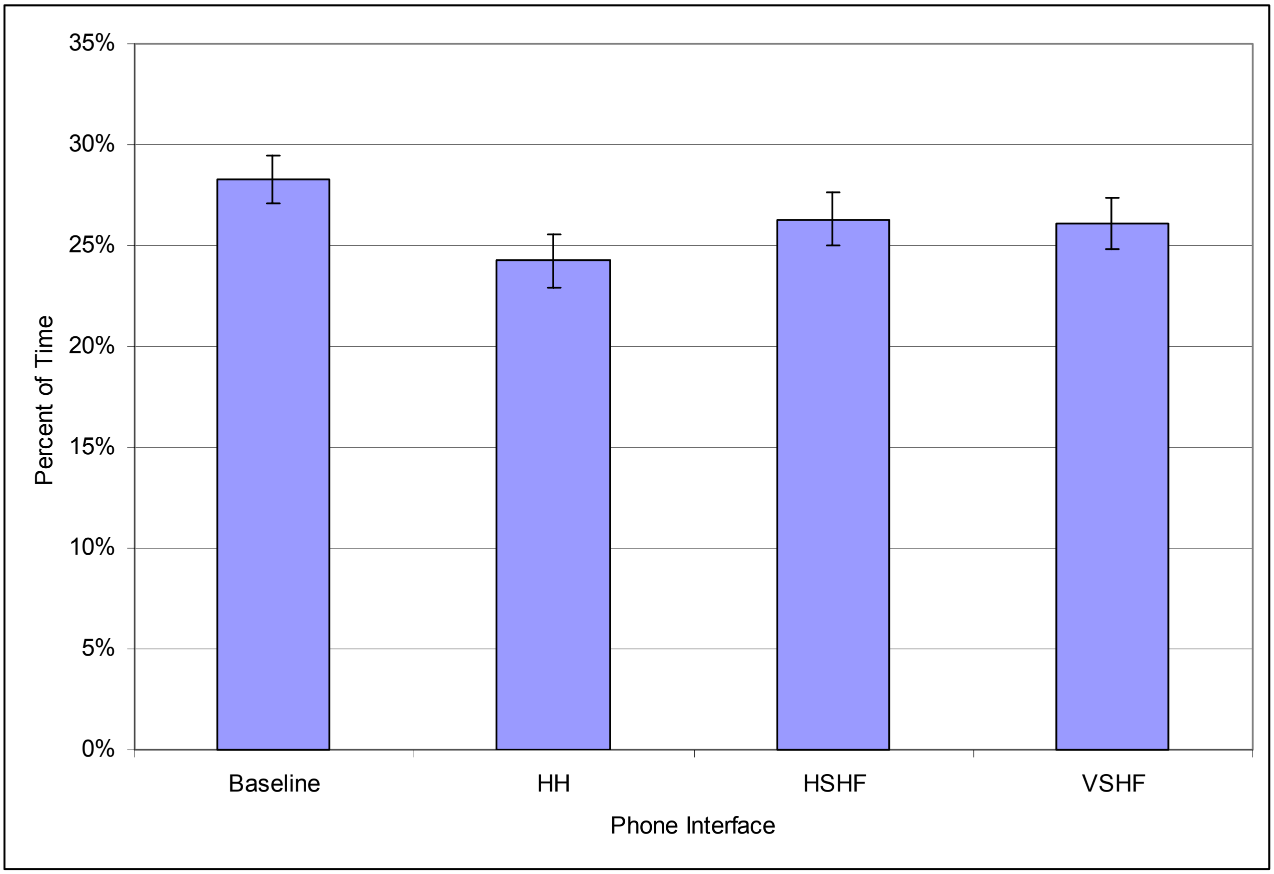

Figure 27. Effect of Phone Interface condition on the percentage of time spent looking left while planning to merge

Clearly, the biggest difference is between the Baseline and Hand-Held conditions. When in the Hand-Held condition, drivers spent significantly less time looking left in order to plan the imminent merge. Differences between the Baseline and other interface conditions were in the same direction, but weaker.

The older drivers spent proportionately more time looking left during merge planning (M = 28.7 percent) relative to the middle-aged drivers (M = 27.2 percent) and younger drivers (M = 22.2 percent). As shown in Table 28, these differences are relatively weak.

Table 28. Individual comparisons for Age Group main effect on percentage of time looking left during merge planning.

Comparison	DF	T value	Pr > |t|
M – O	49	-.36	.7193
M – Y	49	2.00	.0513
O – Y	49	2.39	.0208

4.5.4 Summary of Results for Merge Events

Drivers' speed profiles during the merge event revealed slowing during the initial exit component followed by gradual increases in speed as they prepared to re-enter the traffic stream. There were differences between interface conditions on several measures, including sharper deceleration rates at the beginning of the merge when drivers were in the HH or VSHF conditions, relative to the baseline condition. The VSHF condition was associated with faster speeds at the end of the merge than the baseline and HH conditions. The VSHF condition was also associated with steeper acceleration during the final phases of the merge event, relative to the baseline condition.

Drivers' exhibited more steering entropy (error) during the merge while engaged in the phone conversation task. The entropy values for the HH interface condition were greater than the HSHF condition for the drivers in the middle-age group, indicating a potential conflict between the demands of steering and Hand-Held phone use, but only for this age group.

Drivers spent more time decelerating during the final stages of the merge in the baseline condition, which may reflect increased caution in the baseline condition, relative to the phone conversation conditions. This interpretation is speculative. There were no differences among conditions in the time required to complete the final portion of the merge event.

Drivers made more glances leftward and spent a greater proportion of their time looking left during the latter portion of the merge event when in the baseline condition. This suggests that when engaged in phone conversation drivers devoted less time to planning for the upcoming merge event.

Overall, the pattern of speed results does not directly indicate impaired performance but does suggest that when using the VSHF interface, drivers' speeds during the merge event were slightly more extreme than in other conditions, particularly the baseline. The increases in steering entropy during the merge are the only direct evidence of impaired driving performance while engaged in phone conversation and there is evidence that one age group had more difficulty steering while holding onto the phone, relative to the other interface conditions. The pattern of eye glance results suggests that drivers devoted more visual attention to planning the merge when not engaged in the phone conversation task.

4.6 Analysis of Final Event Scenario

The final event scenario consisted of a series of vehicles that made lane changes in front of the participant followed by a final vehicle that cut in and subsequently performed an aggressive braking maneuver. This maneuver forced the participant to respond to avoid rear-ending the scenario vehicle. Participants were assigned to one of three conditions for this final drive: Hand-Held (HH), Hands-Free speaker kit with voice digit dialing (VSHF), and Baseline (HSHF with no call). Data necessary for these analyses were extracted manually from video data.

At the final brake event, the lead vehicle's brake lights came on and it began to brake. To examine reaction time to this event, the start point was identified as the time at which the lead vehicle's brake lights appeared. Reaction times for accelerator release and braking were computed. The end of the brake event, in the case of no response from the driver, occurred within two video frames (i.e., 0.07 s) of the lead vehicle's velocity reaching zero. There were no missing values for this event; all participants responded with an accelerator release and/or brake pedal press (although two participants also steered to avoid the lead vehicle).

The final distance variable was defined as the distance between the lead vehicle and the participant's vehicle when the participant's velocity reached zero. Negative values for this variable indicated a collision or a case in which the participant steered to the right to avoid the lead vehicle (the latter situation occurred in 2 out of 54 cases). Missing values occurred when the participant did not reach a velocity of zero before the simulation ended. This situation was caused by aborts due to hard braking.

Collisions between the participant's vehicle and the lead vehicle were identified by determining the point, if any, at which the two vehicles overlapped.

4.6.1 Final Event Results

The variables examined were reaction time (braking or accelerating) in response to the final brake event. Means appearing in figures were calculated using the least squares means procedure due to unequal cell sizes (caused by missing data).

For the final event (lead vehicle braking in front of participant), all participants reacted (i.e., there were no missing data points). Out of 54 participants, 21 released the accelerator, and all participants braked. For all but one of those with accelerator release, this was their first response. Based on this examination of the data, brake reaction time and first response (reaction time to first action regardless of whether it was braking or accelerator release) were analyzed (Tables 29 and 30).

Table 29. Analysis of variance for brake reaction time at final LVB event

Model Factor	DF	F value
Interface	2	2.35
Age group	2	2.08
Interface*Age group	4	3.37*
Error	36	(0.05)

Note. Values enclosed in parentheses represent mean square errors. *$p < .05$.

Table 30. Analysis of variance for first response at final LVB event

Model Factor	DF	F value
Interface	2	4.87*
Age	2	0.99
Interface*Age	4	1.55
Error	36	(0.07)

Note. Values enclosed in parentheses represent mean square errors. *$p < .05$.

For brake reaction time, the interaction of Interface and Age was significant, F (4, 36) = 3.37, p = .02 (Figure 28). Examination revealed that older participants in the HH condition reacted significantly faster than drivers in both other groups. In addition, younger participants in the VSHF condition reacted significantly faster than older participants in the VSHF condition and older participants not engaged in a phone call.

For first response, a significant main effect of Interface was found, F (2, 36) = 4.87, p = .01 (Figure 29). Analysis revealed that participants in the HH condition responded significantly faster than those in the VSHF and baseline conditions.

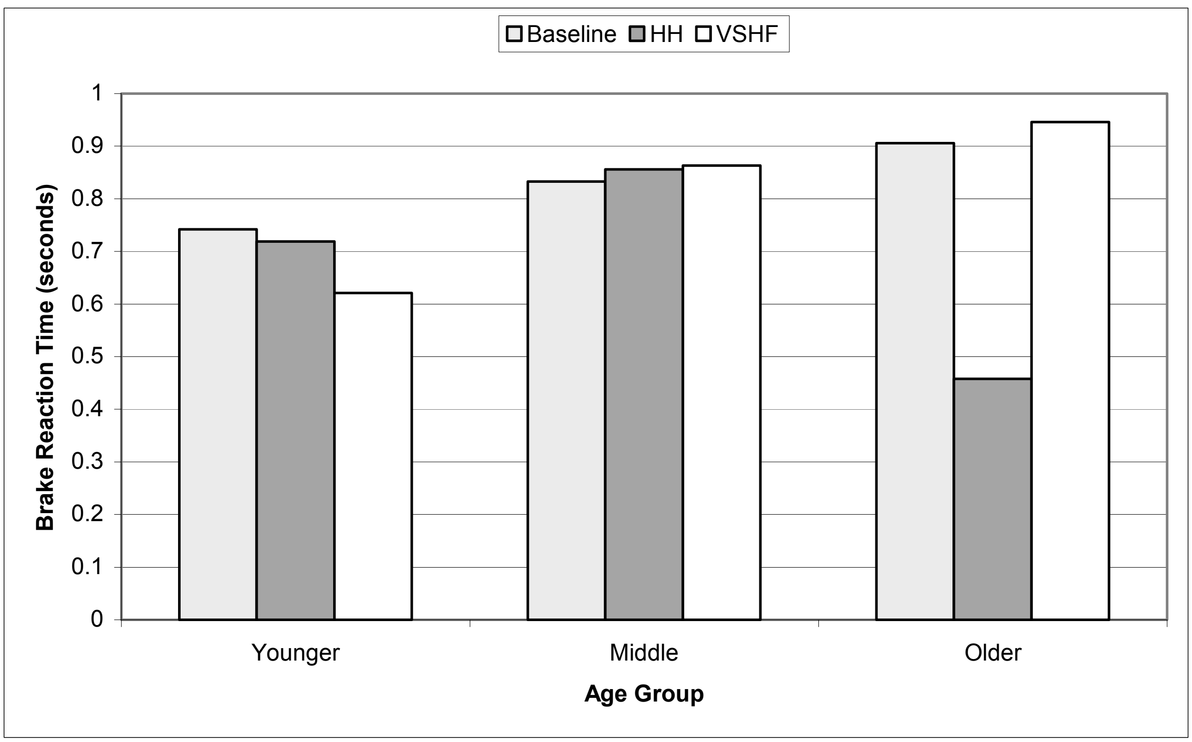

Figure 28. Interaction of Phone Interface and Age Group at final LVB event for brake reaction time.

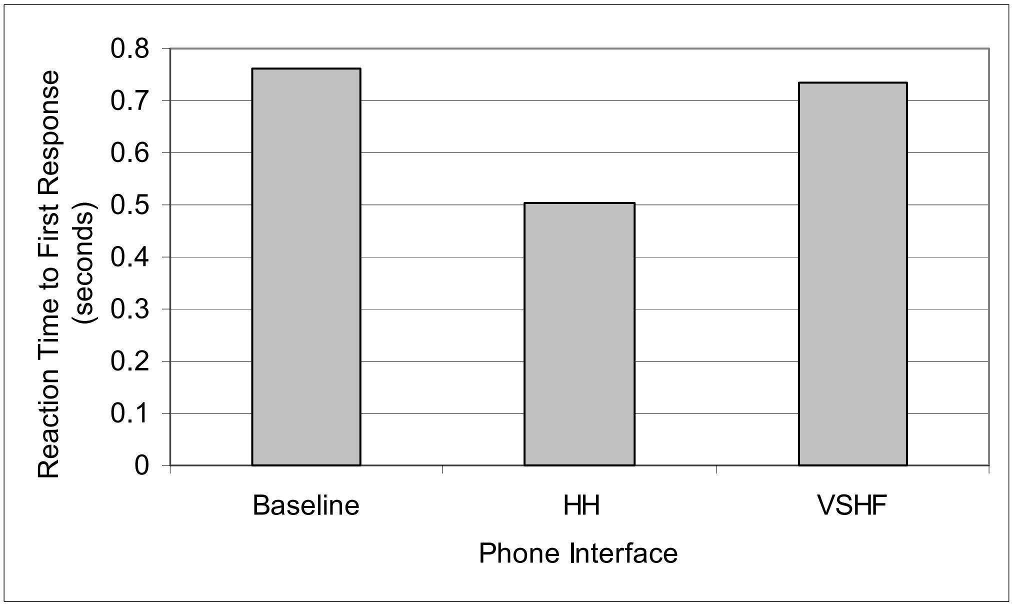

Figure 29. Main effect of Phone Interface at final LVB event for reaction time to first response.

4.6.1.1 Final Distance

For the final distance variable, 22 participants had negative values, 27 had positive values, and 5 had missing values. The data for final distance were categorized into negative, positive, and missing, and examined using chi-square tests of association with interface and age. No significant differences were found.

4.6.1.2 Collisions

Collisions occurred in 26 of 54 drives. No driver had more than one collision. There were 12 collisions in the VSHF condition, 7 in the HH condition, and 7 in the Baseline condition. Examination of collisions using chi-square tests of association with interface revealed no significant differences. Similarly, age had no effect.

4.6.1.3 Final Event Discussion

The present analyses revealed significant differences for some dependent measures. Hypothesized effects related to phone interface were complicated by significant interactions between interface and age. For first response to the final brake event, participants in the HH condition responded significantly faster than those in the VSHF and Baseline conditions, contrary to hypothesis.

4.7 Phone Task Performance Results

Data reduction procedures and analysis of phone task performance are outlined below.

4.7.1 Phone Task Data Reduction

To facilitate data analysis and ensure a means of comparing phone interfaces on common terms, individual phone tasks were broken down into steps specific to each interface. The phone task consisted of 3 consecutive phases: connecting (either dialing an outgoing call or receiving an incoming call), the conversation phase (administering of the pre-recorded Baddeley task) and the disconnect phase, as illustrated in Figure 30.

Figure 30. Components of a phone call.

These phases were defined based on landmarks in the phone call receipt/placement process. For incoming calls, the connecting phase started when the first ring was heard in the cab and ended when the participant said "hello". For outgoing calls, the connecting phase started immediately after the in-cab experimenter said "now" and it ended when the first ring was heard in the control room. The conversation phase began immediately after the participant said "hello" or when an auditory cue indicated the beginning of the wave file playback. The phase ended immediately after the conversation playback said, "stop". The disconnect phase began immediately when the conversation phase ended (i.e., immediately after the conversation playback says "stop") and it ended when the participant returned to normal driving posture. The components of incoming and outgoing calls by interface are outlined in Figures 31 through 33.

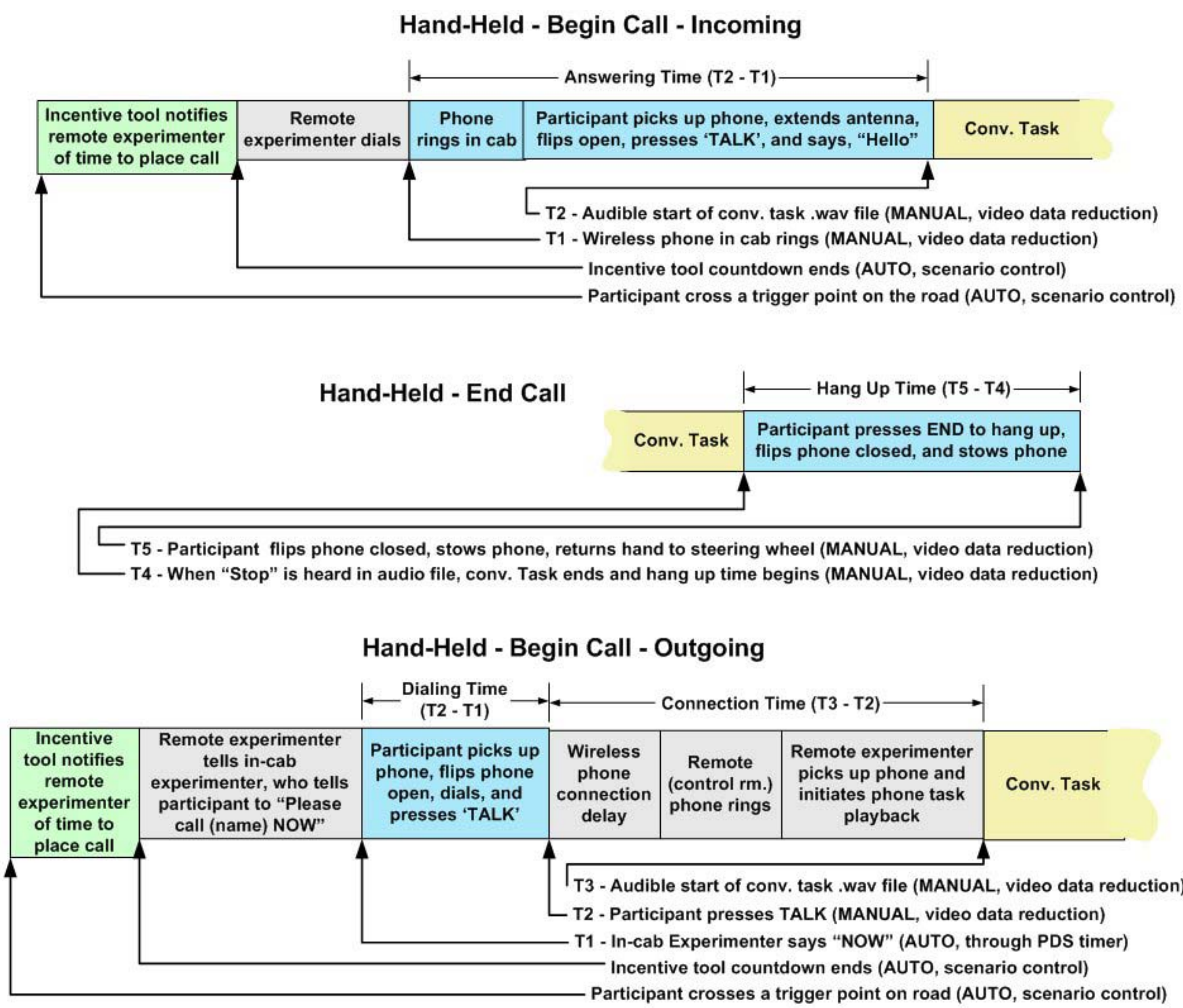

Figure 31. Components of calls using the HH Phone Interface.

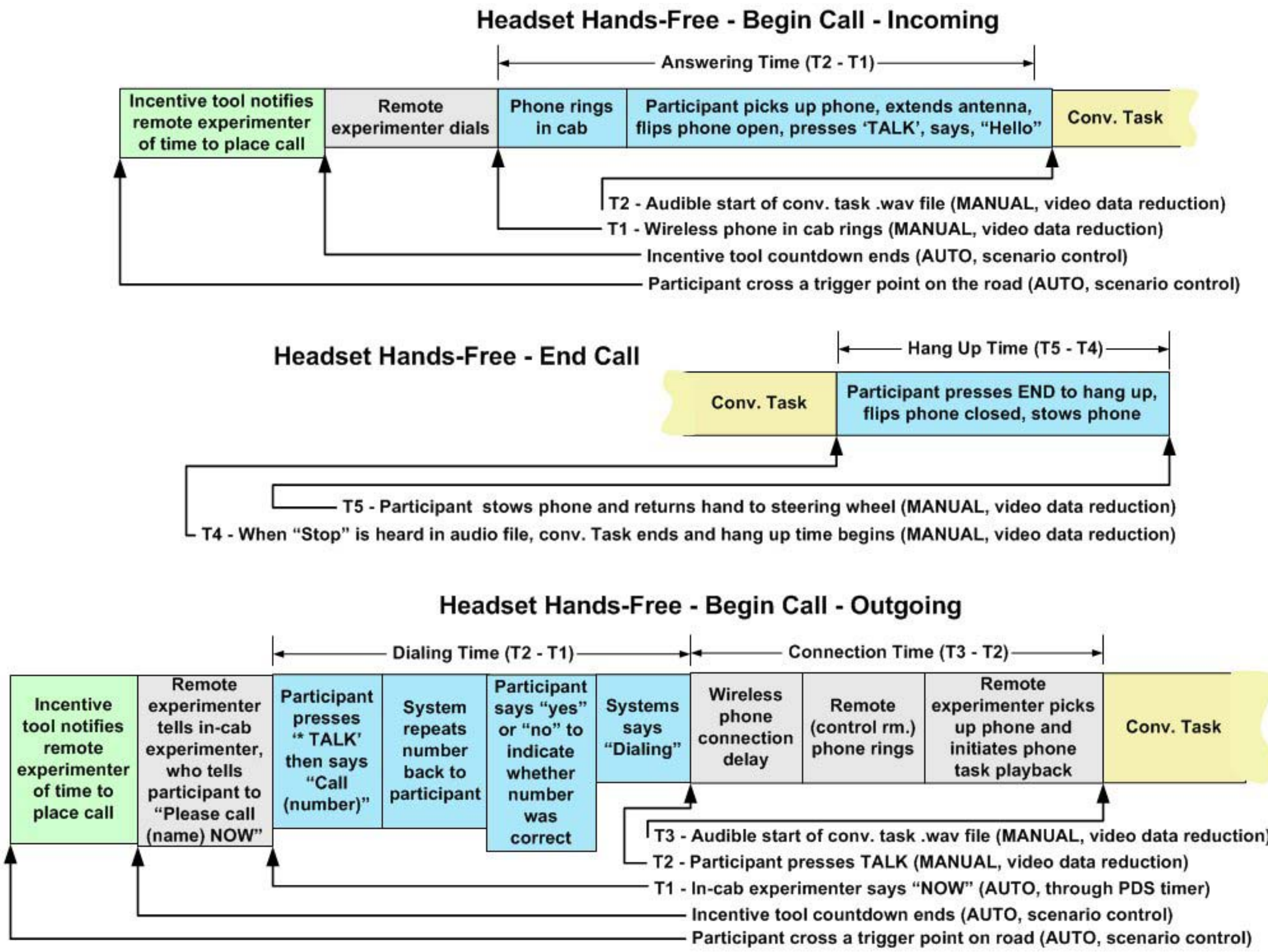

Figure 32. Components of calls using the HSHF Phone Interface.

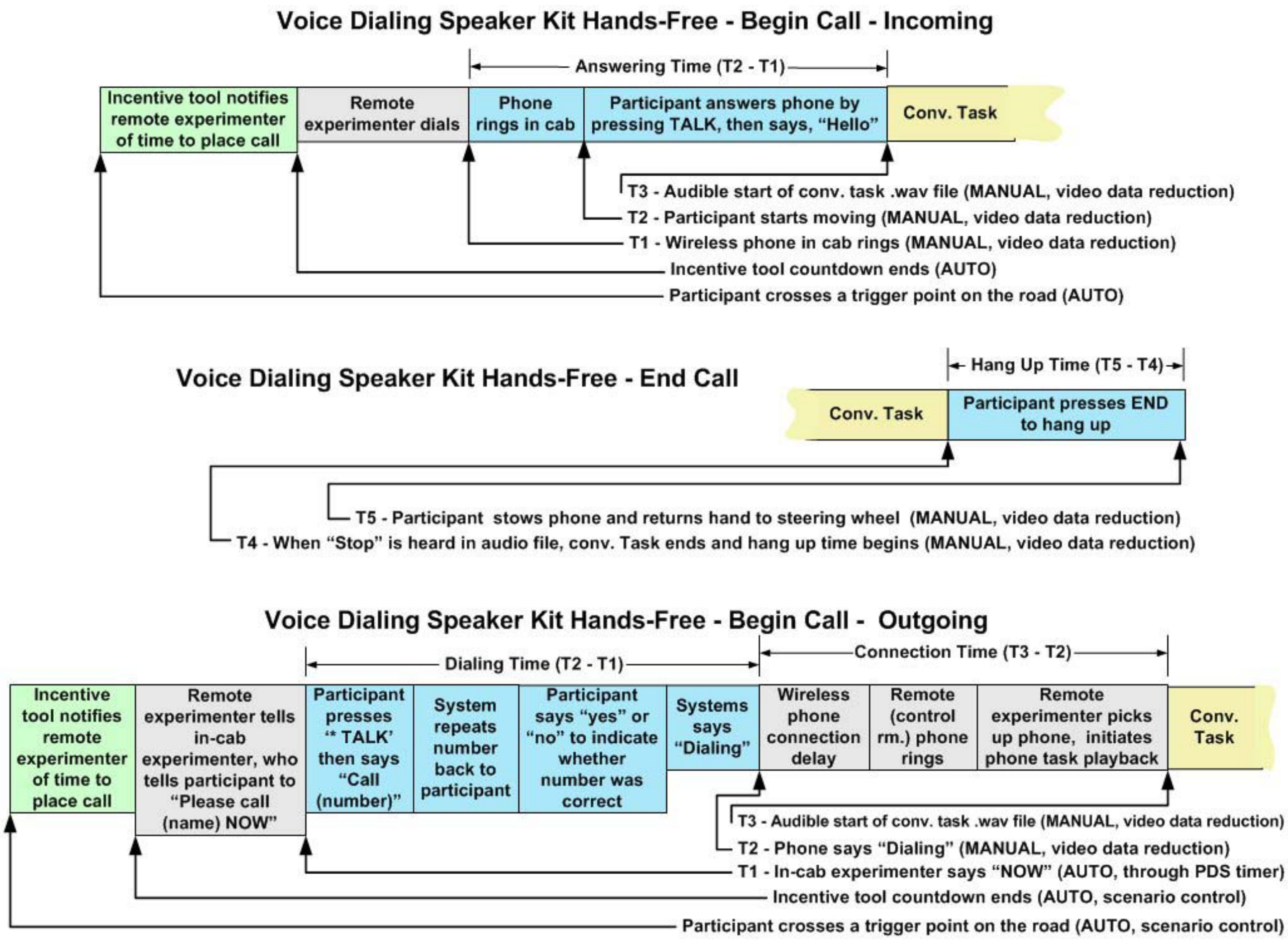

Figure 33. Components of an outgoing call using the VSHF Phone Interface.

Analyses of dialing, answering, conversation task performance, and hanging up were conducted using data obtained from the 54 participants. Results are presented below.

4.7.2 Phone Dialing

4.7.2.1 Number of Phone Dialing Attempts

Overall, approximately 30 percent of the outgoing phone calls required more than one attempt. Use of the Hand-Held interface was least likely to require additional attempts (18 percent), while the Headset Hands-Free interface, which used voice digit dialing, was most likely to require additional attempts (40 percent). This difference was statistically significant ($z = 2.16$, p = .0158). The percentage of VSHF calls requiring more than one attempt was 31 percent, which was not statistically different from either of the other interface values.

4.7.2.2 Phone Dialing Time

An ANOVA was computed on dialing times with Interface and Age group as the independent variables. This analysis found significant main effects of Interface, $F(2,32) = 56.34$, $p < .0001$, and Age group, $F(2,39) = 4.94$, $p = 0.0122$. The interaction of these two factors was also statistically significant, $F(4,32) = 4.23$, $p = 0.0073$. This effect is shown in Figure 34. Examination of differences between pairs of means revealed that the

Hand-Held interface (M = 20.2 s, *SE* = 1.0) was associated with significantly faster dialing times than the other two interfaces (HSHF: M = 30.5 s, *SE* = 1.1; VSHF: M = 37.2 s, *SE* = 1.2) for all three age groups. However, the dialing times for the VSHF and HSHF interfaces were significantly different only for the Middle Age group. The significant main affect of Age group reflects the fact that when the dialing times are collapsed across Interface condition, the mean time for the Younger group (M = 26.7 s, *SE* = 1.0) was significantly faster than for both the Middle (M = 30.6 s, *SE* = 1.2) and Older (M = 30.6 s, *SE* = 0.9) Age groups.

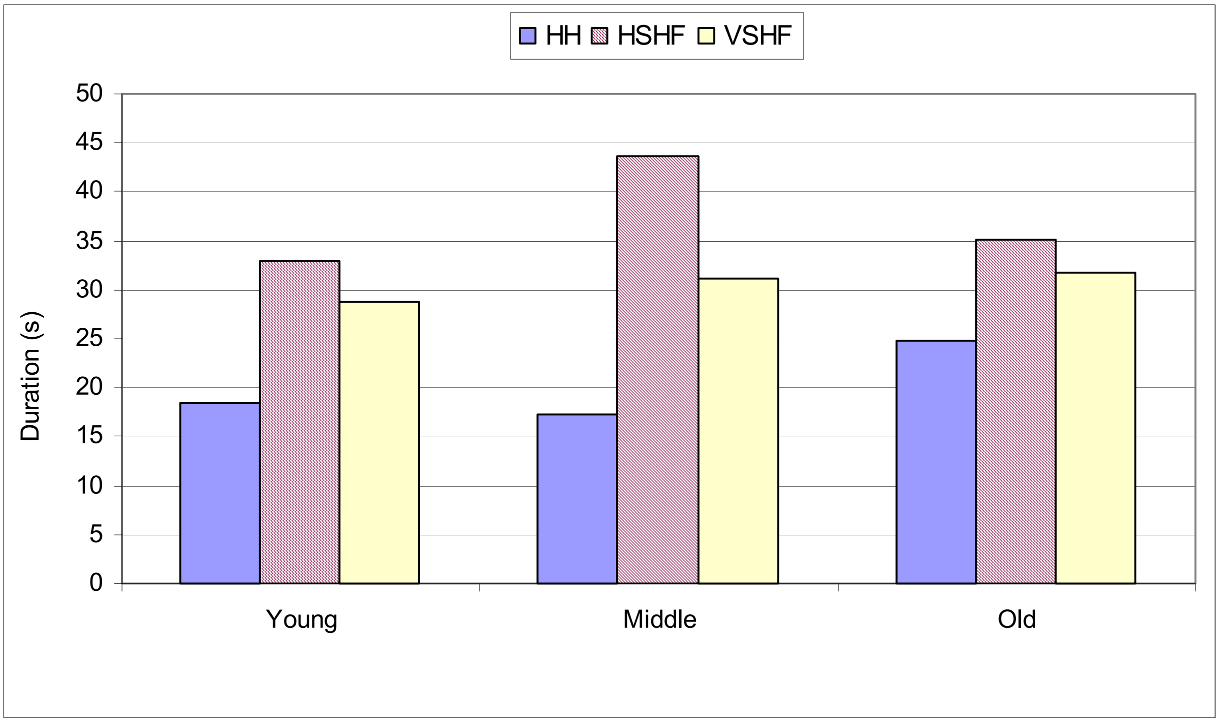

Figure 34. Dialing time by Phone Interface and Age Group

4.7.3 Phone Answering Time

To compare answering time for calls made with each interface, an ANOVA was computed using interface and age group as the independent variables. Significant main effects were found for Phone Interface condition, $F(2, 101) = 128.16$, $p < .0001$, and age group, $F(2, 51) = 8.32$, $p = 0.0007$. Examination of the means revealed that drivers answered much more quickly when using the VSHF interface (M = 5.25 s) than when using the HH (M = 10.28 s) or the HSHF (M = 10.25 s) interfaces. The main effect of age group reflects the fact that the younger drivers (M = 7.9 s) answered significantly more quickly than the older drivers (M = 9.7 s). The middle-aged group had an intermediate value (M = 8.2) that was not statistically different from either group. The Interface x Age group interaction was not significant, $F(4,101) = 2.04$, $p = 0.0947$.

4.7.4 Phone Hang-Up Time

An ANOVA for phone hang-up time was computed using the same model as described above. Interface condition was found to have a significant main effect, $F(2,101) = 96.1$, $p < .0001$. Specifically, hang-up times were faster in the VSHF condition (M = 4.5 s), slowest in the HSHF condition (M = 11.0 s), with an intermediate value in the HH condition (M = 9.0 s). Differences between all pairs of means were statistically significant.

4.7.5 Conversation (Baddeley) Task Results

Analyses were conducted to examine the effects of Age group, Phone Interface, and practice on Baddeley task scores. Two phone task performance measures were considered; overall judgment (total number of sentences correctly identified as sensible or nonsensical), and overall recall (total number of key words correctly recalled). For each call, scores on each measure could range from 0 to 24. An alpha level of .05 was used for all statistical tests, and the Tukey HSD procedure was used for all follow-up tests.

Only the first six of the seven experimental calls were analyzed for conversation task performance. Call 7, associated with the final event, was shorter in duration than the other six calls and thus was analyzed only in conjunction with driving performance data. For call 7, most drivers heard 12 sentences prior to the emergency event, at which point the call was ended (variation in number of sentences heard was due to variation in phone connection time).

4.7.5.1 Missing Data

In several instances, a restart of the simulator resulted in a particular call or portion of a call being heard more than once. In these cases, data from the final playing of the call were used in order to allow for comparison to the corresponding engineering data.

There were several cases in which issues beyond the participant's control caused some sentences within a call to be missed. In the analysis of individual sentences, these values were entered as missing. In the analysis of mean scores, when four or more sentences (out of 24) were missed, these means were entered as missing.

The general linear model (GLM) procedure was used instead of the ANOVA procedure because the former is less sensitive to the effects of unequal cell sizes.

4.7.5.2 Phone Interface Condition and Age Group

Two models were examined; the first used Phone Interface condition (HH, HSHF, VSHF) and Age group, and the second used Age and call number (Call). Dependent variables were judgment and recall.

The first model examined Phone Interface condition and Age. Phone Interface condition did not have a significant effect on judgment results. Age was significant for both judgment and recall.

The second model examined Age group and Call. For judgment, significant differences were found for Age, $F(2, 284) = 4.96$, $p < .01$. Follow-up tests revealed that the older group correctly judged significantly fewer words (M = 23.06) than the middle (M = 23.49) and young (M = 23.41) groups. For recall, significant differences were found for Age, $F(2, 302) = 53.38$, $p < 0.01$. Follow-up tests revealed that the younger group recalled significantly more words on average (M = 20.87) than the middle (M = 17.79) and older (M = 15.89) groups, and the middle group recalled more words on average than the older group. Call did not have a significant effect on judgment results.

4.7.5.3 Total Score

Frequency analyses of Calls 1 through 6 were conducted to examine the patterns present in total score (number of items correct out of 144), for both judgment and recall. Results appear in the following table.

Table 31. Frequency analysis results for total number correct for conversation (Baddeley) task

	Number of Participants (N=50)	
Number Correct Range	**Judgment**	**Recall**
54-65	0	2
66-77	0	2
78-89	0	4
90-101	0	10
102-113	0	9
114-125	1	12
126-137	9	9
138-144	40	2

4.7.5.4 Practice Effects

Phone calls were referred to in terms of their sequential order. The variable, Call, allowed for examination of practice effects, in that each participant completed all calls, and received them in the same order (with the exception of Call 7, which participants receiving the VSHF condition last did not hear). Analyses were conducted to determine whether performance improved over time; that is, across Calls 1 through 6. Examination of call data revealed no significant difference in mean performance across calls for judgment, $F(5, 314) = 0.42$, $p = 0.84$, and a marginally significant difference across calls for recall, $F(5, 314) = 2.20$, $p = 0.05$. Participants' performance in recalling key words improved slightly across the experimental trials. Follow-up tests revealed that participants recalled significantly more words on average during Call 6 ($M = 19.23$) than they did during Call 1 ($M = 16.91$).

4.7.5.5 Sentence Analysis

Item analyses were conducted on the 144 sentences to examine the difficulty of each sentence and its contribution to total score. Data were examined separately for judgment and recall. Most participants achieved high scores on the judgment task, and there were few sentences that more than a few people failed to correctly judge as sensible or nonsensical.

There was more variability in the data for the recall task than for the judgment task. For the nine sentences listed in Table 32, more than half of the participants (27 or more) failed to recall the key word.

Table 32. Conversation task sentences for which greater than 50 percent of participants failed to recall the key word.

Sentence No.	Sentence
6	The manager typed a forest.
10	The train left the station.
22	The garage housed the pond.
23	The criminal broke the success.
45	The salesperson sold the truck.
67	The sailboat entered the bed.
70	The player threw the ball.
141	The lion chased the speech.
142	The sun melted the feeling.

Several of these sentences were missed by more than half of the pilot test participants as well. No pattern is readily apparent in comparing these sentences to those in which the key words were recalled by at least half of the participants.

4.7.5.6 Conversation Task Results Summary

No effect of Phone Interface condition on conversation task performance was found. Age group was the only examined variable significantly related to conversation task performance, with younger individuals performing better than older individuals. Participants' recall performance was significantly better on Call 6 than on Call 1.

4.8 Questionnaire Results

Results of the wireless phone post-drive questionnaire provided information about participants' wireless phone experience, driving experience, and feelings about ease of use and driving performance effects relating to wireless phone interface type.

Analysis of the post-drive questionnaire results showed that participants' average length of use of a wireless phone was 6.01 years (MIN=0.5 years, MAX=30 years, SD=4.7 years). Nineteen participants reported owning Hands-Free kits. Eight participants did not know if they had a Hands-Free kit. Twelve participants did not know whether their personal wireless phone had a speakerphone function. Five of the 54 participants reported regularly using a headset with their wireless phone. Three participants reported regularly using voice tag dialing, while two participants reported regularly using voice digit dialing.

Fifty participants stated that their preferred dialing method was voice dialing, while only 4 preferred manual dialing. For conversation, 39 percent preferred Hands-Free with speaker kit, 26 percent preferred using a headset, and only one person stating a preference for holding the phone while talking.

Participants rated various aspects of wireless phone use driving including ease of dialing and conversing, as well as ease of maintaining lane position and speed while dialing and conversing. The HH phone interface was rated to be most difficult to use while driving for all conditions probed, while the VSHF interface was considered to be the easiest. Participants generally rated their personal phones to be somewhat easier to use than the HH phone interface and somewhat more difficult to use than the VSHF phone interface. Taking an average of the 7 ratings reveals the VSHF interface as the one that participants considered the easiest to use and comparable to participants' personal phones, followed by the HSHF and HH interfaces, respectively. Figure 36 presents the results by activity and Table 35 summarizes the averaged results across activities.

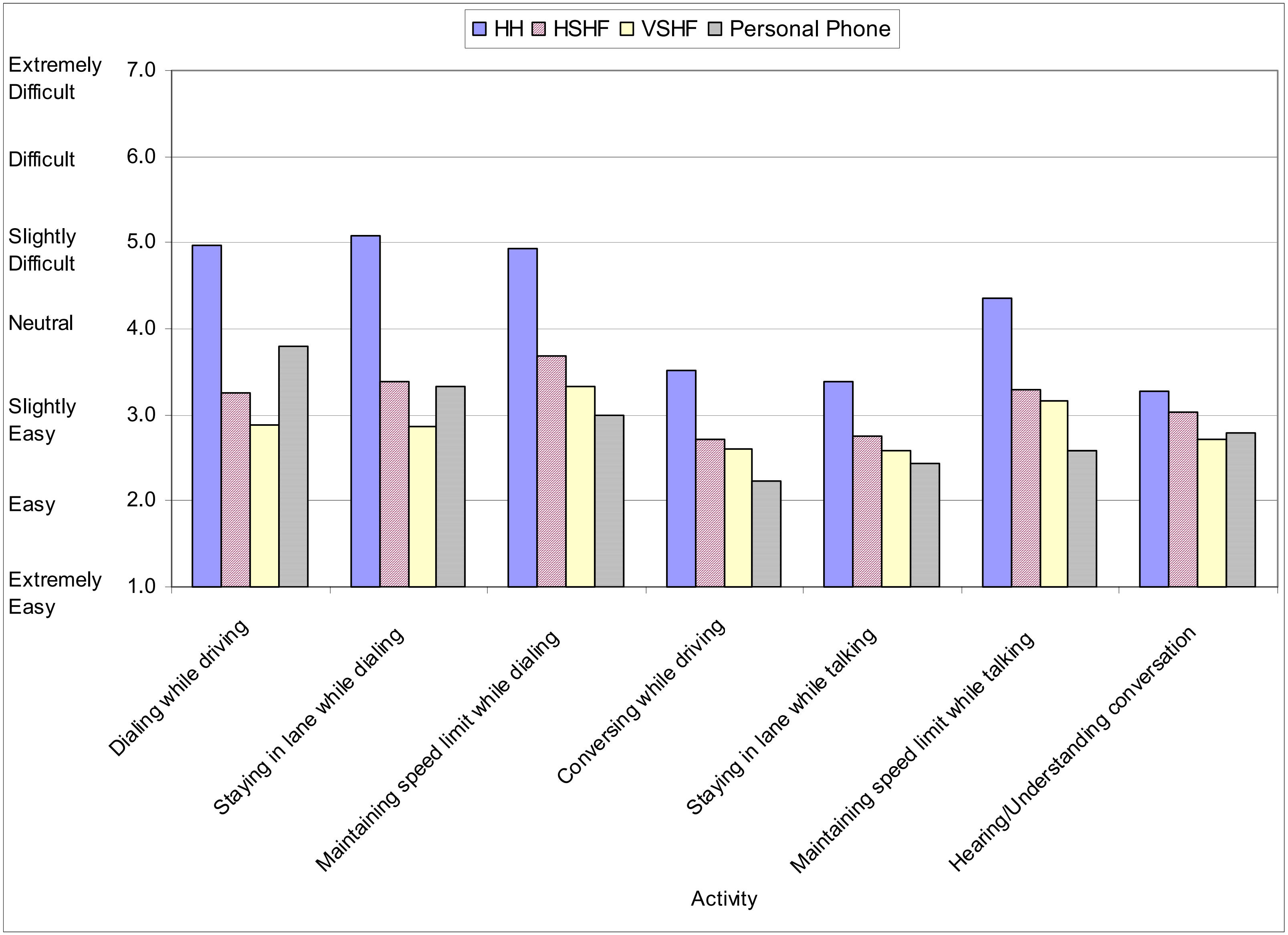

Figure 35. Summary of participants' responses regarding ease of use by Phone Interface for dialing and conversing.

Table 33. Averaged dialing-related questionnaire results by Phone Interface

Scale 1-7:	1=Extremely Easy 2= Easy 3=Slightly Easy 4=Neutral	5=Slightly Difficult 6= Difficult 7=Extremely Hard
HH	4.2	
HSHF	3.2	
VSHF	2.9	
Personal Phone	2.9	

Additional results from this survey are presented in Appendix I.

5.0 DISCUSSION

The study assessed the distraction potential associated with the use of wireless phones while driving on freeways and attempted to determine whether the resulting performance degradation was related to the specific phone interface used. A discussion of results is presented below.

5.1 Driving Performance

The car-following events provided support for the hypothesis that the phone conversation task impaired driving performance. The phone conversation task was associated with increased phase shift between the respective speed signals, which reflects an average increase in delay of approximately 0.3 to 0.4 seconds in responding to lead-vehicle speed changes, relative to performance without phone conversation. Steering entropy was also found to increase during phone conversation in car-following events, reflecting an increase in high-frequency steering corrections. Increased steering reversal rates associated with phone conversation indicate increased workload (MacDonald and Hoffman, 1980).

The results provided some support for the hypothesis that Hand-Held phone use would degrade driving performance more than the Hands-Free interface conditions. Specifically, lane position variability was greater in the Hand-Held condition than in the other interface conditions, presumably reflecting the physical conflict between Hand-Held phone use and steering. However, the interpretation of this result is complicated by the overall finding that phone use generally was associated with decreased lane position variability during car-following events, which suggests improved lane tracking performance while drivers were engaged in phone conversation. Although contrary to our predictions, this pattern is not without precedent (e.g, Brookhuis, De Vries and De Waard, 1991).

The present results for steering holds, which represent periods of steering inactivity and are assumed to reflect increasing neglect of steering due to the demands of other tasks, were consistent with those for lane position variability, reflecting better performance during the simulated phone conversation. Specifically, the baseline condition was associated with higher steering hold rates than the Hands-Free or Hand-Held conditions. These results suggest that drivers may have used the baseline episodes for a break from the combined demands of car following, phone conversation and lateral vehicle control, essentially by giving up the latter. This would be a rational response in that steering and lateral position were not identified as measures that would influence their performance scores. In other words, drivers were instructed about the importance of the conversation task and car following and were given special training in both. No special instructions or training were given concerning steering and lane maintenance. Finally, the observed decrease in modulus (gain) during car following indicates more conservative responses when drivers were engaged in conversation, and may be interpreted as an attempt to compensate for the increased demands of car following and phone conversation.

Beyond the car-following events, there was little evidence consistent with the prediction of performance impairment due to phone conversation for the conditions and tasks examined in this study. Neither the lead-vehicle braking nor lead-vehicle cut-in events exhibited the predicted slowing in accelerator release and brake response times, due in part to difficulties with the consistency of the events. Similarly, we found no evidence of higher deceleration or closer spacing due to phone conversation in these events. Drivers exhibited faster speeds and longer headways at the beginning of the lead-vehicle brake event, relative to the baseline condition, which may indicate that drivers diverted their attention away from speed monitoring while engaged in phone conversation, but compensated for the increased task demands by increasing their headways.

The merge event provided one piece of evidence of impairment due to phone use. Specifically, while engaged in the phone conversation task, drivers devoted less visual attention to planning for an upcoming merge event. They made fewer glances toward the traffic stream and spent proportionately less total time looking in that direction relative to the baseline condition. This suggests that drivers diverted attentional resources from merge planning to manage the phone conversation task.

There is some evidence that Hand-Held phone use interfered with steering more than Hands-Free phone conversation presumably reflecting the conflict between holding the phone and steering, both of which require use of the hands. Specifically, during car following the steering entropy, which summarizes corrective behavior due to error, was highest in the Hand-Held condition. In addition, as mentioned above, lane position variability was greater in the Hand-Held than in the other interface conditions.

There is also evidence that the VSHF interface was associated with faster speeds, relative to the other interfaces. In particular, VSHF speeds were fastest at the beginning of the cut-in events and also at the end of the merge events. VSHF calls were associated with more slowing at the very beginning of the merge and greater speed increases at the end of the merge. Although speed changes are not considered to be clear evidence of impaired performance, one interpretation of the pattern of speed effects is that while engaged in VSHF calls, drivers felt safer and thus paid less attention to speed control. However, the fact that this effect was not observed for both Hands-Free conditions weakens this possible interpretation. Overall, the evidence supporting the hypothesis that Hand-Held phone conversation would impair driving performance more than Hands-Free phone conversation is modest, reflecting the fact that the majority of performance measures revealed no significant differences between the interface conditions.

These results are consistent with drivers' perceptions as found in the post-drive survey responses citing the HH interface as most difficult to use for dialing while driving. Drivers also reported that they felt that it was easier to maintain the speed limit while talking using a Voice Digit Dialing with Speaker Kit Hands-Free interface or a Headset Hands-Free interface than it was with a Hand-Held phone interface. However, the above-mentioned increases in speed associated with the VSHF interface suggest that drivers may not have been fully aware of the differential effects of the interfaces on their speed behavior.

Several differences were found among age groups. Young drivers were more aggressive in their car following, as reflected by higher modulus scores. Older drivers exhibited more steering reversals during car following, indicative of higher workload for this group. Drivers in the middle age group were faster than younger drivers at the beginning of the LV cut-in event. In the merge event, relative to the other age groups, older drivers made proportionately more glances leftward before the merge event and spent more time looking left to plan the merge. Older drivers also maintained greater following distances than younger drivers. Overall, the evidence from this study supporting age-related degradation in driving performance is relatively weak. However, the study did not test elderly drivers for which crash statistics show high fatality rates.

Analysis of the final event scenario revealed significant differences for some dependent measures. Hypothesized effects related to phone interface were complicated by significant interactions between Phone Interface and Age group. For the first response to the final brake event, participants in the Hand-Held condition responded significantly faster than those in the Voice Digit Dialing with Speaker Kit Hands-Free and Baseline conditions, contrary to hypothesis. While participants rated the VSHF phone interface to be generally easiest to use while driving, this interface was associated with the highest number of crashes in the final event scenario. However, this result was not statistically significant.

5.2 Phone Task Performance

Results for dialing, answering time, and hang-up time revealed the strongest differences between interface conditions. Although participants rated the Hand-Held interface to be most difficult to use, this interface was associated with consistently faster dialing times and fewer dialing errors than the other interface conditions, while the VSHF interface was associated with the fastest hang-up times.

Voice dialing times exceeded hand-held dialing times by 84 percent for VSHF and by 51 percent for HSHF. While mean dialing times for the HSHF and VSHF interfaces differed by nearly 7 seconds, these interfaces used the same voice dialing method. These results agree with those of an earlier on-road study of driver behavior during wireless phone use (NHTSA, 2004), which showed voice dialing times to be 30 percent longer than hand-held dialing durations. While hands-free dialing might be assumed safer than hand-held dialing since drivers are free to maintain their visual focus on the forward roadway and both hands on the steering wheel, increased dialing durations may likewise be associated with an increased period of cognitive distraction, as well as increased glances to the device to assess dialing progress.

The shorter dialing times for the HH interface may be attributable to participants' prior experience with hand-held wireless phones, which was approximately 6 years on average. The similarities between a touch-tone phone keypad for home use and a manual wireless phone dialing interface also may be a factor. It should be noted that the time required to perform voice dialing may vary depending on the interface and dialing method used. For example, the Sprint PCS Voice Command system used in this study involved a six-step dialing process. Some newer model phones feature integrated voice digit dialing capability, which may allow shorter dialing times. Use of voice "tags" for dialing may also afford shorter dialing times; however, voice digit dialing was chosen for implementation in this study since it provided the most direct comparison between manual and voice dialing. Lastly, the use of actual wireless phone service in this study meant that dialing times included actual call connect time as a component, which was also a source of variability.

The Hand-Held interface was associated with the fewest dialing errors (in terms of the number of attempts per dialing trial). The HSHF phone interface had significantly more dialing errors than the HH interface. The HSHF was associated with 9 percent more dialing errors than the VSHF interface, despite the fact that they used the same dialing method. This study used 10-digit phone numbers unfamiliar to the participants that were read from a dashboard-mounted card. Thus, in addition to possible voice recognition problems, other factors affecting dialing success included drivers' ability to read and remember the digits, and then speak the numbers in a continuous stream in order for the system accept the verbal input. Moderately loud volume and consistently paced speech were important to a successful dialing attempt using the system used in this study.

The VSHF interface was associated with significantly faster answering times than the other interfaces. Answering with VSHF required only a single button press; HH and HSHF both used a four-step process. Younger drivers answered calls significantly faster than older drivers.

The VSHF interface was also associated with significantly faster hang-up (call termination) times than the other interfaces. Hang-up times were significantly different across all interfaces, despite that the HH and HSHF interfaces used the same four-step process of hanging up.

Conversation task performance did not differ as a function of phone interface. Despite this, participants reported in the post-drive wireless phone survey that the Hand-Held phone interface was the most difficult to use for conversation, followed by the Headset Hands-Free and the Voice Digit Dialing with Speaker Kit Hands-Free interfaces, respectively. Age was the only examined variable significantly related to phone conversation task performance, with younger individuals performing better than older individuals.

Questionnaire results showed the HH phone interface was rated to be most difficult to use while driving for all conditions probed, while the VSHF interface was considered to be the easiest. Participants' ratings that the HH interface was the most difficult to use were not consistent with dialing time results, which showed that the HH interface was associated with significantly faster dialing times than the other two interfaces for all three age groups. It should be noted however that dialing time and ease of use may not represent the same behavioral construct.

5.3 Experimental Challenges

The experiment was one of the first to use the NADS' capabilities for developing complex driving scenarios. It was an ambitious attempt to evaluate driving performance in realistic situations, with task demands more like real world driving than would typically be encountered in driving simulator studies. A considerable amount of effort was devoted to the development and testing of scenario events for this experiment, including the development of parameters for events that heretofore have not been used in experimental research. This effort has helped break ground for other ongoing and planned research studies using the NADS. With a concerted effort among all NADS experimenters, the ultimate outcome is expected to be set of scenario events with realism that far exceeds anything that has been done previously using driving simulators. The events used in this study represent a first step toward that outcome.

5.4 Safety Implications

The present results indicated that some aspects of drivers' performance were degraded when they were involved in simulated phone conversations while driving the NADS. There were also some differences between interface conditions. The interpretation of differences in this study was based on the consistency of effects across drivers, which is reflected in the outcome of statistical testing. For several reasons, however, little consideration was given to the absolute magnitude of the differences. First, it is difficult and somewhat arbitrary to set criteria for magnitudes of differences (e.g. increases in lane-position variability) such that any difference greater than a criterion value would be considered to have safety implications while smaller differences would not. There are no well-established precedents for these types of discriminations, whether demonstrated on a simulator or not. Second, in a study like this one, which examined a number of performance measures, it is very difficult to interpret the pattern of differences, independent of their relative magnitudes. Indeed, we found that for most events, some of the measures indicated performance decrements while others did not. Third, some of our dependent measures are likely to be more directly related to safety than others. For example, we argue that increasing lane-position variability, increasing delay (i.e., response time) in car following, and increasing steering entropy (i.e., increase in error corrections) reflect degraded driving performance, which could, depending upon the situation in which they occur, have adverse safety implications. In contrast, faster speeds and higher levels of acceleration or deceleration are not as directly related to safety. Furthermore, for those measures that we do consider to have potential safety implications, we cannot equate levels of impairment between one measure and another. Finally, whereas the NADS represents the highest driving simulation fidelity available, it is not clear how the performance impairments observed in this study translate to real world, on-road performance. This is a dilemma shared by many highly controlled, on-road research studies. For these reasons, we feel confident in our relative comparisons based on statistical testing and have endeavored to present all relevant mean (and standard error) values so that readers can have the freedom to interpret the absolute differences further, if they so desire.

6.0 CONCLUSIONS

The results of the present study support the following conclusions:

1. Phone use while driving degraded driving performance. Being involved in a simulated phone conversation during car following delayed drivers strategic decision making by approximately 0.3 – 0.4 seconds, on average. Phone conversation also: (1) impaired vehicle control, as indicated by increased steering entropy, and (2) increased driver workload, as reflected by increased steering reversal rate. Finally, based on eye glance data, we found that drivers spent less time planning to merge when engaged in phone conversation.

2. Most driving performance measures revealed no differences among interface conditions. Exceptions include the findings that: (1) Hand-Held phone use interfered with steering and lane control more than the Voice Digit Dialing with Speaker Kit interface, and (2) the Voice Digit Dialing with Speaker Kit interface was associated with faster travel speeds than the Hand-Held interface.

3. Older and younger drivers did not exhibit consistently greater degradation of driving performance due to phone conversation than middle-aged drivers. Older participants had slowest phone task times and lowest conversation task performance.

4. Differences between interface conditions were strongest for dialing and answering. The Hand-Held interface was associated with fastest dialing times and fewest dialing errors, while the Voice Digit Dialing with Speaker Kit phone interface was associated with fastest answering and hang-up times.

5. Phone conversation task performance did not differ as a function of phone interface. Age was the only examined variable significantly related to phone conversation task performance, with younger individuals performing better than older individuals.

6. In the post-drive wireless phone survey, participants rated the Hand-Held phone interface to be the most difficult to use while driving for all conditions probed, including dialing and conversing, while the Voice Digit Dialing with Speaker Kit interface was considered to be the easiest.

7. The NADS has the potential to create complex driving situations with realistic driving challenges. Among the driving situations used in this study, the car-following events provided the most consistent data. The lead-vehicle braking, lead-vehicle cut in and merge events require additional development before being used in future studies of driving performance.

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8.0 APPENDIX A: COMPUTATION OF VEHICLE-BASED METRICS

Authors: Kamel Salaani and Larry Smith

A.1. List of Measures

A.2. Entropy

A.3. Hold and Reversal Steering Measures

A.4. Brake and Accelerator Pedals

A.5. Coherence Calculations for Car-Following Tests

A.1 List of Measures

Data analysis of this experiment was done using Matlab digital signal processing toolbox and statistical toolbox. Dozens of Matlab functions were written to read, analyze, and save the data into spreadsheet format. In this appendix, functions that were developed to compute operator's steering and pedal activities and performances are outlined. Table A1 lists all the measures computed from car-following segments, and Table A2 lists the measures computed for the merge events.

Table A1. Measures for Car-Following Segment

#	Type	UNITS	Description
1	G	M/F	Gender
2	*D*	1/2/3	Drive number
3	*I*	HH/HF/HS	Interface
4	*T*	1/2/3	Treatment
5	*C*	B/I/O	Call type
6	*ENTROPY*		Entropy
7	*SteerRRev*		Steer reversal frequency
8	*RRev_NORM*		Steer reversal frequency normalized to baseline
9	*RRev_NORM2*		Steer reversal frequency normalized to baseline and baseline time
10	*SteerSTD*		Steer std
11	*VelocitySTD*		Steer velocity std
12	*SampOutpSec*		Decimated samples per sec outside steer velocity dead band
13	*SteerHold*		Steer hold frequency
14	*MeanTimeH*		Mean for time spent between steer velocity deadbands
15	*StdTimeH*		Std for time spent between steer velocity deadbands
16	*PrbTimeH*		Probability for spending time > TimeHold within deadband
17	*LaneDSTD*		Lane deviation std
18	*AySTD*		Lateral acceleration std
19	*HingSTD*		Heading angle std
20	*Speedm*		Vehicle speed mean
21	*SpeedSTD*		Vehicle speed std
22	*BrkActn*		Brake activity frequency (normalized to baseline time)
23	*ActnNORM*		Brake activity number normalized to baseline
24	*BrkTRatio*		Ratio of time spent for braking
25	*BrkMax*		Maximum brake force
26	*AccPSTD*		Accelerator pedal std
27	*AccVSTD*		Accelerator pedal speed std
28	*AccHoldn*		Accelerator hold frequency (normalized to baseline time)
29	*AccHoldnNORM*		Normalized accelerator pedal hold frequency
30	*AccelTHRatio*		Accelerator hold time ratio
31	*AccReln*		Accelerator release frequency (normalized to baseline time)
32	*AccRelnNORM*		Normalized accelerator pedal release frequency
33	*AccelTRRatio*		Accelerator time ratio
34	*MaxTime*		Total time for the event

Table A2. Measures for Merge Segments

#	Type	UNITS	Description
1	G	M/F	Gender
2	*D*	1/2/3	Drive number
3	*I*	HH/HF/HS	Interface
4	*T*	1/2/3	Treatment
5	*C*	B/I/O	Call type
6	*ENTROPY*		Entropy
7	SteerRev		Steer reversal frequency
8	SteerHold		Steer reversal frequency normalized to baseline
9	MeanTheld		Steer reversal frequency normalized to baseline and baseline time
10	TimeUnd		Steer std
11	LaneDSTD		Steer velocity std
12	BrkActn		Decimated samples per sec outside steer velocity dead band
13	Brktime		Steer hold frequency
14	BrkMax		Mean for time spent between steer velocity deadbands
15	AccPSTD		Std for time spent between steer velocity deadbands
16	AccVSTD		Probability for spending time > TimeHold within deadband
17	AccHoldn		Lane deviation std
18	AccRel		Lateral acceleration std
19	MeanSpeed		Heading angle std
20	StdSpeed		Vehicle speed mean
21	MaxTime		Vehicle speed std
22	AccMin		Brake activity frequency (normalized to baseline time)
23	AccMax		Brake activity number normalized to baseline
24	EntSpeed		Ratio of time spent for braking
25	ExtSpeed		Maximum brake force
26	LatAccSTD		Accelerator pedal std
27	HeadingSTD		Accelerator pedal speed std
28	TimeP3ToE		Accelerator hold frequency (normalized to baseline time)
29	*DistE2P5*		Normalized accelerator pedal hold frequency
30	*TimePrd35*		Accelerator hold time ratio

A.2. Entropy

Entropy is used as an index to quantify driver's mental workload. It is based on the hypothesis that an increase in mental workload increases steering corrections thus reducing steering angle predictability[1]. The difference between load free attentive driving conditions and intensified workload conditions is quantified by comparing the entropy of steering profiles. The entropy has a delicate relation between task load, skill performance, and workload.

Computational Summary:
The steering angle at NADS is sampled at 60 Hz, and the following computational sequences are done to obtain the entropy.

1. Filter the steering to 4 Hz cutoff-frequency. This provides data consistent with maximum steering frequency that a human driver can exert.
2. Decimate the filtered signal to 0.15 sec intervals, which is at about the average human operator's inherent manual tracking delay time.
3. Compute the Auto-Regression (AR) parameters using baseline data.
4. Compute the residual (error) between actual steering profile and AR model profile, for baseline and loaded drives.
5. Determine the residual bins that produce entropy of 0.5 for baseline data.
6. Using the above bins compute entropy for loaded drives.

The following figure shows typical plots of steering angles of a baseline drive, and two loaded conditions, call-1 and call-2. The decimated data reproduces the original signal without loss of signal properties.

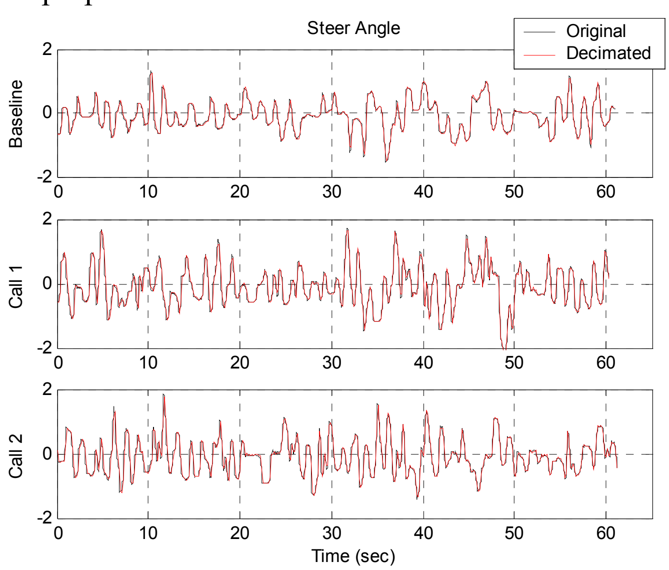

Figure B1. Filtered and decimated steering angles

The coefficients of the AR model are computed using the following Matlab *m-code*. The AR method employed in this research uses the covariance technique to fit the pth AR model to input

[1] Boer, Erwin R., "Behavioral Entropy as an Index of Workload," Proceedings of the IEA 2000/HFES 20000 Congress

steering angle. The method minimizes forward prediction error in least-square sense. The order of the AR can be increased to a higher level, but this is out of scope for this project. AR order and its effects on measure sensitivity should be investigated in future studies. The second order AR model is based on published results by Boer. Figure B2 shows typical results of the actual steering profile and the AR model profile

```
function [b,B,s,r] = ar_fit(x,p)
%
%               Fit a reference posterior AR(p) model to the series x
%               after extracting the mean; length(x) must exceed 2*p
%               Written by Kamel Salaani at VRTC - Cell-phone study - 2004

%  Input:
%              x = steering angle
%              p= auto-regression degree
%
% Output:
%              b: auto-regression coefficients
%              B: Variance matrix
%              s: Variance for the residual error
%              r: Residual error

%
% remove the bias on the steering around the center
%
 arx=x-mean(x);
 %
 n=length(arx);
 %
 y=arx(n:-1:p+1);
 %
 X=hankel(arx(n-1:-1:p),arx(p:-1:1));
 %
 B = inv(X'*X);
 %
 % estimate the coefficients
 %
 b = B*(X'*y);
 %
 % get the residual errors
 %
 r = y-X*b;
 %
 % compute variance for the residual error
 %
 nu = n-2*p;
 s = r'*r/nu;
 %
 % Compute the variance matrix for the y-vector
 %
 B = B.*s;
 %
```

After getting the AR coefficients, the steering residual is computed as follows:

$$r^i = x^i - b_1 x^{i-1} - b_2 x^{i-2} \quad \text{(B1)}$$

Where:

x^i: Actual driver steering angle input

r^i: Steering residual (Difference between AR model and actual profile)

b_1, b_2: AR-coeffieicents (second order)

These steering residuals are used to compute entropy values. First we divide the residuals into different bins then we compute their CDF (Cumulative Distribution Function) using the empirical method. The bin-sizes are computed such that the entropy of a baseline run provides a value of 0.5. With a reference to the baseline steering profile, the loaded cases would have a "coarser" steering profile with an entropy greater than 0.5, or a smoother profile with an entropy lower than 0.5.

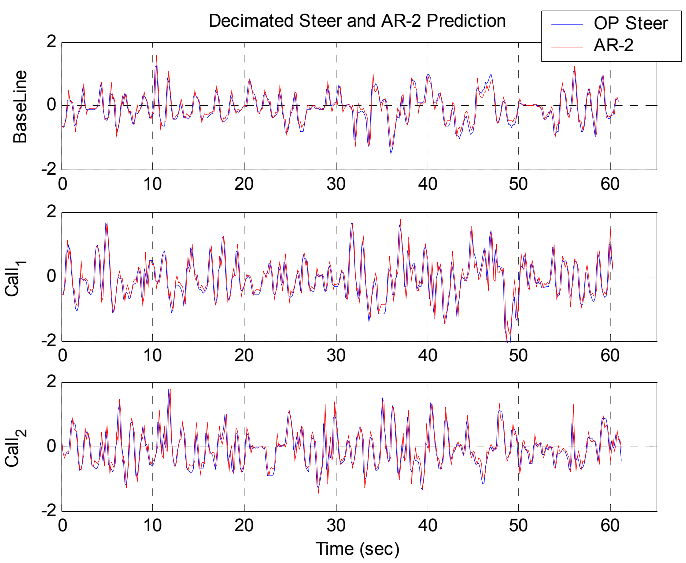

Figure B2. Steering profile of actual and AR model

The ten bins used to compute entropy are:

$$I_e = \begin{Bmatrix} (-\infty\ \text{-}5\alpha], (\text{-}5\alpha\ \text{-}3.5\alpha], (\text{-}3.5\alpha\ -2\alpha], (-2\alpha\ \text{-}\alpha], (\text{-}\alpha\ 0], \\ [0\ \alpha), [\alpha\ 2\alpha), [2\alpha\ 3.5\alpha), [3.5\alpha\ 5\alpha), [5\alpha\ \infty) \end{Bmatrix} \quad \text{(B2)}$$

The parameter α is determined such that the probability of the first bin of the baseline run is 0.4143, following Boer method.

$$prb\langle [0\ \alpha) \rangle = 0.4143 \quad \text{(B3)}$$

Then, probability of each bin is obtained accordingly, with α fixed from base line run.

$$P_i = prb(I_e^i) \quad \text{(B4)}$$

Entropy of each run is then computed using this classical formulation:

$$H = -\log 10\left(\prod_{i=1}^{10} p_i^{P_i}\right) \quad \text{(B5)}$$

The Matlab m-function to compute entropy for baseline runs and bin sizes is as follows:

```
function [H, prb, Bins] = Compute_entropy_Baseline(error, show_plots)
%
% this is just to compute entropy
%
global Vnoise dead_band Holdtime Driver_time Sampl_time p1 HoldTime1 tconfi
pr0 = 0.5;     % data centered around the mean probability at the mean = 0.5%
%
%
%
[fi0 xi0] = ecdf(error);
%figure
%plot(xi0,fi0),grid
%
i = max(find(fi0 < (0.5 - p1)));
%
alpha   = xi0(i);
%
alpha2  = 2*alpha;
alpha35 = 3.5*alpha;
alpha5  = 5*alpha;
%
Bins(1) = alpha;
Bins(2) = alpha2;
Bins(3) = alpha35;
Bins(4) = alpha5;
%
% now we find probabilities bin by bin
%
j = max(find(xi0 < alpha));
pr(1)   = fi0(j);
prb(1) = pr0 - pr(1);
%
j = max(find(xi0 < alpha2));
if ~isempty(j)
   pr(2) = fi0(j);
else
   pr(2) = 0;
end
prb(2) = pr(1) - pr(2);
%
j = max(find(xi0 < alpha35));
if ~isempty(j)
   pr(3) = fi0(j);
else
   pr(3) = 0;
end
prb(3) = pr(2) - pr(3);
%
j = max(find(xi0 < alpha5));
if ~isempty(j)
   pr(4) = fi0(j);
else
   pr(4) = 0;
end
prb(4) = pr(3) - pr(4);
%
prb(5) = pr(4);
%
j = min(find(xi0 > -1*alpha));
pr(6)   = fi0(j);
prb(6) = -1*(pr0 - pr(6));
%
```

```
j = min(find(xi0 > -1*alpha2));
if ~isempty(j)
   pr(7) = fi0(j);
else
   pr(7) = 1;
end
prb(7) = -1*(pr(6) - pr(7));
%
j = min(find(xi0 > -1*alpha35));
if ~isempty(j)
   pr(8) = fi0(j);
else
   pr(8) = 1;
end
prb(8) = -1*(pr(7) - pr(8));
%
j = min(find(xi0 > -1*alpha5));
if ~isempty(j)
   pr(9) = fi0(j);
else
   pr(9) = 1;
end
prb(9) = -1*(pr(8) - pr(9));
%
prb(10) = 1-pr(9);
%
% Computing entropy for baseline
%
H = 0;
for i=1:10
   H = H - log10(prb(i)^prb(i));
End
```

Figure B3 and B4 show histograms and CDF of the steering residuals for baseline, call-1, and call-2 runs. Figure B5 shows the probabilities of each bin and the entropy values for all the runs.

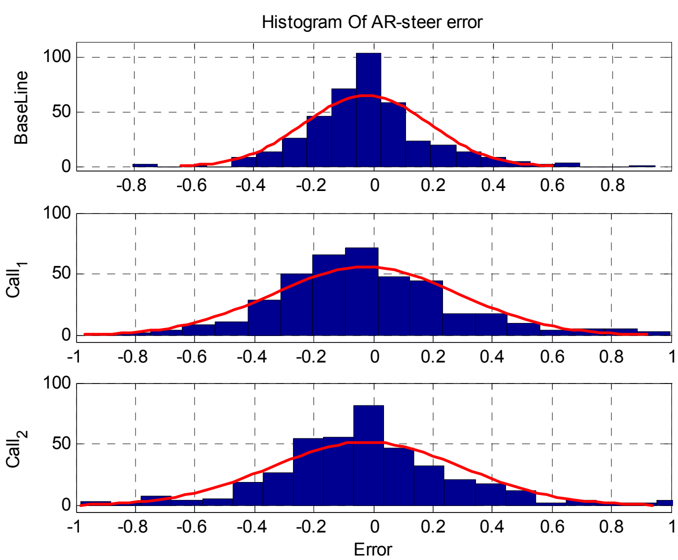

Figure B3. Steering "error" profile of baseline and loaded conditions

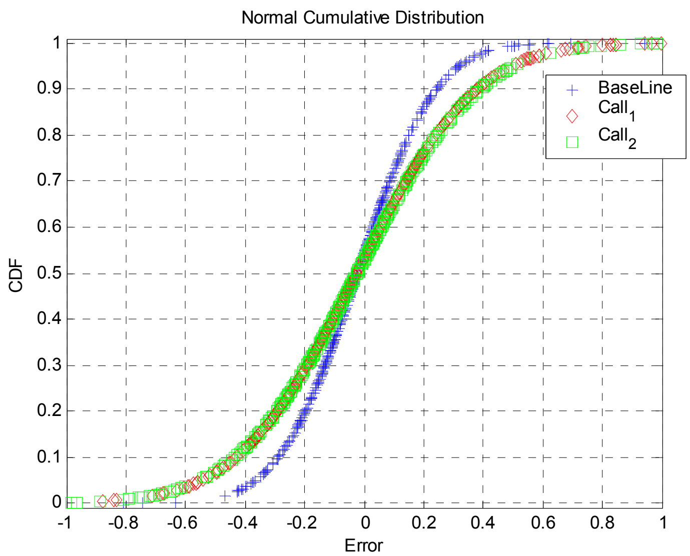

Figure B4. Cumulative Density Function of baseline and loaded conditions

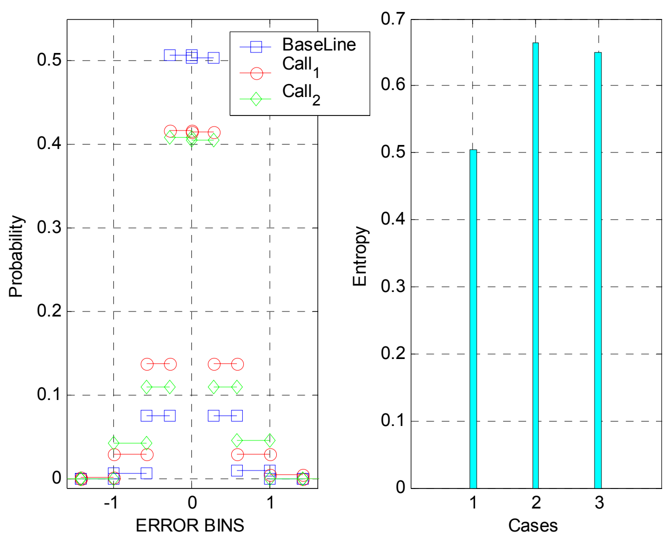

Figure B5. Entropy results of baseline and loaded conditions

The following figures show actual steering profiles and AR model profiles for the merge events. The steering in this section is fundamentally different from driving straight. Negotiating a turn is an active steering exercise, while driving straight might not necessarily be. In practice, keeping the vehicle path straight requires the driver to correct for the inherited vehicle asymmetrical properties, road geometric and tribological differences. However, negotiating a turn the vehicle path is very much determined by the driver tracking skills.

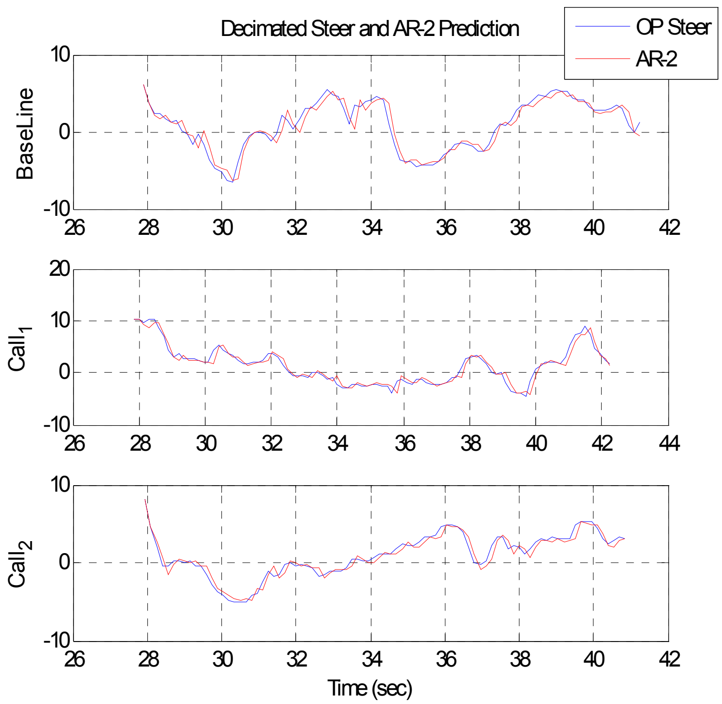

Figure B6. Actual and AR model steering profiles

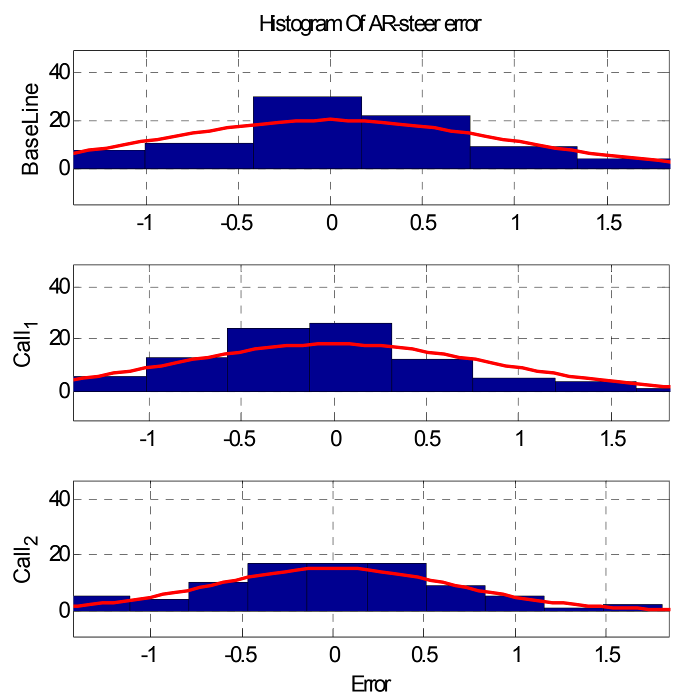

Figure B7. Histogram of residuals for the profiles shown on Figure B6

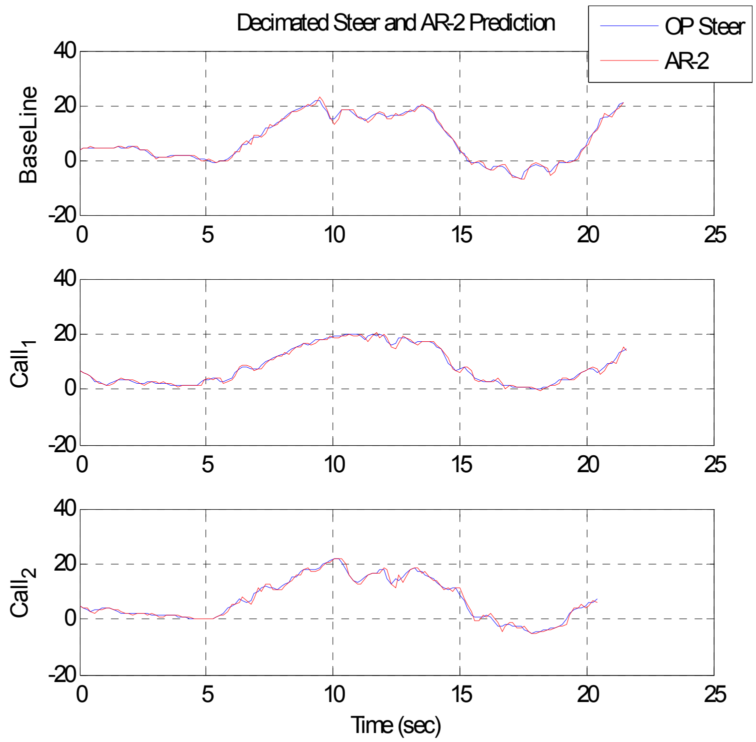

Figure B8. Actual and AR model steering profiles

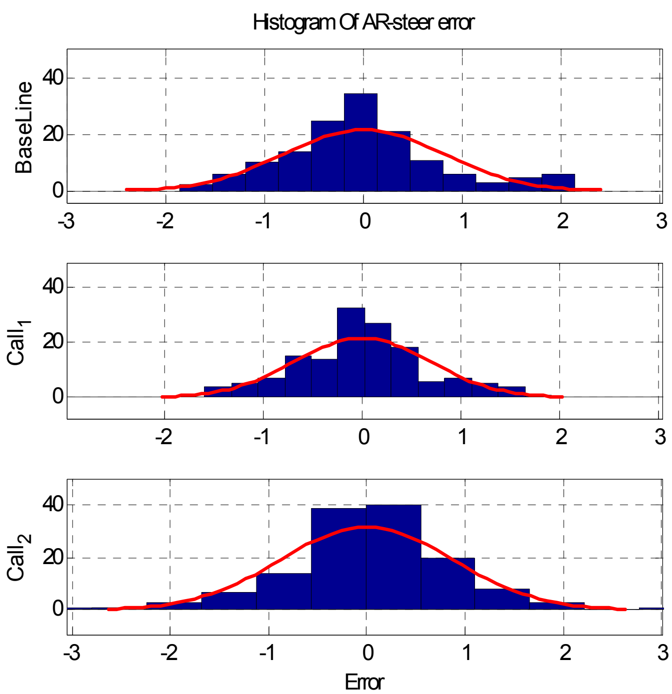

Figure B9. Histogram of residuals for the profiles shown on Figure B8

A.3. Steering Hold and Reversal Measures

The two main steering properties measured for each run are number of steering reversals, and number of steering holds. The computational sequences for these two measures are defined and explained in this section.

Steering Holds: Number of times the handwheel steering is kept within the center position for a period longer than 0.4 sec. Computationally it is determined when the handwheel steering angle and steering rate are less than the corresponding threshold values for a continuous time trace longer than 0.4 sec. The steering angle and angular rates were first filtered with 4 Hz cutoff frequency then decimated to 0.15 sec intervals.

```
function [StrHold, MeanTimeheld, STDTimeheld, prTimeheld] = get_SteerHold(nxr, t0, show_plots)
%
% Computing steering hold
%
%
% Written by Kamel Salaani at VRTC - Cell-phone study
%
global Vnoise dead_band Holdtime Driver_time Sampl_time p1 HoldTime1
%
% finding number of reversals
%
indx  = find(nxr < Vnoise/2 & nxr  > -1*Vnoise/2);
%
nn = length(indx);
%
if length(nxr) == length(indx)
   StrHold = -1;
   MeanTimeheld = -1;
   STDTimeheld = -1;
   prTimeheld = -1;
   return
end
%
StrHold = 0;
tc = 0;
j  = 1;
for i=1:(nn-1)
   if (indx(i)+1) ~= indx(i+1)
      if tc ~= 0
         Timeheld(j) = tc;
         j = j +1;
      end
     tc = 0;
   else
      tc = tc + Sampl_time;
      if tc > Holdtime && tc < (Holdtime + Sampl_time)
         StrHold = StrHold + 1;
      end
   end
end
```

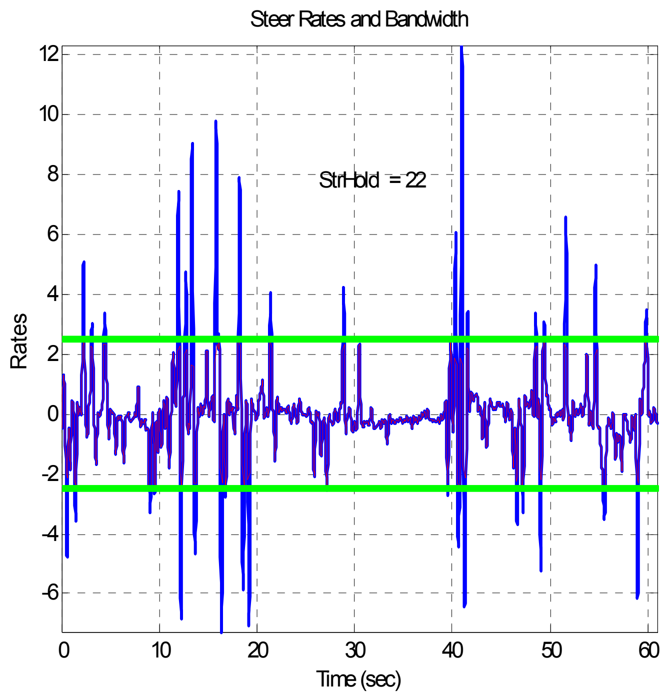

Figure C1. Steering Hold

Steering Reversals: It is the number of times the driver reversed steering directions. It is computed by counting the changes in steering rate signs when steering angle is outside its threshold null value.

```
function [StrRev, SampRate] = get_SteerRev(x, xr, t0, show_plots)
%
% Computing steering reversal
%
%
% Written by Kamel Salaani at VRTC - Cell-phone study
%
global Vnoise dead_band Holdtime Driver_time Sampl_time p1 HoldTime1
%
% finding number of reversals
%
indx  = find( (xr > Vnoise/2 | xr  < -1*Vnoise/2) & ( x > dead_band/2 | x < -1*dead_band/2));
%
nn = length(indx);
StrRev = 1;
for i=1:(nn-1)
   if (xr(indx(i))*xr(indx(i+1)) < 0)
      StrRev = StrRev + 1;
   end
end
```

A.4 Brake and Accelerator Pedals

Brake Pedal: The brake pedal measures consist of number of times the brake pedal was activated, cumulative time of brake activation, and maximum brake pedal force. Figure D1 shows a typical profile of brake activities for the car-following segment. The code to compute these measures is included next.

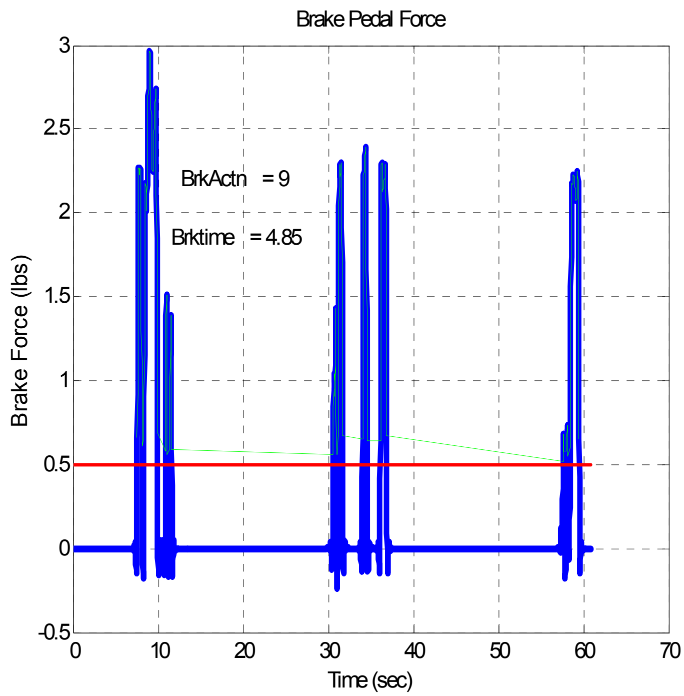

Figure D1. Brake Pedal Measures.

```
function [BrkActn, Brktime, BrkMax]   = get_BrakeActivity(BrakeP, t0, show_plots_brk);
%
% this is just to compute entropy
%
global Vnoise dead_band Holdtime Driver_time Sampl_time p1 HoldTime1
global Brake_Threshold Brake_Holdtime
%
BrkMax = max(BrakeP);
Brktime = 0;
BrkActn  = 0;
%
indx = find( BrakeP > Brake_Threshold);
if isempty('indx')
   return
end
%
nn = length(indx);
tc = 0;
j  = 1;
for i=1:(nn-1)
   if (indx(i)+1) ~= indx(i+1)
      if tc ~= 0
         Timeheld(j) = tc;
         j = j +1;
      end
     tc = 0;
   else
      tc = tc + Sampl_time;
      if tc > Brake_Holdtime && tc < (Brake_Holdtime + Sampl_time)
```

```
            BrkActn = BrkActn + 1;
        end
    end
end
%
if exist('Timeheld')
    Brktime = sum(Timeheld);
end
```

Accelerator Pedal: **The measures consist of number of times the accelerator is held at a constant level and its corresponding cumulative time, the number of times the accelerator was released and its corresponding cumulative time, the standard deviation of pedal position, and the standard deviation of pedal position rates. The following Matlab function is written to compute these measures.**

function [AccPSTD, AccVSTD, AccHold, AcceltimeH, AccRel, AcceltimeR] = get_AccelActivity(AccelPF, t0, show_plots_acc)

```
%
% this is just to compute entropy
%
global Vnoise dead_band Holdtime Driver_time Sampl_time p1 HoldTime1
%
global AccelV_Threshold AccelP_Threshold Accel_Holdtime
%
% initialize
%
AccRel = 0;
AccHold = 0;
AcceltimeR = 0;
AcceltimeH = 0;
%
AccPSTD = std(AccelPF);
%
AccelVF = diff(AccelPF)/Sampl_time;
AccelVF = [0 AccelVF']';
%
AccVSTD = std(AccelVF);
%
AccHold = 0;
AccRel  = 0;
%
% Find the index for release
%
indxR = find( AccelPF < AccelP_Threshold);
if isempty('indxR')
    indxR = 0;
end
%
indxH = find( AccelVF < AccelV_Threshold & AccelVF > -1*AccelV_Threshold & AccelPF > AccelP_Threshold);
if isempty('indxH')
    indxH = 0;
end
%
% counting number of releases
%
nn = length(indxR);
tc = 0;
j  = 1;
for i=1:(nn-1)
    if (indxR(i)+1) ~= indxR(i+1)
        if tc ~= 0
            TimeheldR(j) = tc;
            j = j +1;
        end
       tc = 0;
    else
        tc = tc + Sampl_time;
```

```
        if tc > Accel_Holdtime && tc < (Accel_Holdtime + Sampl_time)
            AccRel = AccRel + 1;
        end
    end
end
%
if exist('TimeheldR')
    pR = find(TimeheldR > Accel_Holdtime);
    AcceltimeR = sum(TimeheldR(pR));
end
%
% computing hold time
%
nn = length(indxH);
tc = 0;
j  = 1;
for i=1:(nn-1)
    if (indxH(i)+1) ~= indxH(i+1)
        if tc ~= 0
            TimeheldH(j) = tc;
            j = j +1;
        end
       tc = 0;
    else
        tc = tc + Sampl_time;
        if tc > Accel_Holdtime && tc < (Accel_Holdtime + Sampl_time)
            AccHold = AccHold + 1;
        end
    end
end
%
if exist('TimeheldH')
    pH = find(TimeheldH > Accel_Holdtime);
    AcceltimeH = sum(TimeheldH(pH));
end
```

A.5. Coherence Calculations for Car-Following Tests

Coherence gives us a measure of how well a driver can follow another vehicle. The speed curves of the two vehicles may be thought of as a primary signal (lead car) and a response curve (following car). A weighted average of the coherence function over a band of frequencies is used, following the example of K. Brookhuis *et al.*[2] and using the equations derived by Bendat and Piersol[3].

The time-series speed data for both vehicles should cover a long enough period of time to provide good definition of the primary frequency – at least twice the "period", defined as the reciprocal of the primary frequency. If the lead vehicle's speed curve is a sine wave, as in the case of some of the data provided in the tests from the National Advanced Driving Simulator (***NADS***), the primary frequency is known and well-defined. If not, it must be estimated by computing the power spectrum of the lead car's speed curve and finding the frequency which has maximum power.

Designate the power spectrum value for the lead car at a frequency f_i to be $P_{xx}(f_i)$, that of the following car to be $P_{yy}(f_i)$, and the complex-valued ***cross-spectral density*** function of the two signals as $P_{xy}(f_i)$. Also, denote the ***magnitude squared coherence*** between the two signals as $C_{xy}(f_i)$. The periodogram in each case is formed by first ***de-trending*** the data by subtracting the mean speed of the lead vehicle, then dividing the data into two or more overlapping windows and using the Hanning (cosine squared) ***windowing*** function on the data in each window to reduce edge effects. At each frequency f_i,

$$C_{xy}(f_i) = \frac{|P_{xy}(f_i)|^2}{P_{xx}(f_i)P_{yy}(f_i)}, \qquad \text{(E1)}$$

where $|P_{xy}(f_i)|^2$ is the squared magnitude of the cross-spectral density function.

To get the ***weighted coherence***, use a band of frequencies $f_1, f_2, \ldots, f_n$ which includes the primary frequency and for which the coherence value is above some selected cut-off value, say 0.35 as recommended by K. Brookhuis *et al*[1]. The weight $W(f_i)$ for the coherence value at each frequency f_i is

$$W(f_i) = \frac{P_{xx}(f_i)}{\sum_{i=1}^{n} P_{xx}(f_i)}, \qquad \text{(E2)}$$

---

[2] Brookhuis, K., DeWaard, D., and Mulder, B. (1994) "Measuring driving performance by car-following in traffic.", *Ergonomics*, **37**, 427-434.

[3] Bendat, J.S., and Piersol, A.G. (1986) "Random Data: Analysis and Measurement Procedures." New York (NY): Wiley.

so that the sum of the weights is unity. This will give a weighted average for coherence over the selected frequency band. The value for the weighted coherence is

$$Coh = \sum_{i=1}^{n} W(f_i) \bullet C_{xy}(f_i) \qquad \text{(E3)}$$

with estimated standard deviation

$$\sigma_{coh} = (1 - Coh) \bullet \sqrt{\frac{2}{N_w \bullet n \bullet coh}}\,, \qquad \text{(E4)}$$

where N_w is the number of windows used. Since the weights and the coherence values fall off rapidly away from the primary frequency, the width of the frequency band is somewhat arbitrary, and using a slightly greater number of frequencies than necessary will not significantly affect the value of the coherence.

Following Bendat and Piersol, the ***modulus*** or amplitude ratio is the sum of the ratios of the magnitude of the cross-spectral density to the power spectrum density of the lead vehicle, that is,

$$M = \sum_{i=1}^{n} \frac{|P_{xy}(f_i)|}{P_{xx}(f_i)}\,,$$

with $$\sigma_M = \sqrt{\frac{1 - Coh}{2 \bullet N_w \bullet n \bullet Coh}}\,, \qquad \text{(E5)}$$

and the ***phase difference*** between the two signals is

$$\phi = \frac{T}{2\pi} \tan^{-1}\left(\frac{\sum_{i=1}^{n} IPxy(f_i)}{\sum_{i=1}^{n} RPxy(f_i)} \right), \qquad \text{with}$$

$$\sigma_\phi = \frac{\sigma_M \bullet T}{2\pi}\,, \qquad \text{(E6)}$$

where ***$IP_{xy}(f_i)$*** is the ***imaginary*** component of the cross-spectral density at frequency ***f_i***, ***$RP_{xy}(f_i)$*** is the ***real*** component, and ***T*** is the ***period*** of the lead car's speed curve. In the case where the lead car's speed does not follow a sine wave, the period is the reciprocal of the primary frequency (frequency with highest spectral power). The phase may be thought of as a "delay" between the two vehicles' speed curves, and is converted above from radians to seconds by multiplying by the period and dividing by ***2π*** .

Another measure of interest is the ***RMS deviation*** between the two curves, defined as

$$\Delta V_{RMS} = \sqrt{\frac{\sum_{i=1}^{n_t} \left(V_{Li} - V_{Fi}\right)^2}{n_t}}, \qquad \text{(E7)}$$

where $\boldsymbol{n_t}$ is the total number of points in the series, $\boldsymbol{V_{Li}}$ is the lead car's speed at point $\boldsymbol{i}$, and $\boldsymbol{V_{Fi}}$ is the following car's speed recorded at the same time. The speed values are filtered before processing to reduce the effect of high-frequency noise on the values, especially the RMS deviation.

9.0 APPENDIX B: INFORMED CONSENT DOCUMENT

Project Title: Assessment of Driver Distraction Relating to Wireless Voice Communications Device Interface

Investigator(s): Ginger Watson, Ph.D., Yiannis Papelis, Ph.D., Shannon Guest, Ph.D., Julie Qidwai, BS,
Sue Ellen Salisbury, BS, Cheryl Benn, BS, Leah Teuwen, BS, Sarah Miller BS

PURPOSE

This study involves driving research. The purpose of this research is to compare the effects of three different types of wireless phones on driving performance in the National Advanced Driving Simulator (NADS). We are inviting you to participate in this research study because you are 18-25, 30-45 or 50-60 years old, have a valid, unrestricted U.S. driver's license (except for corrective eyeglasses and contact lenses), have a minimum of two years driving experience, drive at least 3,000 miles per year, are in good general health, and have been using your wireless phone on average at least 7 times per week for at least 6 months.

If you agree to participate, you will be asked to sign an Informed Consent Document indicating that you have read the following form and have been given the goals of this study.

PROCEDURES

Your participation today will take approximately 3 hours.

Upon arrival at the simulator facility, you will be briefed on the experimental procedure and participant rights, and be asked to read and sign this Informed Consent Document. Upon completion of the form, you will be asked to complete a questionnaire that focuses on your driving experience and wireless phone usage. Then the researcher will provide an overview of what you will drive today, train you on the usage of the wireless phone that will be used in this study, and provide practice with the telephone tasks that you will complete in this study. The researcher will then apply 4 small stickers to your face to allow tracking of your head and eyes while driving. The experimenter will then escort you to the simulator bay, brief you on the simulator cab, and explain the study path. After a short practice drive that will help you become familiar with the simulator environment and the usage of the wireless phone, you will drive for approximately 2 hours and complete a few short questionnaires regarding your experience in this study.

The simulator contains sensors that measure certain aspects of vehicle operation, vehicle motion, and driver actions. The system also contains video cameras that capture images of driver actions (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.

<u>All driving trials will be recorded on video.</u>

RISKS

The possible risks associated with participating in this research project are as follows. The risk to you, if you drive the simulator, is discomfort associated with simulator disorientation. Previous studies with similar driving intensities and simulator setups have produced mild to moderate disorientation effects such as slight uneasiness, warmth, or eyestrain for a small number of subjects. These effects are believed to last for only a short time, usually 10-15 minutes, after leaving the simulator. If you ask to quit driving as a result of discomfort, you will be allowed to quit at once. You will be asked to sit and rest before leaving, while consuming a beverage and a snack. This time may coincide with completion of the questionnaires. There is no evidence that driving ability is hampered in any way; therefore, if you show little or no signs of discomfort, you should be able to drive home. If you experience anything other than slight effects, transportation will be arranged through other means. This seems unlikely since studies in similar devices have shown only mild effects in recent investigations and evidence contends that symptoms decrease rapidly after simulator exposure is complete. If you are driven home, a follow-up call will be made 24 hours later to ensure that you are not feeling ill effects. Most people enjoy driving in the simulator and do not experience any discomfort.

An experimenter will be present in the back seat of the simulator cab with you to ensure your safety while driving the simulator.

BENEFITS

There may be no personal benefit to you for participating in this study. However it is hoped that this study will provide the University of Iowa, the National Highway Traffic Safety Administration (NHTSA), and the public at large with useful information on the safety of using a wireless phone while driving.

COSTS AND COMPENSATION

You will not have any costs for participating in this research project.

Compensation for participating in this study is partially based on your performance in this study. No matter how well or poorly you drive, you will be paid $30 for your participation. In addition, a total of $24 is available to you if you perform perfectly in the driving and phone tasks. However, the tasks are difficult, and it is not expected that many participants will receive the entire $24 performance bonus.

Compensation for driving performance will work like this:

In addition to your base pay of $30, you will have the opportunity to earn additional incentive pay based on your performance on driving and wireless phone tasks. Generally, you will earn incentive money for driving safely, attentively, and smoothly while completing phone tasks accurately and quickly. Unsafe driving, including speeding, reckless driving, and collisions that could have been avoided will result in monetary penalties from the incentive, not from your base payment. For example, extreme steering responses or excessively hard braking will be considered unsafe responses.

The monetary rewards and penalties are based on a total number of points allocated for each task during each 12-15 minute drive. Incentive pay will range between $0 and $8 per drive. The following tables present the tasks and the total number of points possible for each. At the end of each drive, your point total will be multiplied by a pay rate that determines the actual amount of money received. The total of your incentive pay will never be negative. No incentive will be given for practice drives.

You will drive on one of two different kinds of roads in this study, either an urban arterial or a freeway. The performance criteria are different for the two different types of roads and are detailed in the following tables:

Urban Arterial

Task	Points Per Drive	You receive money for:
DRIVING		
Vehicle slowing unexpectedly or cutting in	6	Safe and timely response
Traffic signal intersection performance	3	Safely stopping on yellow onset or clearing the intersection before the red onset
Time to complete drive	+2 to –2	Timely completion of the drive
Speeding	-1	Keeping speed within the posted maximum & minimum speed limit
Unsafe/reckless behavior	-2	Driving safely and attentively
Collision avoidance	-5	Avoiding collisions
PHONE		
Phone conversation task performance	4	Correctly answering sentences and correctly recalling target words
Phone answering speed	1	Answering the phone quickly when it rings
Phone dialing speed	1	Quickly dialing phone number without making errors
OTHER		
Target detection	9	Correct target detection

Freeway

Task	Points Per Drive	You receive money for:
DRIVING		
Car Following	9	Maintaining constant following distance
Vehicle slowing unexpectedly or cutting in	6	Safe and timely response
Merging in traffic	3	Safely stopping on yellow onset or clearing the intersection before the red onset
Time to complete drive	+2 to –2	Timely completion of the drive
Speeding	-1	Keeping speed within the posted maximum & minimum speed limit
Unsafe/reckless behavior	-2	Driving safely and attentively
Collision avoidance	-5	Avoiding collisions
PHONE		
Phone conversation task performance	4	Correctly answering sentences and correctly recalling target words
Phone answering speed	1	Answering the phone quickly when it rings
Phone dialing speed	1	Quickly dialing phone number without making errors

The experimenter will discuss these performance criteria with you in greater detail, and any questions you have regarding driving performance and compensation for performance will be answered before you start driving.

In addition, if you are in need of childcare in order to participate in this study, you may be reimbursed up to $3 per hour for a maximum of $10 for your participation today.

FUNDING
The National Highway Traffic Safety Administration (NHTSA) is funding this research study. This means that the University of Iowa is receiving payments from NHTSA to support the activities that are required to conduct the study. No one on the research team will receive a direct payment or an increase in salary from NHTSA for conducting this study.

CONFIDENTIALITY

Records of participation in this research project will be kept confidential to the extent permitted by law. However, federal government regulatory agencies and the University of Iowa Institutional Review Board (a committee that reviews and approves research studies) may inspect and copy records pertaining to this research. It is possible that these records could contain information that personally identifies you, especially where video data are concerned. Participants in the study will be given a subject number to which they will be referred to, thereby reducing personal identification of participants. In the event of any report or publication from this study, your name and responses to questionnaire items will not be disclosed. Results will be reported in a summarized manner in such a way that you cannot be identified. Please note that general health information obtained from you during the screening process is not retained in study records.

USE OF INFORMATION COLLECTED

The **engineering data** collected and recorded in this demonstration (including any performance scores based on these data) will be analyzed along with data gathered from other participants. NHTSA may publicly release these data in final reports or other publications or media for scientific (e.g., professional society meetings), educational (e.g., educational campaigns for members of the general public), outreach (e.g., nationally televised programs highlighting traffic safety issues), legislative (e.g., data provided to the U.S. Congress to assist with law-making activities), or research purposes (e.g., comparison analyses with data from other studies). Engineering data may also be released individually or in summary with that of other participants, but will not be presented in a way that permits personal identification, except when presented in conjunction with video data.

The **video data** (video image data recorded during your drive) recorded in this demonstration includes your video-recorded likeness and all in-vehicle audio including your voice (and may include, in some views, superimposed performance score information). Video and in-vehicle sounds will be used to examine your driving performance and other task performance while driving. NHTSA may publicly release video image data (in continuous video or still formats) and associated audio data, either separately or in association with the appropriate engineering data for scientific, educational, outreach, legislative, or research purposes (as noted above).

VOLUNTARY PARTICIPATION

Taking part in this research study is voluntary. You may choose not to take part at all. If you agree to participate in this study, you may stop participating at any time. If you decide not to take part, or if you stop participating at any time, your decision will not result in any penalty or loss of benefits to which you may otherwise be entitled.

Under certain circumstances, your participation in this research study may be ended without your consent. This might happen if you fail to operate the research vehicle in accordance with the instructions provided by NHTSA and NADS staff.

RESEARCH RELATED INJURY

In the event of research related injury, medical treatment is available at the University of Iowa Hospitals and Clinics. No compensation for treatment of research related injury is available from the University of Iowa unless the injury is proven to be the direct result of negligence by a University employee. Should a research-related injury occur, the cost of treatment must be paid for by you and/or your medical or hospital insurance carrier.

QUESTIONS:

Questions are encouraged. If you have any questions about this research project, please contact: Ginger Watson, (319) 335-4679. If you have questions about the rights of research subjects or research related injury, please contact the Human Subjects Office, 300 College of Medicine Administration Building, The University of Iowa, Iowa City, Iowa, 52242, (319) 335-6564, or e-mail irb@uiowa.edu.

DISPOSITION OF INFORMED CONSENT:

Investigators at the University of Iowa will retain a signed copy of this Informed Consent form. A copy of this form will also be offered to you at the time you begin your participation in this study.

INFORMED CONSENT STATEMENT:

Your signature indicates that you have read this document and that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

I, ______________________________, VOLUNTARILY CONSENT TO PARTICIPATE.

Signature	Date

VIDEO DATA RELEASE STATEMENT:

I, _________________________, grant permission to the National Highway Traffic Safety Administration (NHTSA) and its contractors to use, publish or otherwise disseminate 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 scientific, educational, outreach, legislative, and research purposes or to demonstrate the fidelity of the National Advanced Driving Simulator. 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.

I may withdraw the permissions granted in this video data release by contacting Ginger Watson at (319) 335-4679 or g-watson@uiowa.edu. Withdrawal of this video data release may only be accomplished **within seven days (1 calendar week)** of the date recorded on this consent. The ability to withdraw video data does not extend to the ability to withdraw engineering data.

In the event of court action, NHTSA may not be able to prevent release of your name or other personal identifying information.

Signature	Date

INVESTIGATOR STATEMENT:

I have discussed the above points with the subject or, where appropriate, with the subject's legally authorized representative, using a translator when necessary. It is my opinion that the subject understands the risks, benefits, and procedures involved with participation in this research study.

Signature of Investigator	Date

Initials of witness	Date

10.0 APPENDIC C: NADS DRIVING SURVEY

Study # Wireless I, Phase I_______
Date ________________________
Participant # __________________
Trail # ______________________
Treatment:____________________

NADS Driving Survey

As part of this study, it is useful to collect information describing each participant. The following questions ask about you and your health, personal vehicle, and driving patterns. Please read each question carefully, marking only one response unless otherwise indicated. If something is unclear, ask the research assistant for help. Your participation is voluntary and you have the right to omit questions you find offensive.

Background Information

1) What is your birth date? ______/_____/______

Month / Day /Year

2) What is your gender?

- ☐ Male
- ☐ Female

3) What is the highest level of education you have completed? (Check only one.)

- ☐ Primary School
- ☐ High School Diploma or Equivalent
- ☐ Technical School or Equivalent
- ☐ Some College or University
- ☐ Associate’s Degree
- ☐ Bachelor’s Degree
- ☐ Some Graduate or Professional School
- ☐ Graduate or Professional Degree

4) How old were you when you started to drive?

_____ years of age

5) For which of the following vehicles do you currently hold a valid driver’s license? (Check all that apply.)

Vehicle type	Year when FIRST licensed (may be approximate)	Country and state of license (e.g., USA—Iowa)
☐ Car		
☐ Motorcycle		
☐ Truck		
☐ Other:		

6) How often do you drive? (Check the most appropriate category.)

- ☐ Do not drive
- ☐ Less than once weekly
- ☐ At least once weekly
- ☐ At least once daily

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

_____

8) In which environment do you most typically drive? (Check only one.)

- ☐ Rural highway (e.g., Route 1, Route 6, or Route 218)
- ☐ Small town (e.g., Solon, West Branch)
- ☐ Suburban (e.g., Iowa City, Cedar Rapids)
- ☐ City (e.g., Des Moines, Davenport)
- ☐ High density city (e.g., Chicago, Los Angeles)
- ☐ Highway/freeway (e.g., Interstate 80)

9) What speed do you typically drive on the highway when the speed limit is:

55? _

65? _

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

Primary

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

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

Year:

Secondary

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

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

Year:

11) Within the past five years, how many moving violations have you received?

_____

12) Have you ever participated in any special driving schools (e.g., AARP or insurance courses, racing school, or as part of law enforcement training)?

- ☐ No
- ☐ Yes (Please describe.)____

13) Have you participated in other driving studies?

- ☐ No

☐ Yes

If yes, briefly describe what you did in each study.

What vehicle was used for these studies? (Check all that apply.)	year?	.... many studies?
☐ The National Advanced Driving Simulator only............	_______	______
☐ The Iowa Driving Simulator only..................................	_______	______
☐ Another simulator – only...	_______	______
☐ Actual car – only..	_______	______
☐ Both - actual car and another simulator.......................	_______	______
☐ Both - actual car and the Iowa Driving Simulator..........	_______	______
Brief Description:____		
____		
____		

14) Have you consumed any alcohol or other drugs within the last 12 hours? (Check only one.)

☐ No

☐ Yes

15) Have you taken any medication(s) in the past 48 hours? (If yes, Please list all.)

☐ No

☐ Yes

_____

_____

16) On a scale of 0 to 10, how often do you experience motion sickness?

Never										**Always**
0	1	2	3	4	5	6	7	8	9	10

a) On a scale from 0 to 10, how severe are the symptoms when you experience motion sickness?

Minimal										**Incapacitated**
0	1	2	3	4	5	6	7	8	9	10

11.0 APPENDIX D: PARTICIPANT INSTRUCTION HANDOUT

INSTRUCTIONS

This task will simulate a phone conversation. You will perform this task using a portable phone while driving the simulator. For this task, you will listen to a number of sentences and answer specific questions about the sentences. Each sentence will have three parts, including: a subject, a verb, and, an object. For example, if you hear the sentence:

The boy hit the ball.

"boy" is the subject, "hit" is the verb, and " ball" is the object.

In the following sentence please identify the subject, the verb, and the object:

The frog ate the fly.

>

Your task will have two parts. First, you will be asked to determine whether the sentence makes sense or not. In this context, "makes sense" means the action expressed in the sentence could happen. The examples presented previously make sense because a boy could hit a ball, and, a frog could eat a fly. An example of a nonsensical sentence or one that does not make sense, is:

The dog ate the noise.

This sentence is nonsensical because it cannot happen.

Immediately after you hear a sentence, you should try to decide if it makes sense and respond as quickly as possible. If the sentence makes sense, you will say "YES". If the sentence does not make sense, you will say "NO". You will have a limited amount of time to respond to each sentence, after which the next sentence will begin, whether or not you have responded.

Sentences will be presented in groups of 4. The second part of your task is to remember a specified word in each sentence, so that you can say these words aloud when prompted by the computer at the end of a group of sentences. The specified word will either be the subject of the sentence, or the object. You will be told which word to recall before each group of sentences. You should remember the specified word even if the sentence does not make sense. When all sentences in the group have been completed, you will be prompted with "NOW," to indicate that you should say the specified words aloud as quickly as possible. You do not need to say them in the order presented. You should just try to recall as many of the subjects or objects as possible.

After you hear the prompt "NOW," you will be given a limited amount of time to say the cue words (subjects or objects) aloud. Then the next group of sentences will be presented. During each phone call, you will be given six groups of sentences without interruption. The cue word type (subject or object) will not change during a phone call. Please do not ask questions or say anything other than the answers to the questions during this time, unless it is urgent.

To summarize, one phone call will consist of six groups of sentences, each of which will have 4 sentences. Before each group of sentences, you will be prompted to be ready, and will be reminded whether you are to recall the subjects or the objects for that group of sentences. You will then hear the group of 4 sentences, one at a time. As soon as possible after each sentence, you will say "YES," or "NO" to indicate whether or not the sentence makes sense. After you have had time to respond to the last sentence, you will be prompted with "NOW," which is the signal for you to say aloud the words you were instructed to recall, either the subjects or the objects. After you have been given time to say the subjects or objects aloud, you will be prompted again to be ready for the next group of sentences to start.

After six groups of sentences, you will hear "STOP." This indicates the end of the call, and you should hang up.

Here are two examples of two consecutive groups of sentences. You can see your responses in capital letters, and will hear them as a male voice. The first example has subjects as the cue word. The second example has objects as the cue word.

Ready.
Recall <u>Subjects.</u>

The boy drank the water. .... YES.
The girl swallowed the dream. .... NO.
The fish ate the ceiling. .... NO.
The shortstop caught the ball. .... YES.

Now.
BOY, GIRL, FISH, SHORTSTOP.

Ready.
Recall <u>Subjects.</u>

The <u>officer</u> caught the robber. .... YES.
The <u>goat</u> ate the ocean. .... NO.
The <u>cyclist</u> rode the bicycle. .... YES.
The <u>maid</u> boiled the rock. .... NO.

Now.
OFFICER, GOAT, CYCLIST, MAID.
Stop.

And now for example two:

Ready.
Recall <u>Objects.</u>

The bear ate the <u>fish</u>.		YES.
The king wore the <u>verb</u>.		NO.
The neighbor entered the <u>paint</u>.	NO.	
The girl rode the <u>horse</u>.		YES.

Now.
FISH, VERB, PAINT, HORSE.

Ready.
Recall <u>Objects.</u>

The radio played the <u>water</u>.	NO.	
The hen laid the <u>egg</u>.		YES.
The dog chased the <u>tree</u>.		NO.
The knife sliced the <u>bread</u>.	YES.	

Now.
WATER, EGG, TREE, BREAD.
Stop.

Do you have any questions?

12.0 APPENDIX E: NADS SIMULATOR SICKNESS QUESTIONNAIRE

SIMULATOR SICKNESS QUESTIONNAIRE

....

Directions: Circle one option for each symptom to indicate whether that symptom applies to you right now.

1. General Discomfort.................... None................ Slight............... Moderate.......... Severe
2. Fatigue .... None................ Slight............... Moderate.......... Severe
3. Headache .... None................ Slight............... Moderate.......... Severe
4. Eye Strain .... None................ Slight............... Moderate.......... Severe
5. Difficulty Focusing .... None................ Slight............... Moderate.......... Severe
6. Salivation Increased .... None................ Slight............... Moderate.......... Severe
7. Sweating .... None................ Slight............... Moderate.......... Severe
8. Nausea .... None................ Slight............... Moderate.......... Severe
9. Difficulty Concentrating .... None................ Slight............... Moderate.......... Severe
10. "Fullness of the Head" .... None................ Slight............... Moderate.......... Severe
11. Blurred Vision .... None................ Slight............... Moderate.......... Severe
12. Dizziness with Eyes Open .... None................ Slight............... Moderate.......... Severe
13. Dizziness with Eyes Closed ...... None................ Slight............... Moderate.......... Severe
14. *Vertigo .... None................ Slight............... Moderate.......... Severe
15. **Stomach Awareness .... None................ Slight............... Moderate.......... Severe
16. Burping .... No .... Yes .... If yes, no. of times ________
17. Vomiting .... No .... Yes .... If yes, no. of times ________
18. Other ____________________________________

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

13.0 APPENDIX F: NADS REALISM SURVEY

Study: Wireless I, Phase I
Date _______________
Participant #__________
Trial #_______________
Treatment: Highway

REALISM SURVEY

For each of the following items, circle the number that best indicates how closely the simulator resembles an actual car in terms of appearance, sound, and response. If an item is not applicable, circle NA.

	General Driving	Not at all realistic						Completely Realistic	
1	Response of the seat adjustment levers	0	1	2	3	4	5	6	NA
2	Response of the mirror adjustment levers	0	1	2	3	4	5	6	NA
3	Response of the door locks and handles	0	1	2	3	4	5	6	NA
4	Response of the fans	0	1	2	3	4	5	6	NA
5	Response of the gear shift	0	1	2	3	4	5	6	NA
6	Response of the brake pedal	0	1	2	3	4	5	6	NA
7	Response of accelerator pedal	0	1	2	3	4	5	6	NA
8	Response of the speedometer	0	1	2	3	4	5	6	NA
9	Response of the steering wheel while driving straight	0	1	2	3	4	5	6	NA
10	Response of the steering wheel while driving on curves	0	1	2	3	4	5	6	NA
11	Feel when accelerating	0	1	2	3	4	5	6	NA
12	Feel when braking	0	1	2	3	4	5	6	NA
13	Feel when passing other cars	0	1	2	3	4	5	6	NA
14	Feel when driving straight	0	1	2	3	4	5	6	NA
15	Feel when driving on curves	0	1	2	3	4	5	6	NA
16	Ability to read road and warning signs	0	1	2	3	4	5	6	NA
17	Appearance of roads and road markings	0	1	2	3	4	5	6	NA
18	Appearance of signs	0	1	2	3	4	5	6	NA
19	Appearance of car interior	0	1	2	3	4	5	6	NA
20	Appearance of roadside scenery	0	1	2	3	4	5	6	NA
21	Appearance of other vehicles	0	1	2	3	4	5	6	NA
22	Appearance of rear-view mirror image	0	1	2	3	4	5	6	NA
23	Sound of the car	0	1	2	3	4	5	6	NA
24	Sound of other vehicles	0	1	2	3	4	5	6	NA
25	Overall feel of the car when driving	0	1	2	3	4	5	6	NA
26	Overall similarity to real driving	0	1	2	3	4	5	6	NA
	Highway Driving								
27	Feel of approximate speed when driving 65 mph	0	1	2	3	4	5	6	NA
28	Appearance of rural scenery	0	1	2	3	4	5	6	NA
29	Ability to respond to other vehicles	0	1	2	3	4	5	6	NA
30	Ability to follow lead vehicle	0	1	2	3	4	5	6	NA
31	Ability to keep straight in your lane	0	1	2	3	4	5	6	NA
32	Ability to respond to traffic	0	1	2	3	4	5	6	NA
33	Ability to stop the vehicle	0	1	2	3	4	5	6	NA
34	Ability to merge with traffic	0	1	2	3	4	5	6	NA
35	Overall appearance of driving scenes	0	1	2	3	4	5	6	NA

14.0 APPENDIX G: WIRELESS PHONE POST-DRIVE SURVEY

Study: Wireless I, Phase I
Urban Freeway ....
Date _______________

Participant # _________

NADS Wireless Phone Post-Drive Survey

The following questions ask about your use of and opinions related to wireless phones. Please read each question carefully, marking only one response unless otherwise indicated. If something is unclear, ask the research assistant for help. Your participation is voluntary, and you have the right to omit questions you choose not to answer.

Part 1: Your Experience Today

Hand-Held Condition

1) How difficult or easy did you find each of the following tasks while using the **Hand-Held wireless phone for dialing and conversing** (i.e., listening to sentences and responding) in the study today? (Please check only one box per task.)

	Extremely difficult	Difficult	Slightly difficult	Neutral/not sure	Slightly easy	Easy	Extremely easy
Dialing the phone while driving	☐	☐	☐	☐	☐	☐	☐
Maintaining vehicle within lane while dialing the phone	☐	☐	☐	☐	☐	☐	☐
Maintaining posted speed limit signs while dialing the phone	☐	☐	☐	☐	☐	☐	☐
Carrying on a phone conversation while driving	☐	☐	☐	☐	☐	☐	☐
Carrying on a phone conversation while searching for pedestrians	☐	☐	☐	☐	☐	☐	☐
Maintaining vehicle within lane while conversing	☐	☐	☐	☐	☐	☐	☐
Maintaining posted speed limit signs while conversing	☐	☐	☐	☐	☐	☐	☐
Hearing and understanding what the person on the other end of the line is saying	☐	☐	☐	☐	☐	☐	☐

Headset Hands-Free Condition

2) How difficult or easy did you find each of the following tasks while using the **phone for voice dialing using digits** and the **headset for Hands-Free conversing** (i.e., listening to sentences and responding) in the study today? (Please check only one box per task.)

	Extremely difficult	Difficult	Slightly difficult	Neutral/not sure	Slightly easy	Easy	Extremely easy
Dialing the phone while driving	☐	☐	☐	☐	☐	☐	☐
Maintaining vehicle within lane while dialing the phone	☐	☐	☐	☐	☐	☐	☐
Maintaining posted speed limit signs while dialing the phone	☐	☐	☐	☐	☐	☐	☐
Carrying on a phone conversation while driving	☐	☐	☐	☐	☐	☐	☐
Carrying on a phone conversation while searching for pedestrians	☐	☐	☐	☐	☐	☐	☐
Maintaining vehicle within lane while conversing	☐	☐	☐	☐	☐	☐	☐
Maintaining posted speed limit signs while conversing	☐	☐	☐	☐	☐	☐	☐
Hearing and understanding what the person on the other end of the line is saying	☐	☐	☐	☐	☐	☐	☐

Enhanced Hands-Free Condition

3) How difficult or easy did you find each of the following tasks while using the **Hands-Free wireless phone for voice dialing using digits** and the **Hands-Free (using external speaker kit) for conversing** (i.e., listening to sentences and responding) in the study today? (Please check only one box per task.)

	Extremely difficult	Difficult	Slightly difficult	Neutral/not sure	Slightly easy	Easy	Extremely easy
Dialing the phone while driving	☐	☐	☐	☐	☐	☐	☐
Maintaining vehicle within lane while dialing the phone	☐	☐	☐	☐	☐	☐	☐
Maintaining posted speed limit signs while dialing the phone	☐	☐	☐	☐	☐	☐	☐

	Extremely difficult	Difficult	Slightly difficult	Neutral/not sure	Slightly easy	Easy	Extremely easy
Carrying on a phone <u>conversation</u> while driving	☐	☐	☐	☐	☐	☐	☐
Carrying on a phone <u>conversation</u> while searching for pedestrians	☐	☐	☐	☐	☐	☐	☐
Maintaining vehicle within lane while <u>conversing</u>	☐	☐	☐	☐	☐	☐	☐
Maintaining posted speed limit signs while <u>conversing</u>	☐	☐	☐	☐	☐	☐	☐
Hearing and understanding what the person on the other end of the line is saying	☐	☐	☐	☐	☐	☐	☐

4) Of the two phone **<u>dialing methods</u>** you were instructed to use in this study, which did you prefer? (Please check one.)

☐ Manual dialing

☐ Voice digit dialing

Why? ____

____

5) Which phone **<u>conversation (talking) method</u>** did you prefer? (Please check one.)

☐ Hand-Held conversation

☐ Hands-Free conversation with ear bud / headset

☐ Hands-Free conversation with external accessory speaker

Why? ____

____

6) How did the conversation task in the study today compare with the mental effort, or concentration, required by your ordinary phone conversations? (Please check one.)

Much more mental effort in this study	More mental effort	Slightly more mental effort	Neutral/not sure	Slightly less mental effort	Less mental effort	Much less mental effort in this study
☐	☐	☐	☐	☐	☐	☐

Please explain your rating. ____

____

Part 2: Personal Wireless Phone Experience

7) How long have you been using a wireless phone?

_________years ________months

8) What brand and model is your current wireless phone?

Brand ______________________

Model ______________________

9) During a **typical day**, how much time do you spend driving?

Hours: ....

10) During a **typical day**, how much time do you spend using the wireless phone **while driving**?

Hours: ....

11) Does your current wireless phone have any of the following Hands-Free capabilities? (Check all that apply.)

	Does your phone **have this feature (please check only one)**	**If yes**, how frequently do you use this feature?
Optional Hands-Free accessory kit with external speaker	☐ No ☐ Yes ☐ Unsure	☐ Never ☐ Once ☐ Multiple Times ☐ Regularly
Speaker phone capability within the phone itself	☐ No ☐ Yes ☐ Unsure	☐ Never ☐ Once ☐ Multiple Times ☐ Regularly
Voice tag dialing (i.e., dialing by saying a person's name)	☐ No ☐ Yes ☐ Unsure	☐ Never ☐ Once ☐ Multiple Times ☐ Regularly
Voice digit dialing	☐ No ☐ Yes ☐ Unsure	☐ Never ☐ Once ☐ Multiple Times ☐ Regularly
Ear bud / headset capability	☐ No ☐ Yes ☐ Unsure	☐ Never ☐ Once ☐ Multiple Times ☐ Regularly
Other Hands-Free capability	☐ No ☐ Yes ☐ Unsure	☐ Never ☐ Once ☐ Multiple Times ☐ Regularly

12) During a **typical day**, how many **outgoing** calls do you make while driving? (Please check one.)

- ☐ Zero
- ☐ 1-5
- ☐ 6-10
- ☐ 10-14
- ☐ 15 +

13) During a **typical day**, how many **incoming** calls do you receive while driving? (Please check one.)

- ☐ Zero
- ☐ 1-5
- ☐ 6-10
- ☐ 10-14
- ☐ 15 +

14) How often do you use a wireless phone **while driving**? (Please check one.)

- ☐ Less than once weekly
- ☐ At least once weekly
- ☐ Only once daily
- ☐ Several times daily

15) What percentage of your wireless phone calls are work-related? (Please check one.)

- ☐ Zero
- ☐ 1% - 25%
- ☐ 26% - 50%
- ☐ 51% - 75%
- ☐ 76% - 100%

16) What percentage of time do you normally use a **Hands-Free** device when talking on your personal wireless phone? (Please check one.)

- ☐ Zero
- ☐ 1% - 25%
- ☐ 26% - 50 %
- ☐ 51% - 75%
- ☐ 76% - 100%

17) What percentage of the time do you pull off the road to use a wireless phone? (Please check one.)

- ☐ Zero
- ☐ 1% - 25%
- ☐ 26% - 50 %
- ☐ 51% - 75%
- ☐ 76% - 100%

18) How difficult or easy did you find each of the following tasks **when using your personal wireless phone**? (Please check only one box per task.)

	Extremely difficult	Difficult	Slightly difficult	Neutral/ not sure	Slightly easy	Easy	Extremely easy
Dialing the phone while driving	☐	☐	☐	☐	☐	☐	☐
Maintaining vehicle within lane while dialing the phone	☐	☐	☐	☐	☐	☐	☐
Maintaining posted speed limit signs while dialing the phone	☐	☐	☐	☐	☐	☐	☐
Carrying on a phone conversation while driving	☐	☐	☐	☐	☐	☐	☐
Carrying on a phone conversation while searching for an address, parking spot, pedestrian etc.	☐	☐	☐	☐	☐	☐	☐
Maintaining vehicle within lane while conversing on the phone	☐	☐	☐	☐	☐	☐	☐
Maintaining posted speed limit signs while conversing on the phone	☐	☐	☐	☐	☐	☐	☐
Hearing and understanding what the person on the other end of the line is saying	☐	☐	☐	☐	☐	☐	☐

19) Have you ever had to take sudden action while driving to avoid hitting something, due in part to being distracted by a wireless phone call? (Please check one.)

- ☐ No, never
- ☐ Yes, once
- ☐ Yes, multiple times
- ☐ I don't know

If yes, please describe the most significant situation. ______________________________

____

____

20) Have you ever veered out of your lane while driving due to being distracted by a wireless phone call? (Please check one.)

- ☐ No, never
- ☐ Yes, once.
- ☐ Yes, multiple times.
- ☐ I don't know

If yes, please describe the most significant situation. ______________________________

____

____

Part 3: Opinions Regarding Wireless Phone Usage

21) How safe or unsafe do you feel in each of the following situations? (Please check one box per scenario.)

	Extremely unsafe	Unsafe	Slightly unsafe	Neutral/ not sure	Slightly safe	Safe	Extremely safe
Driving and talking on a phone	☐	☐	☐	☐	☐	☐	☐
Conducting a call while driving	☐	☐	☐	☐	☐	☐	☐
Pulling off the road to conduct a call	☐	☐	☐	☐	☐	☐	☐
Using a wireless phone with a Hands-Free device while driving	☐	☐	☐	☐	☐	☐	☐
Using a wireless phone in a Hand-Held manner while driving	☐	☐	☐	☐	☐	☐	☐

22) Do you feel it is appropriate to impose legal limits regarding the use of wireless phones while driving?

Strongly disagree	Disagree	Somewhat disagree	Neutral/not sure	Somewhat agree	Agree	Strongly agree
☐	☐	☐	☐	☐	☐	☐

If you feel that imposing limits is appropriate, what sort of limits would be acceptable? __________

____

____

23) How often do you use a wireless phone in the following conditions while driving? (check the most appropriate answer for each condition)

	Frequently	Occasionally	Rarely	Never	Not Applicable
At night	☐	☐	☐	☐	☐
In fog	☐	☐	☐	☐	☐
In rain	☐	☐	☐	☐	☐
In snow or sleet	☐	☐	☐	☐	☐
During rush hour	☐	☐	☐	☐	☐
On residential streets	☐	☐	☐	☐	☐
On city streets	☐	☐	☐	☐	☐
On rural roadways	☐	☐	☐	☐	☐
On highway/freeway	☐	☐	☐	☐	☐
While smoking	☐	☐	☐	☐	☐
While eating	☐	☐	☐	☐	☐
After drinking alcohol	☐	☐	☐	☐	☐
With children in car	☐	☐	☐	☐	☐
In high density traffic	☐	☐	☐	☐	☐
In high density traffic with pedestrians present	☐	☐	☐	☐	☐
In low density traffic	☐	☐	☐	☐	☐

In low density traffic with pedestrians present	☐	☐	☐	☐	☐
When passing other cars	☐	☐	☐	☐	☐
While following other vehicles	☐	☐	☐	☐	☐
While completing an alternative task such as following directions	☐	☐	☐	☐	☐
When changing lanes	☐	☐	☐	☐	☐
When traveling in an unfamiliar area	☐	☐	☐	☐	☐
When making left hand turns at uncontrolled intersections	☐	☐	☐	☐	☐

24) How comfortable would you feel using a wireless phone in the following conditions while driving? (check the most appropriate answer for each condition)

	Very Comfortable	Somewhat Comfortable	Somewhat Uncomfortable	Very Uncomfortable	Not Applicable
At night	☐	☐	☐	☐	☐
In fog	☐	☐	☐	☐	☐
In rain	☐	☐	☐	☐	☐
In snow or sleet	☐	☐	☐	☐	☐
During rush hour	☐	☐	☐	☐	☐
On residential streets	☐	☐	☐	☐	☐
On city streets	☐	☐	☐	☐	☐
On rural roadways	☐	☐	☐	☐	☐
On highway/freeway	☐	☐	☐	☐	☐
While smoking	☐	☐	☐	☐	☐
While eating	☐	☐	☐	☐	☐
After drinking alcohol	☐	☐	☐	☐	☐
With children in car	☐	☐	☐	☐	☐
In high density traffic	☐	☐	☐	☐	☐
In high density traffic with pedestrians present	☐	☐	☐	☐	☐
In low density traffic	☐	☐	☐	☐	☐
In low density traffic with pedestrians present	☐	☐	☐	☐	☐
When passing other cars	☐	☐	☐	☐	☐
While following other vehicles	☐	☐	☐	☐	☐
While completing an alternative task such as following directions	☐	☐	☐	☐	☐
When changing lanes	☐	☐	☐	☐	☐
When traveling in an unfamiliar area	☐	☐	☐	☐	☐
When making left hand turns at uncontrolled intersections	☐	☐	☐	☐	☐

15.0 APPENDIX H: STRUCTURED POST-DRIVE INTERVIEW

We would like to ask you a few questions about your drives today. We are interested in whether you **observed** any changes in your driving behavior or driving style, while on and off the phone. In other words, we are trying to understand to what extent you were **aware** of various aspects of your driving behavior. Please use this scale to rate your agreement with each statement [give scale to participant]:

Strongly Disagree	Disagree	Neutral/Unsure	Agree	Strongly Agree
1	2	3	4	5

Statement	Agreement while **on** the phone (number)	Comments	Agreement while **off** the phone (number)	Comments
I paid attention to the distance between my vehicle and the vehicle in front of me.				
I paid attention to the position of my vehicle in the lane.				
I paid attention to the speed of my vehicle.				
I paid attention to vehicles that cut in front of me				
I paid attention to traffic lights.				
I paid attention to my driving performance while searching for pedestrians				
I paid attention to the position of other vehicles in relationship to my vehicle.				
I paid attention to my overall driving performance.				

Now we'd like to ask about **changes** you may have made to aspects of your driving behavior, while on and off the phone. We would like to know to what extent any changes were **purposeful**. In other words, rate the extent to which you **intentionally** made adjustments to your driving behavior. Please use the same scale to rate your agreement with each statement [review scale]:

Strongly Disagree	Disagree	Neutral/Unsure	Agree	Strongly Agree
1	2	3	4	5

Statement	Agreement while **on** the phone (number)	Comments	Agreement while **off** the phone (number)	Comments
I paid attention to the distance between my vehicle and the vehicle in front of me.				
I paid attention to the position of my vehicle in the lane.				
I paid attention to the speed of my vehicle.				
I paid attention to vehicles that cut in front of me				
I paid attention to traffic lights.				
I paid attention to my driving performance while searching for pedestrians.				
I paid attention to the position of other vehicles in relationship to my vehicle.				
I paid attention to my overall driving performance.				

Please rate your agreement with the following statement, using the same scale: My driving performance improved throughout my drives today (i.e., my last drive was better than my first drive).

[Circle participant's response.]

Strongly Disagree	Disagree	Neutral/Unsure	Agree	Strongly Agree
1	2	3	4	5

Please explain your rating; in other words, in what ways do you think your driving performance improved or did not improve?

____

____

____

____

____

____

16.0 APPENDIX I: SELECTED RESPONSES TO WIRELESS PHONE POST-DRIVE SURVEY

16.1.1 Opinions Regarding Wireless Phone Use While Driving

Approximately 50 percent of participants indicated that they felt it was not unsafe to conduct a wireless phone call while driving. A large majority of participants felt it was safe to pull off of the road to make a wireless phone call. These results are illustrated in Figure 37.

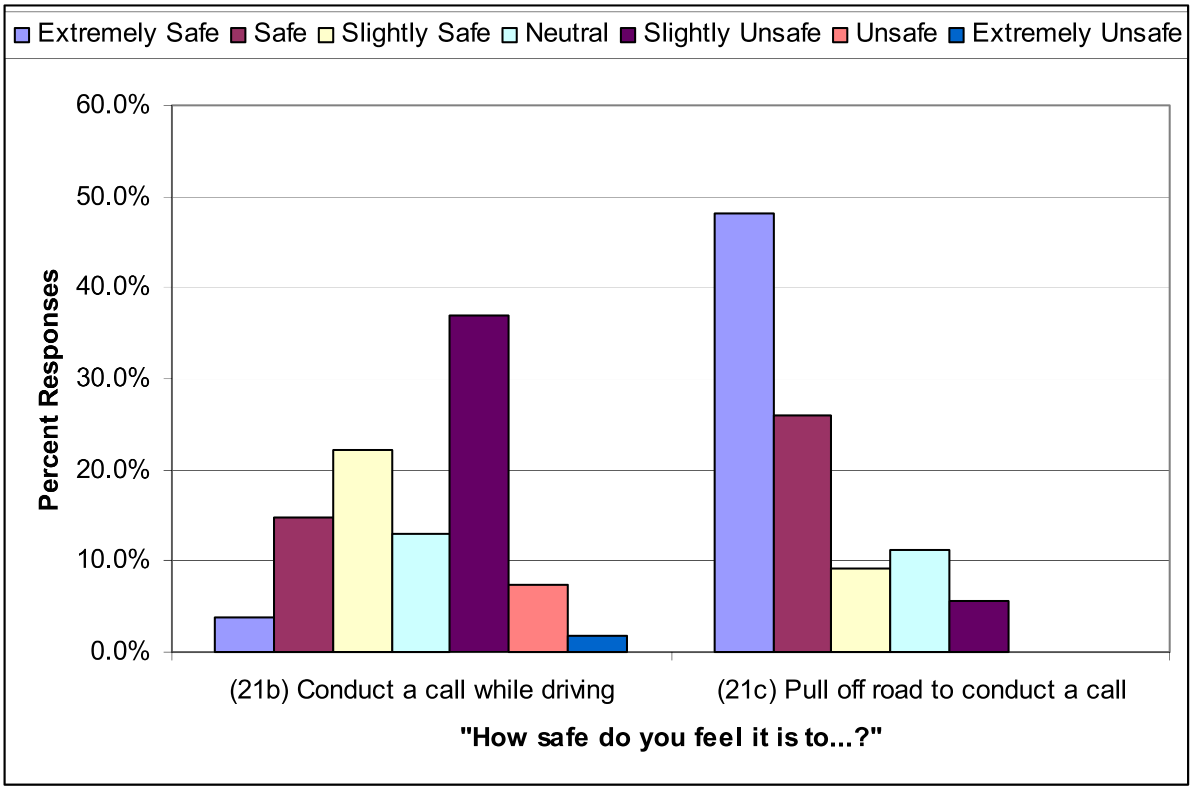

Figure 36. Participant responses regarding the safety of making wireless calls while driving and while pulled over to the side of the road.

Figure 38 illustrates that participants in this study generally felt that making a Hands-Free phone call while driving was safe, while participants were somewhat divided on the issue of Hand-Held call safety.

When probed about their inclinations to make wireless phone calls under certain weather conditions, participants reported a fair degree of comfort in making calls at night, and somewhat less comfort making calls in rainy conditions. Participants seemed least inclined to make calls in snow and fog, respectively. These results are summarized in Figure 39.

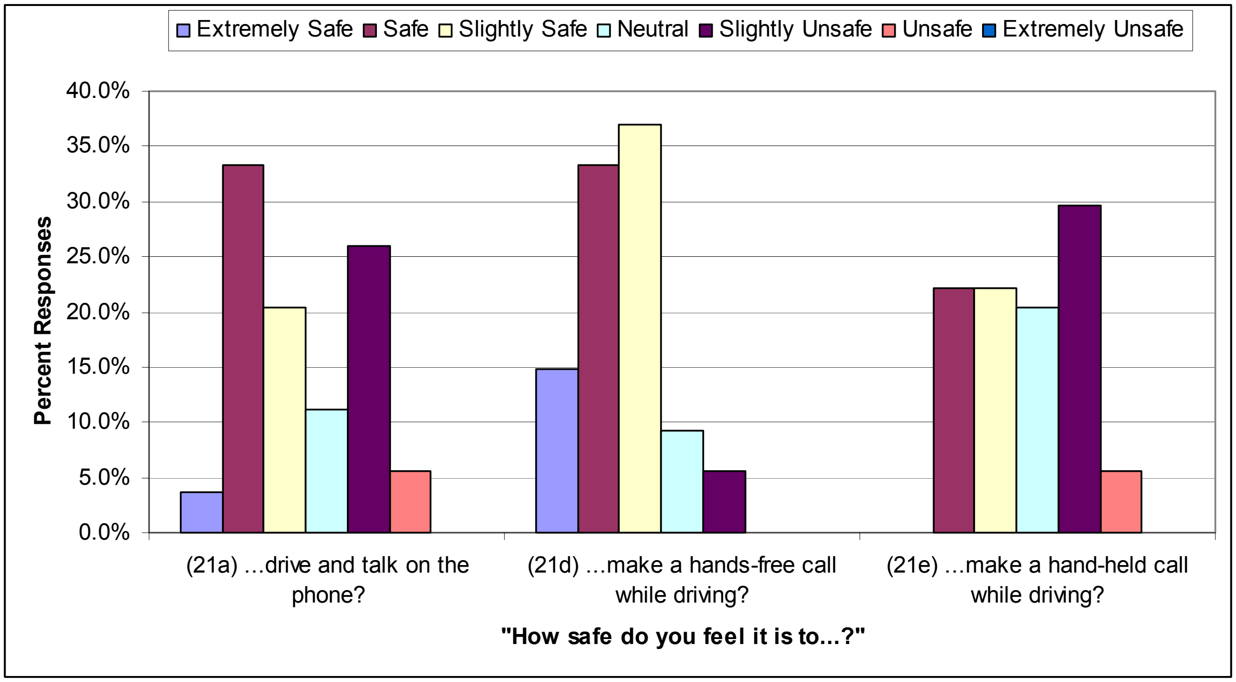

Figure 37. Participant responses regarding the safety of making Hand-Held and Hands-Free wireless calls while driving.

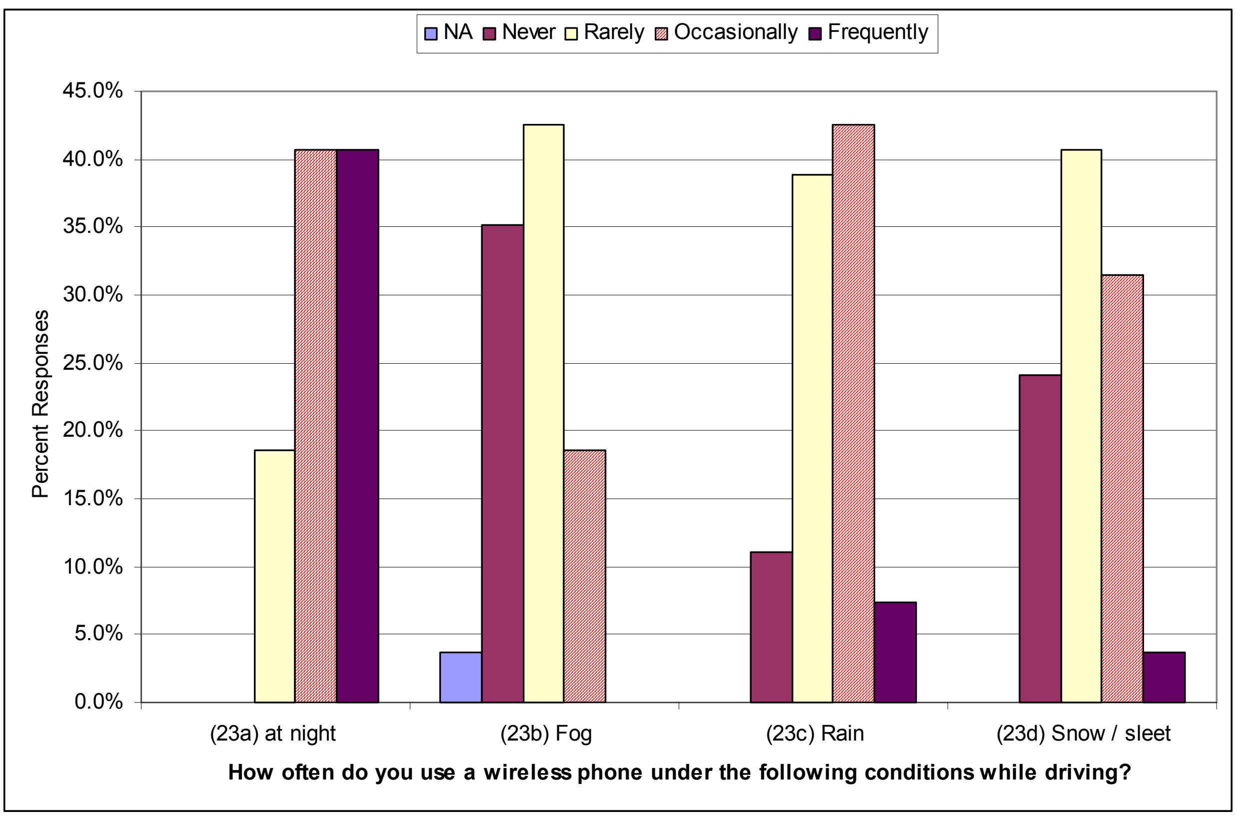

Figure 38. Responses regarding use of wireless phones while driving as a function of weather conditions.

Participants reported using a wireless phone most often under highway/freeway conditions, followed by rural, city, and residential streets types, respectively. These responses are shown in more detail in Figure 40. This response supports findings from a previous NHTSA study of drivers' use of wireless phones on public roadways (NHTSA, 2004), which showed that calls are made under a wide variety of road and traffic conditions.

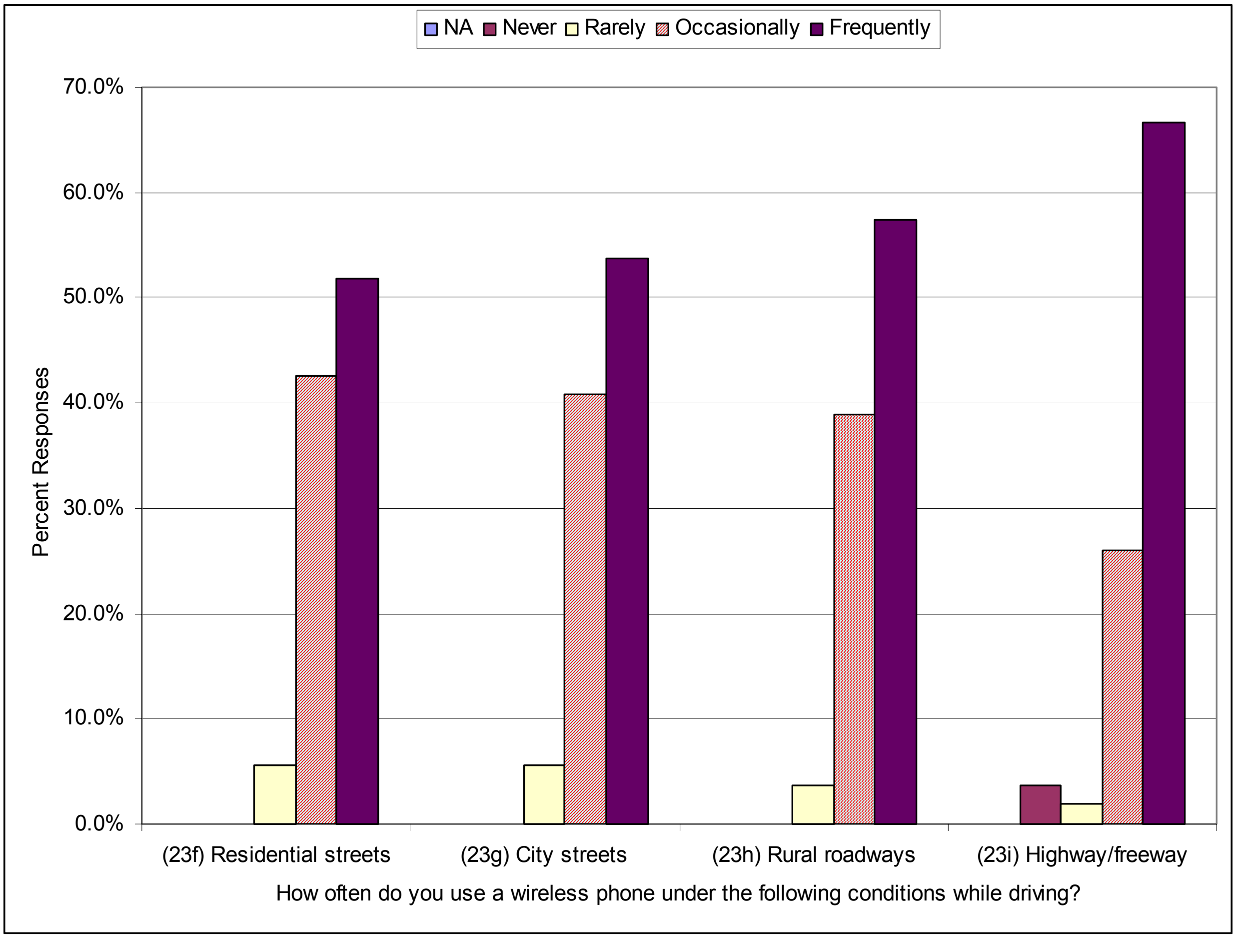

Figure 39. Participants' self-reported rates of wireless phone use by road type.

Participants indicated a mild willingness to use a wireless phone in combination with several other factors that might also reduce their attention to driving. Of the conditions probed, using their phone while driving with children in the vehicle received the highest proportion of responses. Nearly 45 percent of participants stated that they would not use a wireless phone while driving and eating. Nearly 10 percent of participants said they frequently smoke while using a wireless phone and driving. These results are summarized in Figure 41.

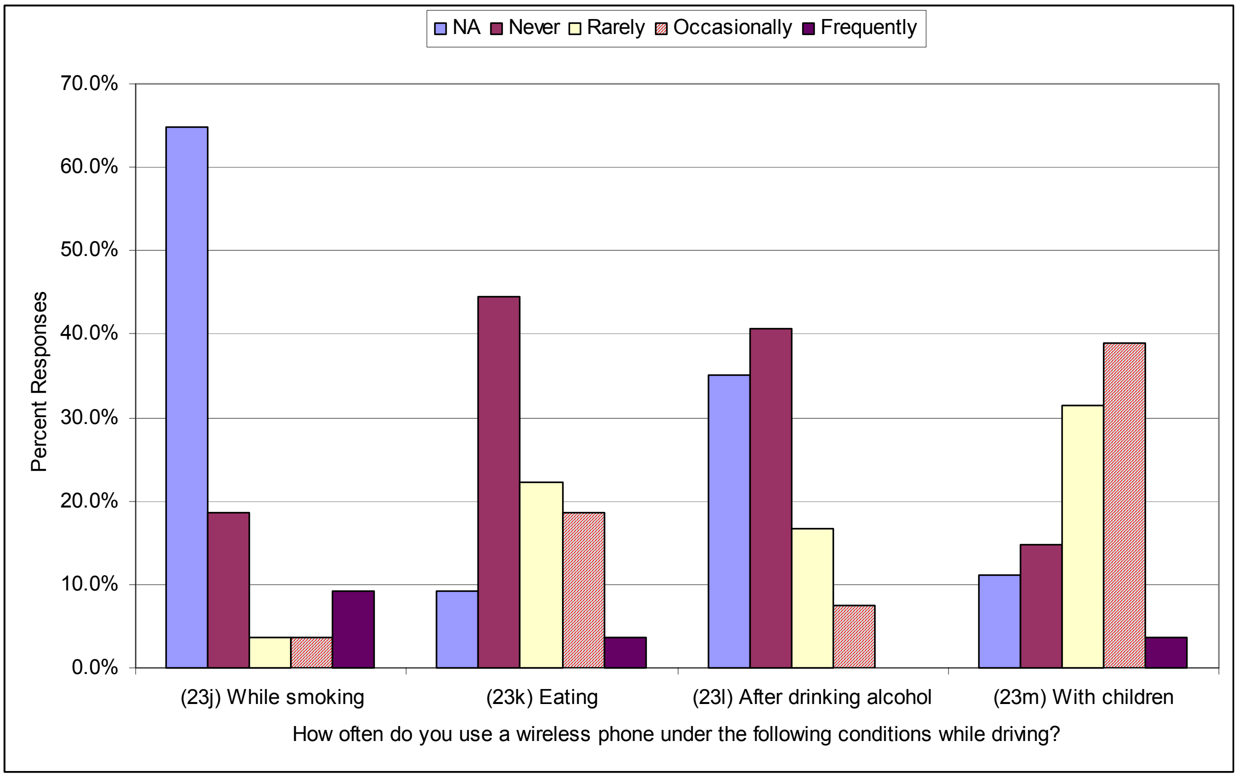

Figure 40. Participants' willingness to use a wireless phone under various combined conditions.

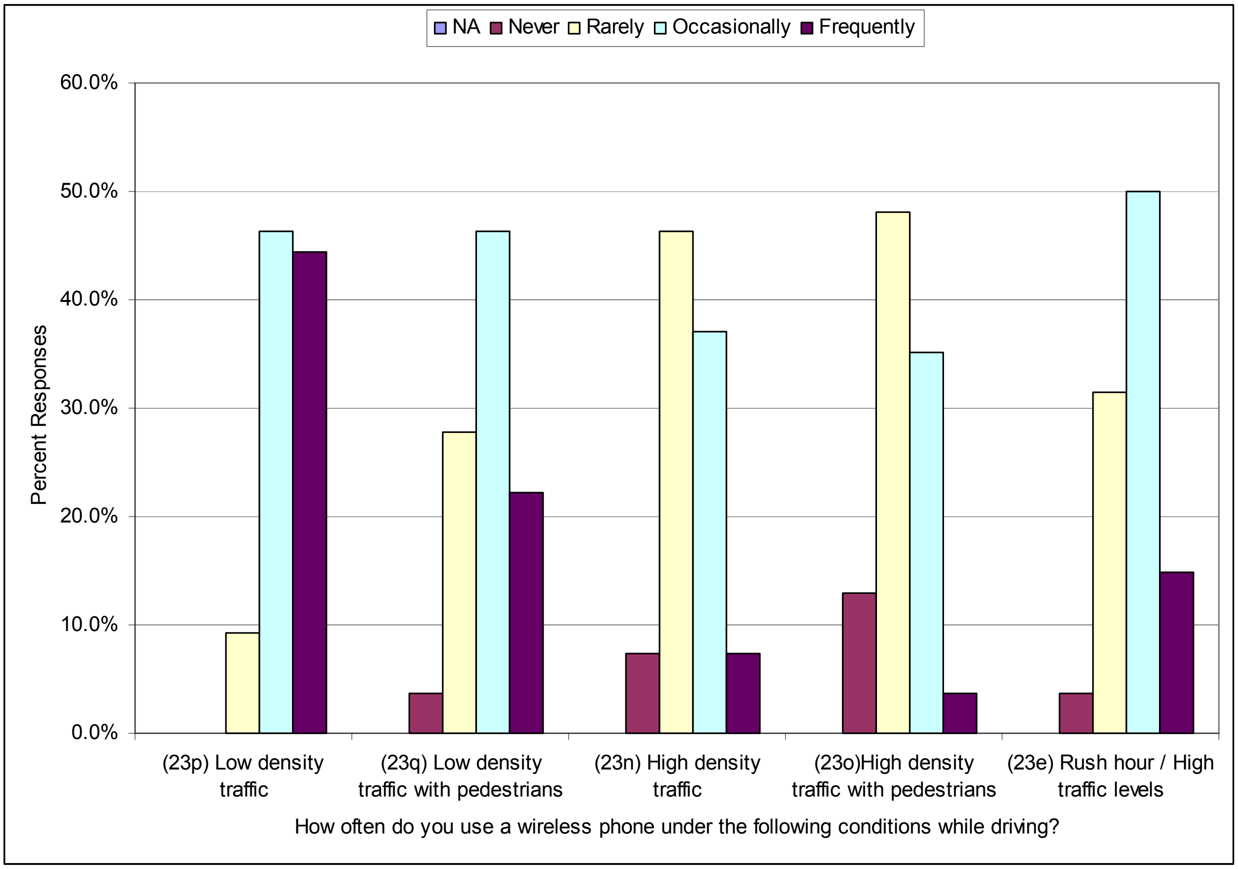

Figure 41. Reported frequency of wireless phone use as a function of traffic conditions.

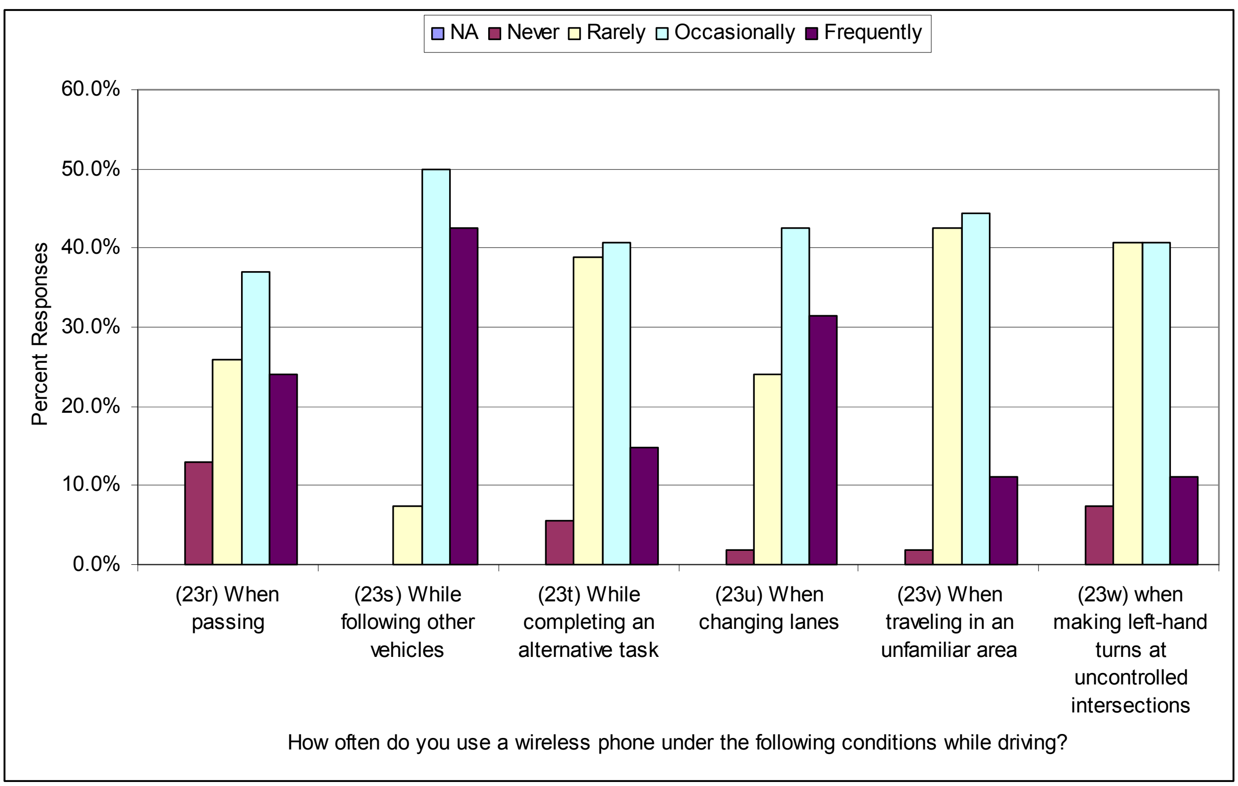

Figure 42. Report frequency of wireless phone use during various driving situations.

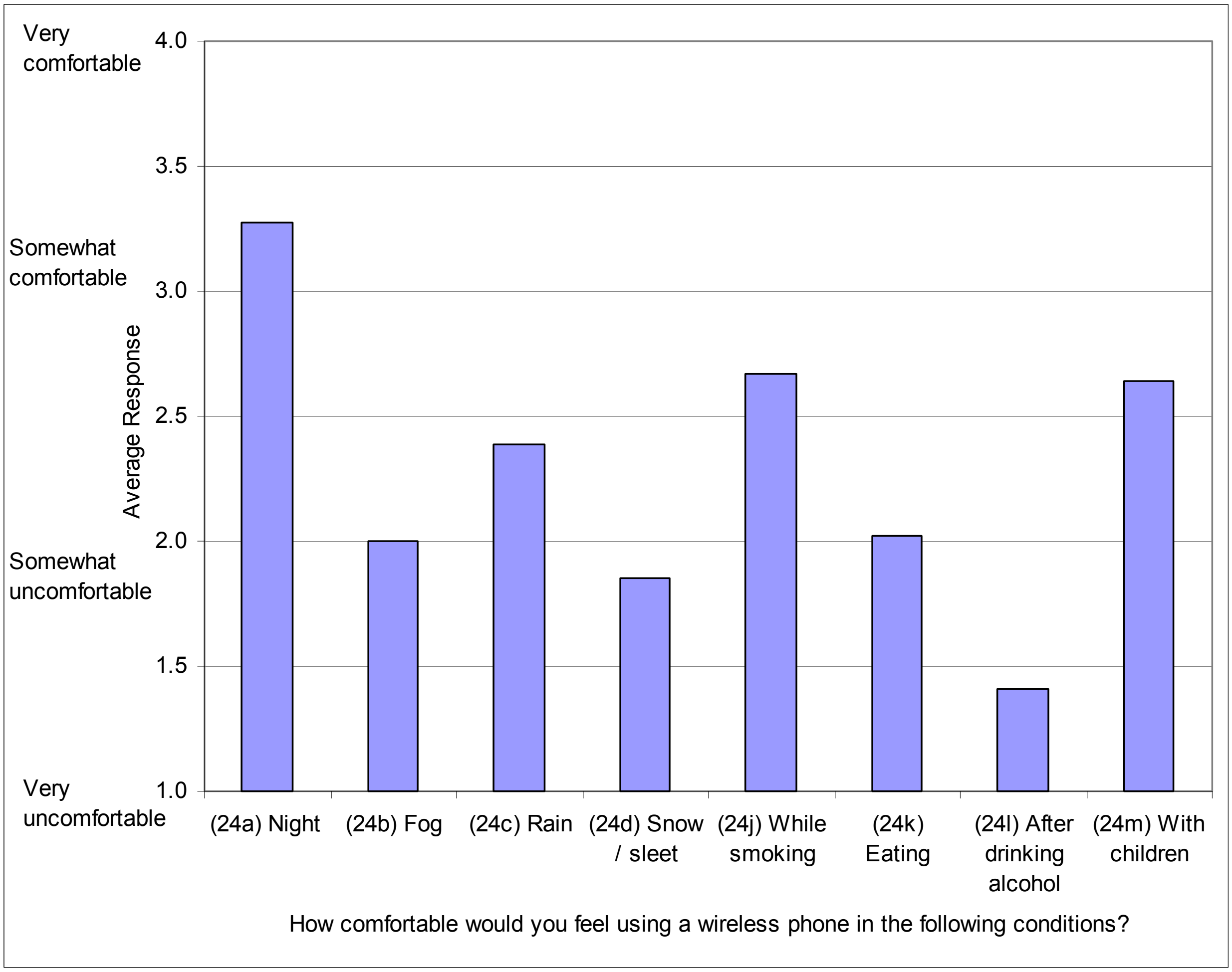

Figure 43. Participants' report comfort levels in using a wireless phone in conjunction with various weather conditions and in-vehicle activities.

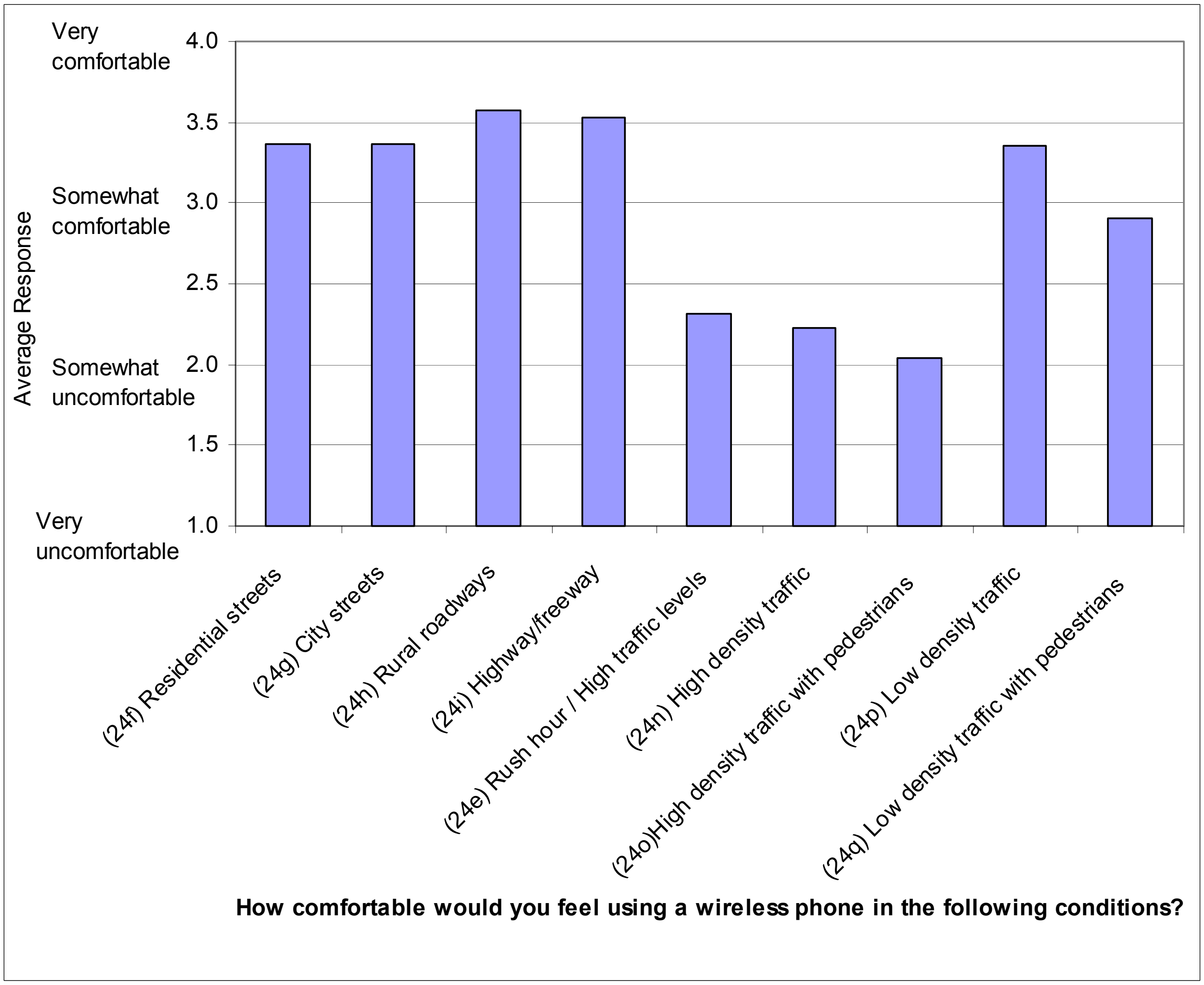

Figure 44. Participants' reported comfort levels in using a wireless phone in various road types and traffic levels.

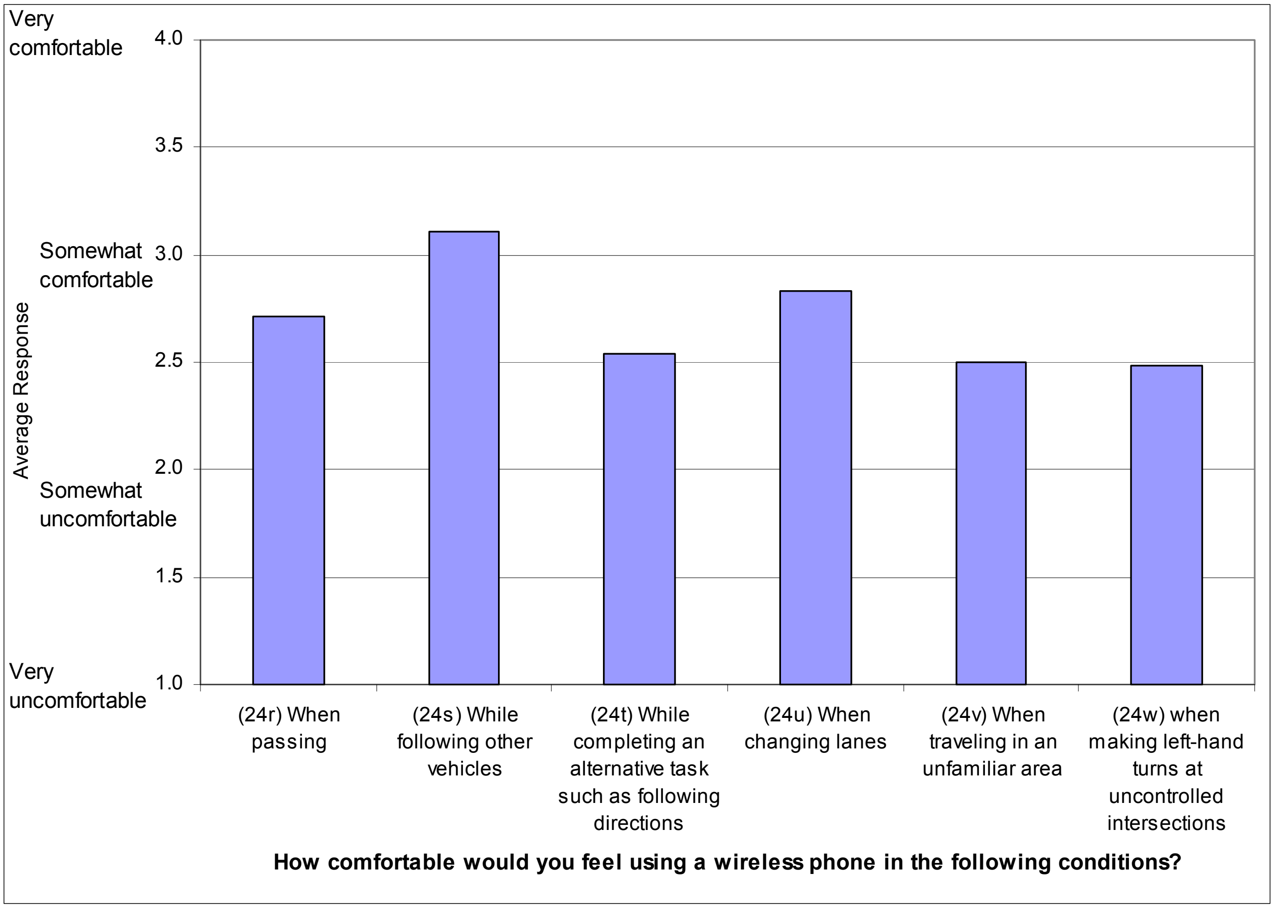

Figure 45. Participants' report comfort level using a wireless phone in various driving situations/maneuvers.

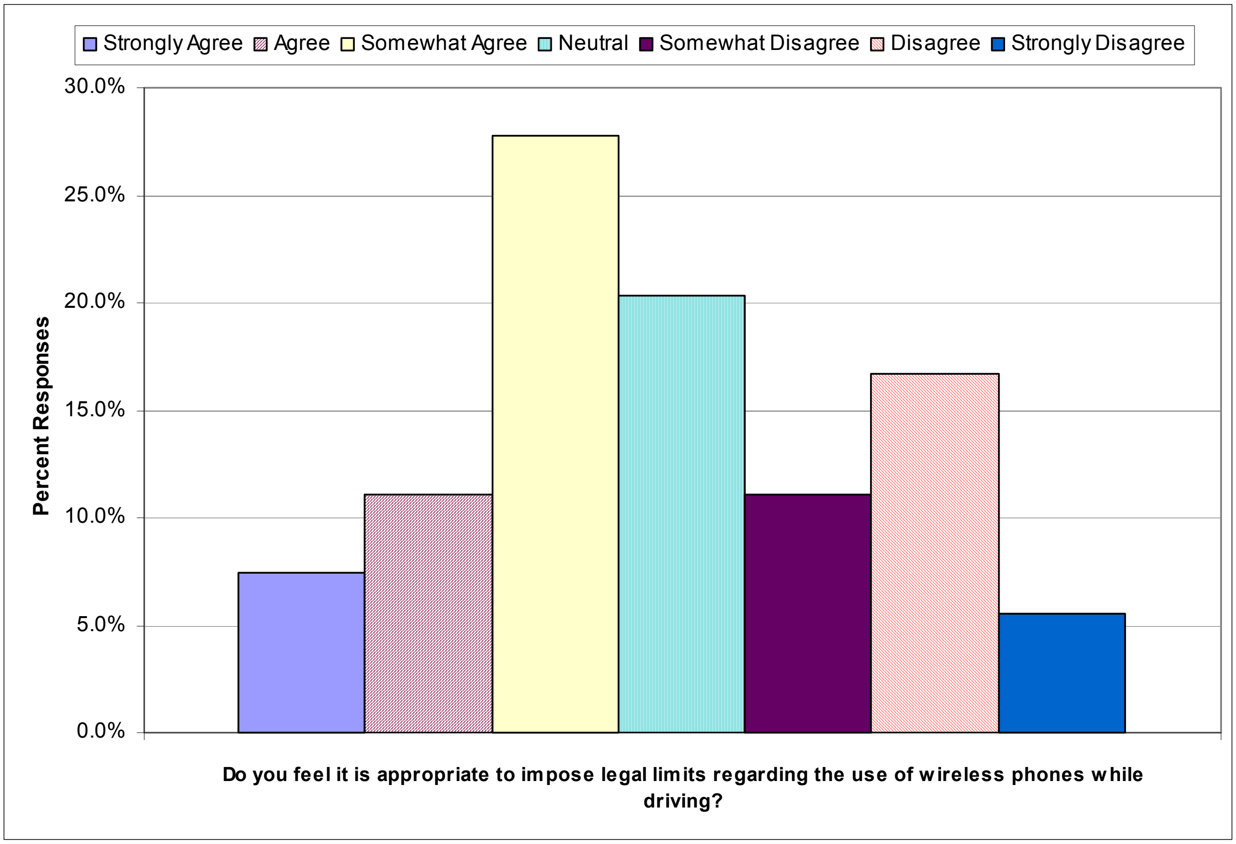

Figure 46. Participants' feelings regarding appropriateness of legal limits being placed on the use of wireless phones while driving.