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

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16. Abstract

The report provides a preliminary description of research currently underway to investigate the effects of wireless phone use on driving performance and behavior. The main objective of the research is to collect information useful in the assessment of 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 is being conducted by NHTSA using the National Advanced Driving Simulator (NADS) in collaboration with NADS staff. This preliminary report describes the development of a freeway driving scenario and associated driving and wireless phone tasks. Also provided is a brief description of the freeway pilot study and associated example data. Lessons learned during the process of developing the simulator scenario and experimental methods are outlined in hopes of benefiting other researchers involved in similar projects. Results of the main freeway experiment and details of the refined test protocol will be provided in a subsequent report.

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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. Through research, NHTSA seeks to contribute to a better understanding of the implications of hands-free wireless phone operations while driving.

The report provides a preliminary description of NHTSA research currently underway to investigate the effects of wireless phone use on driving performance and behavior. The main objective of the research is to collect information useful in the assessment of 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. Of particular interest is whether using hand-held wireless phone interfaces (e.g., dialing, answering, conversation) while driving degrades driving performance more than does hands-free wireless phones. In addition, research will address the question of whether younger and/or older drivers exhibit worse driving performance during wireless phone task components than middle-aged drivers. Lastly, the research will examine whether drivers glance away from the forward roadway more when using a hands-free wireless phone interface than they do when using a wireless phone in a hand-held configuration.

This research is being conducted by NHTSA using the National Advanced Driving Simulator (NADS) in collaboration with NADS staff. The researchers have prepared this preliminary report to describe and document the development of a four-lane divided freeway driving scenario and associated events, as well as driving and wireless phone tasks. Documentation of the scenario and experimental design processes is intended to assist other researchers in preparing to conduct research on the NADS.

Lessons learned during the process of developing the simulator scenario and experimental methods are outlined in hopes of benefiting other researchers involved in similar projects. Results of the main freeway experiment and details of the refined test protocol will be provided in a subsequent report.

1.0 INTRODUCTION

This document outlines the initial stages of research currently underway to examine driver distraction and performance issues relating to the use of wireless phones while driving. The research is being conducted by the National Highway Traffic Safety Administration (NHTSA) using the National Advanced Driving Simulator (NADS) located at the University of Iowa. This report presents the rationale for performance of the research, the development of experimental methods, and the development of driving scenarios and associated events. A description of a small-scale pilot study is provided. Results of the pilot study are discussed in terms of how they were used to identify needed improvements to scenario events and experimental procedures. In addition, example results are presented using data acquired during the pilot study.

1.1 Background

As of January, 2004 there are over 154 million wireless phone subscribers (CTIA, 2004) in the U.S. and the 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. Data from 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. have suggested 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, conventional hands-free, and totally hands-free). Note that this report is a preliminary one that discusses the methodology used but does not contain conclusions about these issues.

Numerous efforts are under way to pass legislation that allows only hands-free wireless phones to be used 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. It is interesting to note that hands-free wireless phones most commonly allow only for hands-free conversation; accessing the phone, dialing, and hanging up still involve visual-manual tasks. The legislative initiatives reflect this level of technology. However, some experts suspect that the distraction levels caused by phone use is independent of the interface design due to the fact that the cognitive demand of conversation tasks are the same no matter what the interface.

As the federal agency concerned with highway safety, NHTSA has both a mandate and an opportunity to contribute to a better understanding of the implications of hands-free wireless phone operations while driving. 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 objective of this research was to assess the distraction potential and safety implications (i.e., impact on driving performance) associated with the use of a wireless phone while driving. Of primary interest is the examination of whether hands-free operation and/or voice-activated dialing substantively affect the distraction potential associated with wireless phone use while driving and the assessment of the impact of wireless phone use on safety-relevant driving performance and behavior as a function of phone interface type. This research also addresses the question of how phone use affects driving behavior under different levels of driving task demand and driver behavior during phone use as a function of driver age.

The effects of wireless phone use on driver behavior and performance were examined for the following pairs of experimental conditions:

(1) Hand-held versus hands-free conversation;
(2) Manual dialing versus hands-free dialing;
(3) Manual answering versus hands-free answering; and
(4) Answering, dialing, and conversing versus baseline driving task.

Comparisons will be made overall, as well as by age, where appropriate.

1.3 Research Hypotheses and Approach

To assess whether hands-free wireless phone use while driving may be less unsafe than driving while using a hand-held wireless phone, NHTSA designed a study to assess the following hypotheses:

1. Hand-held conversation degrades driving performance more than hands-free conversation.
2. Hand-held conversation diverts more attentional resources away from driving than hands-free conversation.
3. Manual dialing degrades driving performance more than hands-free dialing.

4. Manual dialing diverts more attentional resources away from driving than hands-free dialing.
5. Answering the phone in the hand-held condition (requires picking up the phone, flipping it open, and pressing the ‘talk’ button) degrades driving performance more than answering with a hands-free interface (requires one button push).
6. Answering the phone in the hand-held condition (requires picking up the phone, may involving flipping it open, and pressing the ‘talk’ button) diverts more attentional resources away from driving than answering with a hands-free interface (requires one button push).
7. Drivers in the “Younger” and/or “Older” age group exhibit worse driving performance during wireless phone task components than drivers in the “Middle” age range.
8. In the “Voice Digit Dialing Hands-Free” condition, drivers glance away from the forward roadway more than they do in the hand-held or headset hands-free conditions.

While the hypotheses assert that hands-free task performance may be less distracting than manual task performance, the authors note that it is plausible that the opposite effect will occur (i.e., hands-free may be found to be more distracting in some aspects).

The approach to this research involves the simulation of voice communications in a variety of common driving situations with controlled variation of task demand levels. A series of integrated scenarios was developed in which driving and communication task objectives were combined such that drivers are required to use wireless phones. Monetary incentives are used to establish priorities with respect to primary (driving) and secondary (phone communication) task performance. The method requires making and receiving phone calls while driving. Wireless phone use was scheduled to coincide with selected driving situations to ensure that all participants use the phones under comparable driving conditions.

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.

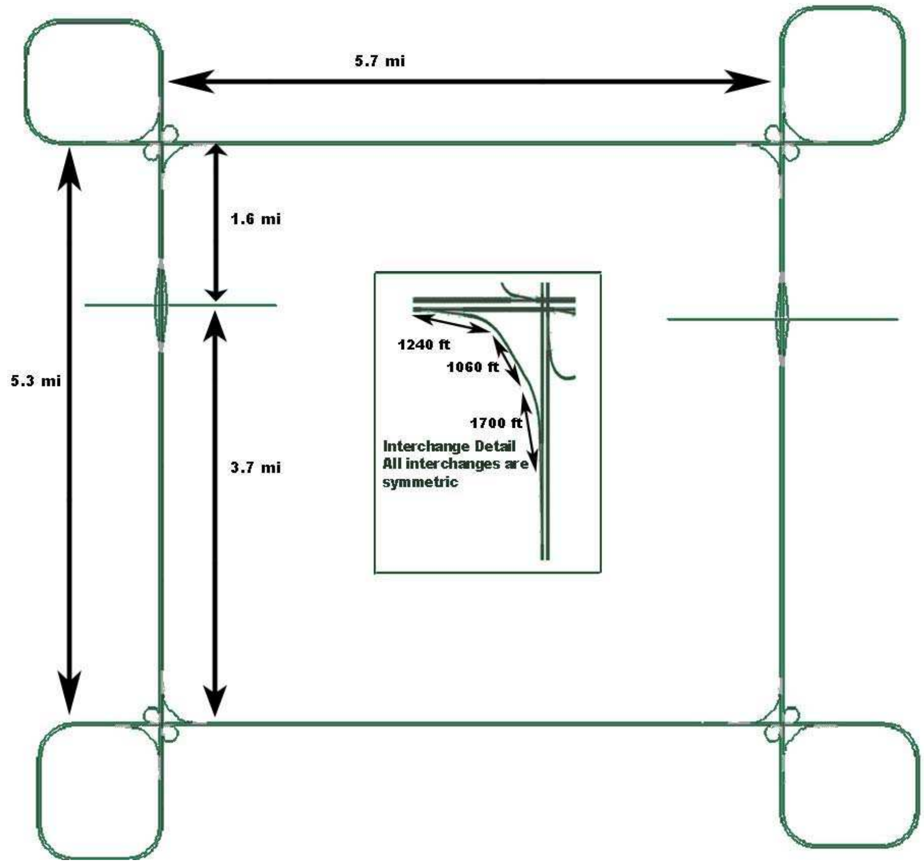
2.1 Rationale for Road Type

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 was developed first. The development of the freeway driving scenarios, experimental design, and experimental protocol are the main focus for this preliminary report. 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 the pilot study used a four-lane divided roadway with a 65-mph speed limit. The route generally consisted of 4 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.



2.2.1 Freeway Familiarization Drive

The familiarization drive consisted of the freeway route without any traffic present. The purpose of this drive was to permit participants to become familiar with the driving environment and the feel of the simulator. This route was the same as the one used in the treatment drives, except that it had no traffic and no scenario events.

2.2.2 Freeway Practice Drive

The 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 (described in Section 3).

Figure 1. Layout of Freeway Scenario Route With Inset Showing Interchange Dimensions.

2.2.3 Freeway Treatment Drives

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, corresponding respectively to the incoming phone call, outgoing phone call, and baseline (no call) periods. Each phone call period was further broken down in sub-sections. Outgoing calls involved call initiation (i.e., dialing), conversation, and call disconnect. Incoming calls involved call answer, conversation, and call hang-up. More details on the breakdown of the phone task are provided later in this report.

Each segment 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), 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 first phone call was an outgoing one while the second was incoming. 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.

Table 1. Relation of Phone Tasks to Scenario Events for One Treatment in the 15 Minute Freeway Scenario (unoccupied time not noted)

Phone task	Phone Task Duration (s)	No Phone Task Duration (s)	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. Similarly, 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.

The baseline phase included the same events, 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 “unoccupied time” when the participant was not performing a task or responding to an event. This unoccupied time total approximately 41 percent of the 15 minutes (900 s) 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 (incoming or outgoing) 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 (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-15 B-LVB-15 B-30 B-F-60 B-M-15	C-30 C-CF-60 C-LVC-15 C-M-15	C-30 C-M-15 C-LVB-15 C-CF-60
C-30 C-LVB-15 C-CF-60 C-M-15	B-30 B-LVC-15 B-CF-60 B-M-15 B-LVB-15	C-30 C-M-15 C-CF-60 C-LVC-15
C-30 C-LVC-15 C-CF-60 C-M-15	C-30 C-CF-60 C-M-15 C-LVB-15	B-CF-60 B-LVB-15 B-M-15 B-LVC-15 B-30
End	End	End

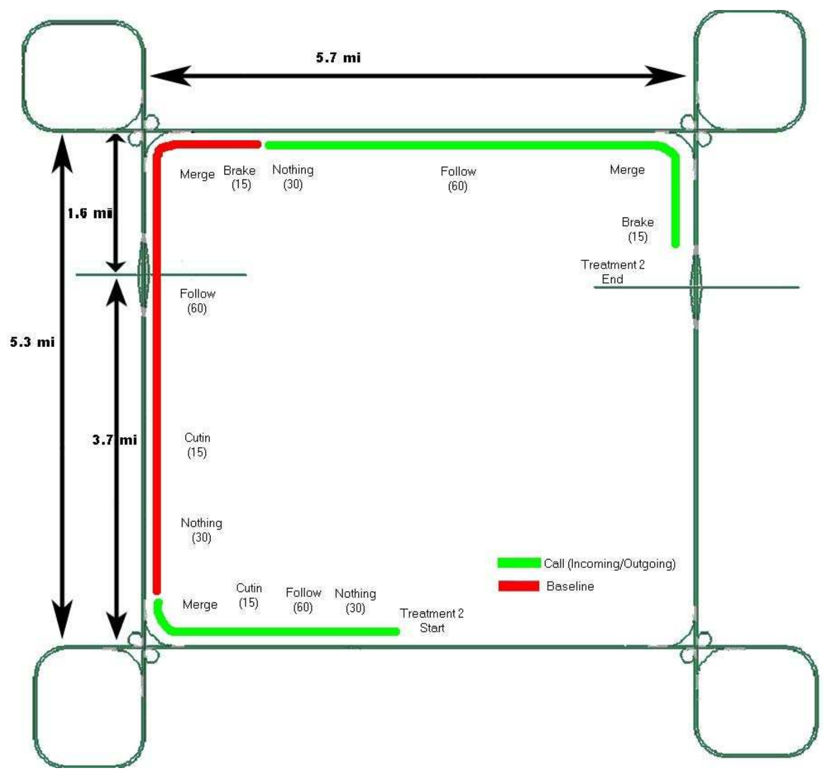
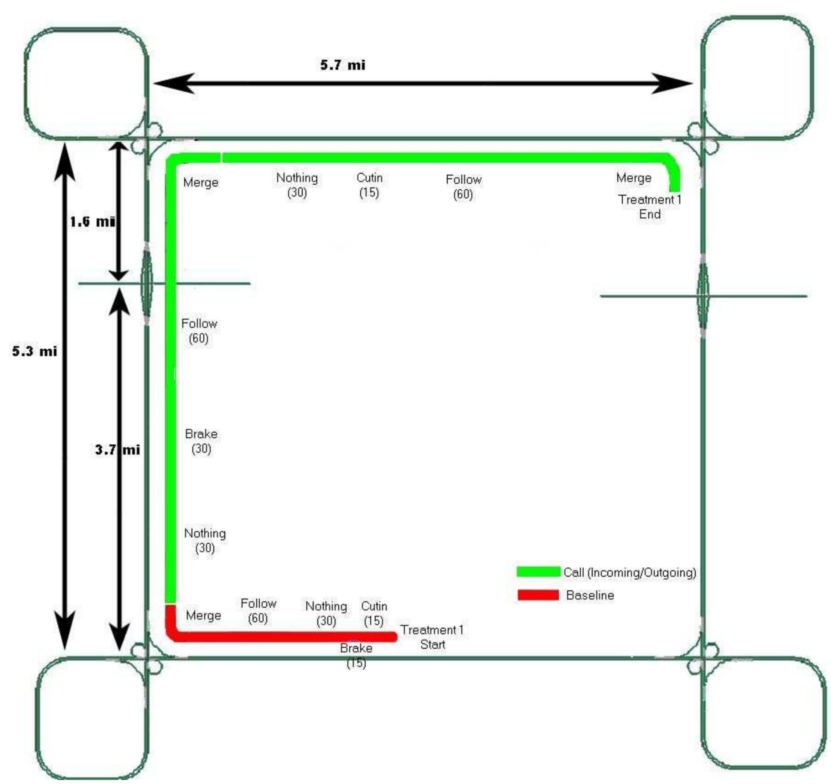


Figure 2. Treatment 1 Illustration (numbers in parentheses are in units of seconds).

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



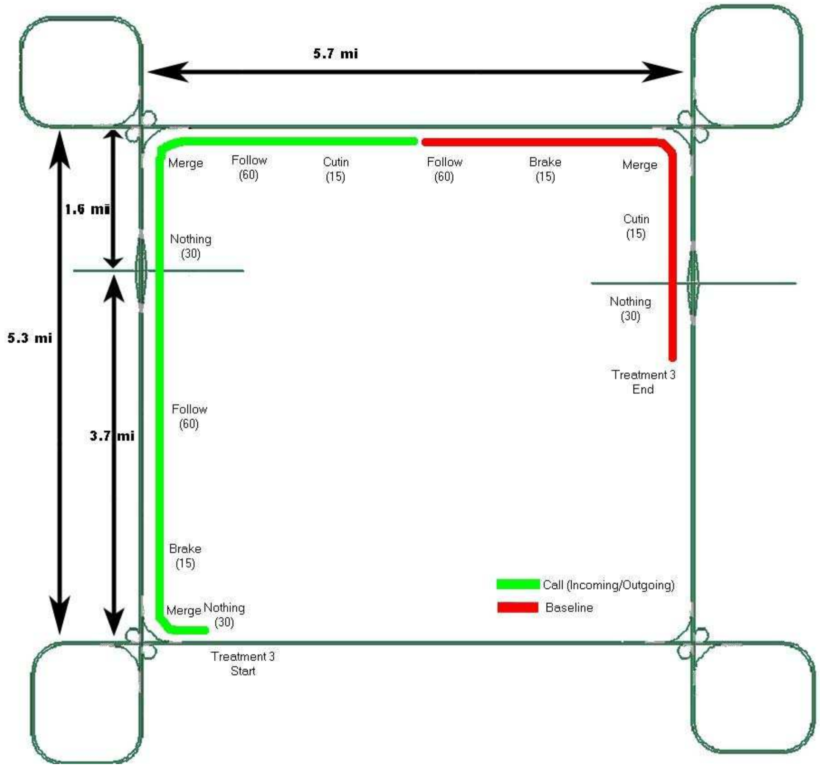


Figure 4. Treatment 3 Illustration (numbers in parentheses are in units of seconds).

2.2.3.1 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., 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.

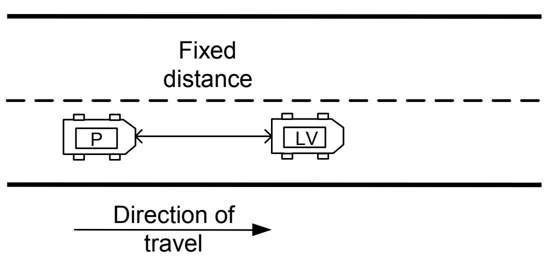


Figure 5. Illustration of Initial Condition for the Lead Vehicle Braking Event.

2.2.3.2 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.

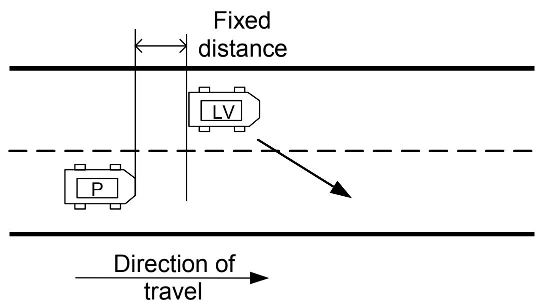


Figure 6. Illustration of Initial Conditions for the Lead Vehicle Cut-In Event.

2.2.3.3 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 and coherence analysis.

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.

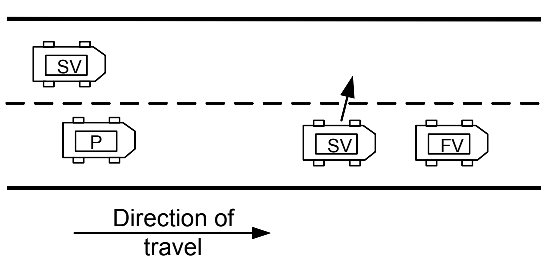


Figure 7. Illustration of Initial Conditions for the Car Following Event.

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:

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

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 quickly 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.

2.2.3.4 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.

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.

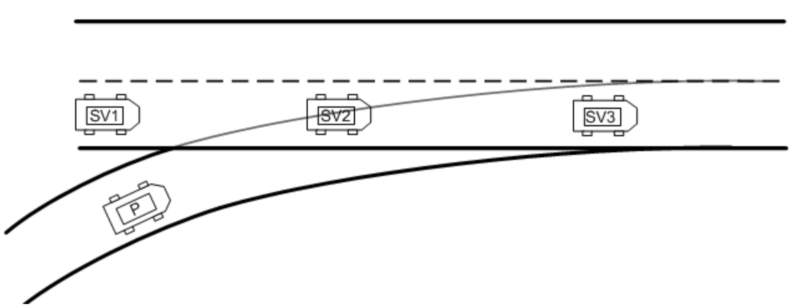


Figure 8. Illustration of the Merge Event.

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

It was desired that before completing their driving, participants would experience a critical event (i.e., an event intended to elicit some crash avoidance response). However, the schedule did not permit preparation of such an event for the pilot study. A critical event will be included in the main freeway experiment.

3.0 CONVERSATION TASK DEVELOPMENT

3.1 Selection of Conversation Task

In examining participants' driving performance while using a wireless phone, three components of wireless phone use were of interest: dialing, answering, and conversing. While dialing and answering a wireless phone are purely functions of the interface, conversation characteristics can vary widely.

In order to isolate the effects of the interface on driving performance during conversation, it was necessary to make the conversations consistent across all conditions. Thus, a method of presenting a controlled conversation that would impose a constant level of mental load on the driver throughout the entire conversation was desired. A review of verbal tasks used in previous distraction research was performed. Verbal tasks identified for possible use in this study were categorized according to the type of interaction involved, i.e., Baddeley verbal tasks, arithmetic tasks, naturalistic conversation tasks, and verbal reasoning or other decision-making tasks. The goal was to find a verbal task that could be presented continuously and that minimized the effect of individual differences (e.g., mathematical ability). A full description of the various tasks considered will be provided in the final report for this study.

3.2 Baddeley Task

The conversation task chosen for this study was a modification of the Baddeley working memory span task. The Baddeley task generally involves administration of a sequence of sentences to a subject. After each sentence is presented, the participant is required to respond as to whether or not the sentence made sense. After a group of sentences (e.g., 4 or 5) is presented, the participant is prompted to recall either the subjects or the objects of the sentences, as indicated by the experimenter. Thus, the participants' responses to the task require both a decision-making, or judgment, component and a memory recall component.

The desire was to implement a variation of the Baddeley task that would result in phone conversations of a specified length. A description of how the Baddeley task for this study was designed and implemented follows.

3.2.1 Sentence Selection

In anticipation of a larger study (possibly needing up to 24 calls), 288 sentences or 144 pairs were created. Each sentence pair consisted of one meaningful and one nonsensical sentence having the same subject and action verb.

All sentences were of the following construction:

Subject - action verb - object

Sentences were constructed so that the classification decision as to whether or not the sentence was sensible could not be made until the object was heard. This required the participant to pay attention to the whole sentence before answering and also forced a consistent start to the response period (i.e., the completion of the last word of the sentence is the beginning of the response period.). For example, in the following, the first sentence is nonsensical, but is unacceptable because it can be classified without knowing the object. The second sentence is also nonsensical but adheres to the stricter criterion that requires the listener to hear the object before being able to classify the sentence.

The phone drank the breeze - unacceptable
The boy drank the phone – acceptable

Other criteria for sentence construction included:

1. There are no gender-based occupational titles (e.g., waitress, fireman).
2. There are no ambiguous sentences or violations of population stereotypes.
3. There are no words with more than three syllables.
4. Each sentence has a maximum of eight syllables.
5. There are no adjectives.

Sentences were constructed using common words. The source used for determination of the most common words was the web page titled, "Vocabulary Workshop: 1000 Most Common Words in English" on the web site "About.com" (http://esl.about.com/library/vocabulary/bl1000_list1.htm) (see Appendix A). To the extent possible, only words from this particular list of the 1000 most common words were used.

3.2.2 Development of Means of Conversation Task Presentation

Consistent presentation of the conversation task, both in terms of the timing of sentence presentation as well as the tone of the speech, was a primary goal in developing the conversation task. To this end, text-to-speech software was investigated as a means of conversation task presentation. AT&T True Voice software was selected for its realistic sounding voice models and its ability to convert entire text files to computer audio files very quickly.

Pronunciation of some words was found to be awkward in some cases, hindering recognition of the words and thus understanding of the sentence. A large number of sentences were generated such that only sentences that were "spoken well" by the software were retained. These sentences were tested for their ability to be understood and usefulness in Baddeley task performance in a pre-pilot test, described in the following section.

3.2.3 Conversation Task Pre-Pilot

The following issues were identified with respect to the use of the Baddeley working memory task to simulate phone conversation.

1. Number of sentences per group (trial)
2. Subject vs. object as the word to be recalled
3. Sentence construction
4. Time delay between sentences for participant response
5. Pace at which sentences are presented

A pre-pilot study was conducted to address three of these issues, namely the number of sentences per trial, the use of subject vs. object as cue word and the time between sentences for participant response. The pre-pilot study provided information about the time required per trial, which was needed to assist with development of the method for the NADS experiment. Pre-pilot work helped determine the pace at which the sentences would be recorded and the range of values for the timing interval between sentences.

Based on the results of the pre-pilot test, it was decided that groups of 4 sentences would be used. In addition, the time period allowed for participants to respond as to whether or not a sentence made sense was determined to be 2.5 seconds, while the recall period was set to 6 seconds.

3.2.4 Resulting Call Construction

To ensure that phone calls spanned the desired events, calls were constructed to last approximately 3.5 minutes. Each group of four sentences comprised one Baddeley task trial. Thus, each call had six groups of four for a total of 24 sentences (12 meaningful + 12 nonsensical sentences). It was also necessary to balance the recall component of the task (subject/object) across calls. Thus, half of the calls requested a recall of the subjects of the sentence and half requested a recall of the sentence objects. Any grouping of the calls during experimentation balanced the recall component.

Sentence groups (4 sentences per group) and calls (6 sentence groups) were created in the following manner. First, no call could contain both members of a sentence pair. Also, in a given call, no two sentences would have the same subject or object. The 24 sentences in each call were organized so that the six groups had a balanced and varied number of meaningful and nonsensical sentences: The number of meaningful to nonsense sentences within a group could be 2-2, 3-1, or 1-3. Using these combinations, the six different call orders of sentence groups were constructed as shown below in Table 3:

Table 3. Orders of Meaningful-Nonsensical Combinations for Phone Conversation Task

Call 1	Call 2	Call 3	Call 4	Call 5	Call 6
1-3	2-2	3-1	2-2	1-3	3-1
2-2	1-3	2-2	1-3	3-1	1-3
3-1	3-1	1-3	3-1	2-2	2-2
1-3	2-2	3-1	1-3	3-1	2-2
3-1	1-3	1-3	2-2	2-2	3-1
2-2	3-1	2-2	3-1	1-3	1-3

3.2.5 Evaluation of Conversation Task in the NADS

Once design of the conversation task and implementation method were completed, the audio files containing the "conversations" and instructional documentation were provided by NHTSA to the NADS staff to prepare for their use in the testing. At NADS, the conversation task was presented for the first time via wireless phone in the actual simulator. Problems were identified including inability to understand the sentences presented due to distortion (related to transmission via wireless phone) and insufficient volume. Attempts were made to increase the volume of the audio files presented, but these efforts did not provide noticeable improvement. As a result, the conversation task was recorded using an actual human voice. Files were saved as computer audio files (.wav) to permit later playback using a computer. Baddeley task timing was somewhat less consistent with a human voice; however, efforts were made to minimize this difference.

4.0 METHOD

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

4.1 Experimental Design

The freeway pilot 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.

4.1.1 Independent Variables

4.1.1.1 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). Additional details, including methods for dialing, answering, and conversing, are presented in Table 4.

Table 4. Wireless Phone Task and Wireless Phone Interface Combinations

Phone Task	**Hand-Held (HH):** (Phone stowed in drink holder)	**Headset Hands-Free (HSHF):** (Participants wears headset throughout drive, phone stowed in drink holder)	**Voice Digit Dialing, Speaker Kit Hands-Free (VSHF):** (Phone stowed in cradle, microphone provided for hands-free voice input)
Dialing	D1 (Flip phone open in hand, extend antenna, dial 10-digit number, press 'talk')	D2 (Flip phone open in hand, extend antenna, press '*' then 'talk', say "Call 319-335-xxxx", if number is correctly repeated back, say "yes")	D3 (Reach toward phone in cradle, press '*' then 'talk', say "Call 319-335-xxxx", if number is correctly repeated back, say "yes")
Answering	A1 (Flip phone open in hand, extend antenna, press 'talk', raise phone to ear, say "hello")	A2 (Flip phone open in hand, extend antenna, press 'talk', raise phone to ear, say "hello")	A3 (Reach toward phone in cradle, press '*' then 'talk', say "hello")
Conversing (Talking)	T1 (Phone in hand)	T2 (Phone in hand or resting on lap/seat)	T3 (Phone in cradle)
Baseline	B1/B2/B3		

4.1.1.2 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).

4.1.1.3 Age

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

4.1.2 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.

Table 5. Scenario event stimuli and related dependent measures

STIMULUS	DEPENDENT MEASURE
Lead-Vehicle Braking Event	Accelerator drop reaction time (s) Brake reaction time (s)
Lead Vehicle Cut-In Event	Accelerator drop reaction time (s) Brake reaction time (s)
Car Following Scenario	Delay (s) Modulus Time headway (s) Lane position variability
Merging Scenario	Natural gap stability Time to collision (s) Speed at time of merge (mph) Speed range (mph) Speed differential (mph)
Phone Task Performance	Dialing time (s) Answering time (s) Hang up time (s)

4.1.2.1 Lead Vehicle Braking Event

Reaction time, in seconds, was the main dependent variable examined for the LV braking event.

4.1.2.2 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, brake reaction time (seconds) and three measures of accelerator release time (seconds). 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. The accelerator drop uses the point at which the accelerator pedal reaches zero. The average method uses a criterion of a 66% reduction from the average pedal position value immediately preceding the start of the event. The third method, LMRT, uses a criterion of based on 10% of the minimum value it reaches after the event.

4.1.2.3 Car Following Performance

Dependent variables for the car following event included coherence, delay, and modulus. 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., $\geq .70$), 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.

Delay was the main performance measure in the coherence paradigm. In this study, minimal delay would suggest that the phone task had little impact on driving performance, while a significant delay associated would suggest that the phone task had a negative impact on driving performance.

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 overcorrection, typically resulting from aggressing following. Values less than 1 represent undercorrection, 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.

4.1.2.4 Merging Performance

Aspects of merging performance examined as dependent variables included natural gap stability, time required to merge, TTC (seconds), speed at time of merge (mph), speed differential at time of merge (mph), speed range (mph), and lane position variability.

Natural gap stability was defined as the number of samples immediately before the merge for which the projected gap remained the same. It was hypothesized that the stability of the natural gap would reflect the driver's concentrated attention, such that changes in the natural gap, especially near the merge point, would reflect distracted behavior, presumably due to phone use during merging. Time to collision and velocities of the front and rear vehicles comprising the gap were used to compute distances from the participant vehicle to the front and rear vehicles at the time of merge completion; the two distances were added, ignoring the participant vehicle length to compute gap size at time of merge completion.

The total number of timed samples recorded between the beginning and end of the merge event was used as a measure of the amount of time required to complete the merge. Time to collision (seconds) was computed between the participant vehicle and both the lead vehicle and the following vehicle at the point in time at which the merge event was completed.

The measures of speed at time of merge, speed range, and speed differential were examined for this event. Generally, slower (participant vehicle) speed at the time of entry into the traffic stream may be considered as poorer merging performance. Speed range was indicated by speed at the time the participant's vehicle entered the stream of traffic as well as the computed speed difference between the rear gap vehicle and simulator vehicle (participant vehicle) at the time of merge. Analysis of speed at time of merge assumes that the driver was entering a similar stream on each trial, however due to the autonomy of the vehicles in the stream, this may not be true. Therefore, relating the behavior of the merging vehicle to that of the surrounding vehicles may provide more precision in characterizing merging behavior.

4.1.2.5 Non-Event Driving

For periods of non-event driving, dependent measures examined included lane position variability and speed variability. Lane position variability was defined as the standard deviation of lane position (SDLP).

4.1.2.6 Glance Behavior

Glance behavior was examined during calls as well as during baseline and non-event periods. Dependent measures examined included frequency of glances to various locations of interest and glance duration (in seconds). Glance locations of interest included the forward roadway, the left and right mirrors, and the wireless phone.

4.1.2.7 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.

4.1.3 Incentives

In addition to their base pay ($30), participants earned incentive pay based on their driving performance and wireless phone task performance. The purpose of the incentive system was to set priorities for participants and to promote a balance between driving performance and task performance. The incentive scheme was intended as a method of reliably rewarding participants for performance; it was not intended or designed to be used as a dependent measure.

The monetary rewards and penalties were based on a total number of points allocated for each task during each 15-minute 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 or gained points for performing above expectations. It was not possible for participants to "lose" money beyond what was allocated for incentives. Incentive pay ranged between $0 and $8.00 per drive. Incentive pay totals were never negative (i.e., no pay was taken away from the base pay).

A computer was used to score some tasks. Other tasks were scored by an experimenter located in the control room, who rated driving performance based on criteria such as attentiveness and the smoothness of driving responses.

Table 6 presents the tasks, the total number of points assigned to each task per drive, and the performance criteria. Each drive was also worth a maximum number of points.

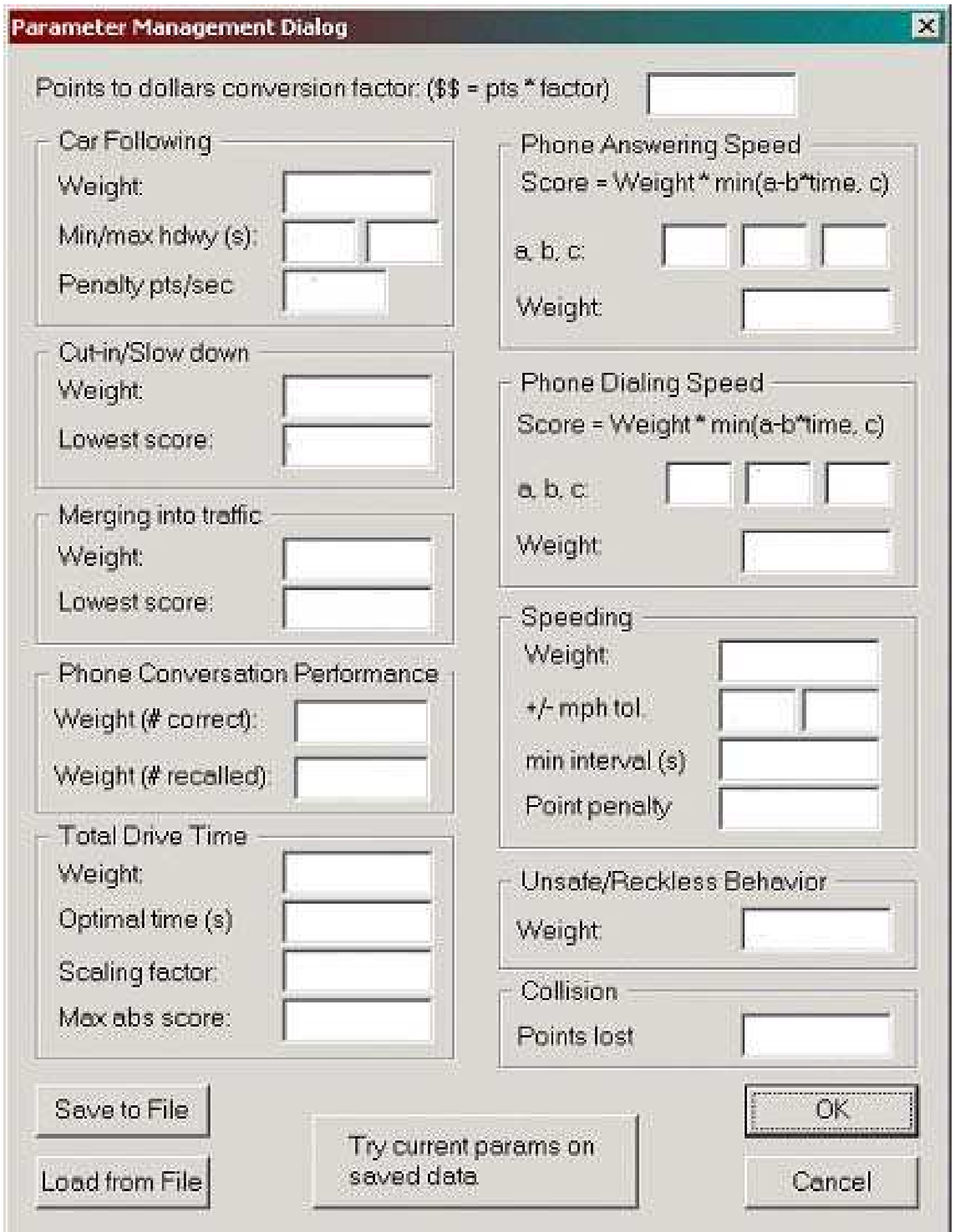
Table 6. Freeway Performance Compensation

Task	Points Per Drive	You receive money for:	Who will score you	Performance Criteria
DRIVING				
Car Following	9	Maintaining constant following distance	Computer	• Following distance varies by less than 30 feet for 90 percent of car following time
Vehicle slowing unexpectedly or cutting in	6	Safe and timely response	Experimenter	• Safe response • Acceptable response • Unsafe response
Merging in traffic	3	Merging without collision	Computer	• Correct decision • Safe execution of decision
Time to complete drive	+2 to – 2	Timely completion of the drive	Computer	• Completion time relative to target completion time
Speeding	-1	Keeping speed within the posted maximum & minimum speed limit	Computer	• Keeping speed within the posted maximum and minimum speed limit
Unsafe/reckless behavior	-2	Driving safely and attentively	Experimenter	• Safe • Unsafe
Collision avoidance	-5	Avoiding collisions	Computer	• Hit other cars or objects • Did not hit other cars
PHONE USE				
Conversation task performance	4	Correctly answering sentences and correctly recalling target words	Experimenter	• Percent correct classification and recall
Answering speed	1	Answering the phone quickly when it rings	Computer	• 2 rings or faster • Slower than 2 rings
Dialing speed	1	Quickly dialing phone number without making errors	Computer	• 10 seconds or less • Greater than 10 seconds

During the treatment drives, the incentive scheme tool calculated the incentives in real-time by sampling the performance of the participant at regular intervals. The actual duration of the interval varied, ranging from 0.2 to 1.0 seconds. At each sampling interval, the current state of the simulator variables was collected along with the current state of the scores that had been typed in by an experimenter. A score was then calculated based on a set of scoring parameters and the current state of variables. The scores for each rule were weighted by a scaling factor and summed together to compute a total score. At the end of each drive, point totals were multiplied by a pay rate that determines the actual amount of money received.

The rules used variable names as placeholders for parameters that were changeable. The automated tool allowed for the specification of all parameters and provided the ability to save them, to load them, and to "record" a drive and allow what-if scenarios by using the same driving performance but different parameters/weights. Since the weight parameters were changeable, they are not shown explicitly. Figure 9 contains an image showing the layout of window that pops up when the "Manage Parameters" button was pressed. Figures 10 shows a screenshot of the incentive system graphical interface.

Figure 9. Incentive Tool Parameter Management Dialog User Interface.



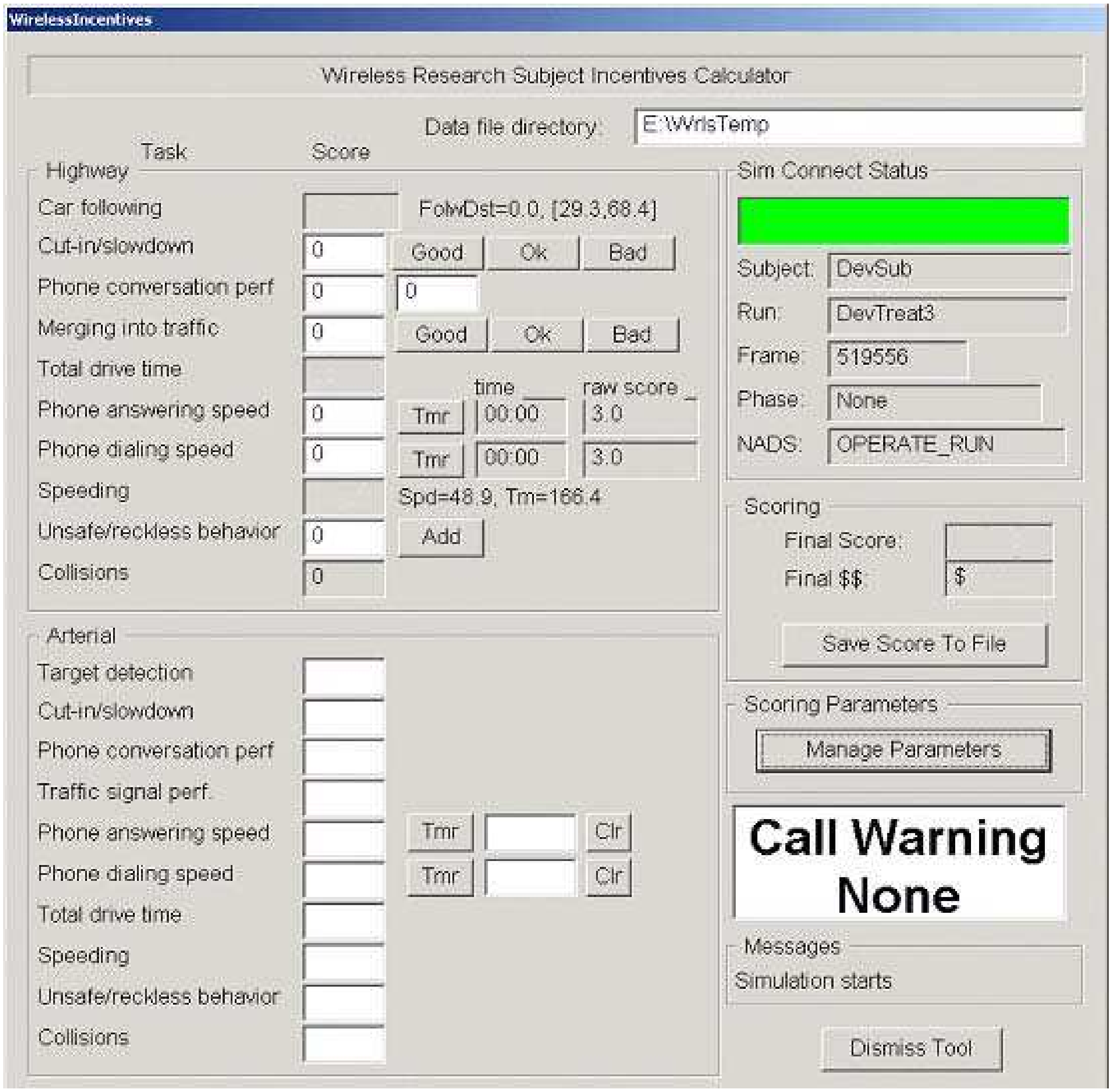


Figure 10. Incentive System Graphical Interface.

4.2 Participants

Participants were recruited to produce a balance of gender and age. All participants were required to be existing users of wireless phones with a minimum of 6 months of wireless phone experience. In addition, to be accepted for participation in the study potential participants had to have responded affirmatively when asked whether they at least occasionally talked on a wireless phone while driving.

4.3 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 11. The phone ring tone was set to ringer #6, since this tone was judged to sound most like a typical phone ring tone. Figure 12 shows the headset selected for use in the study (Plantronics M120). This headset was selected because it had a noise-canceling boom microphone. The earpiece of the headset wrapped around the ear and could be manipulated such that it conformed to the shape of the individual's ear. The ear piece could also be made to fit tightly against the ear by pressing it tightly to the ear, causing the 2 parts of the ear piece to clamp down on the exterior of the ear.

Figure 11. Wireless Phone Model Used in the Experiment (Samsung A460).

Figure 12. Phone Headset Used in the "Headset Hands-Free" Condition (Plantronics M120).

Figure 13 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 14 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 13. Photograph Showing VSHF Hands-Free Speaker Kit Setup and Phone Cradle Location.

Figure 14. Photograph Showing Location of Phone Cradle and Phone Number Pad Location.

4.4 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.

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/.

4.4.1 Eye Tracker

Although an eye tracker was not installed for use in the pilot study, as part of this research project an eye tracking system was purchased for installation in the NADS with the intention of using it to record drivers' eye glance behavior in the main experiment. The system selected was the "faceLAB™" by Seeing Machines. A combination of stereo video cameras and software allows the system to track a participant's head direction, face direction, and blink events. Additional details about this system and its use in the main experiment will be provided in a subsequent report.

4.4.2 Wireless Phone Service Implementation in the NADS

Early on, the decision was made to use 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, with custom single chip designs many of the functions are implemented without discrete circuitry possibly requiring proprietary knowledge of the chip design. 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 actual digital wireless service was chosen.

4.5 Experimental Procedures

Twelve individuals participated in the pilot study. All participants first completed a 15-minute familiarization drive, in which they experienced the experimental scenario without the use of the wireless phone. Experimental treatments were presented to participants in randomized order. For each of the three wireless interface conditions, participants completed a 5-minute practice drive. The practice drive required participants to both place and receive one phone call. The practice drive did not contain scenario events. Following the 5-minute practice drive, each participant completed a 15-minute experimental drive where they experienced all scenario events while completing baseline, one outgoing, and one incoming call. Thus, each participant in the pilot study initiated three calls and received three calls during the course of their drives. During each call, participants performed the conversation task. Thus, each pilot study participant experienced 75 total minutes of simulator driving. The total time each participant spent in the simulator including driving and in-vehicle instruction was approximately 1.5 hours.

Procedures for each segment of the experiment are presented in the following sections. Additional procedural details will be provided in the subsequent final report.

4.5.1 Screening

Experimental staff completed a standard telephone screening procedure, augmented with questions regarding wireless phone use. Details of this screening procedure will be provided in the subsequent final report.

4.5.2 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 and were 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 (reference). The participant preparation period concluded when the participant was instructed as to how the incentive scheme for driving performance was applied.

4.5.3 Prep Room Pre-Drive Instruction and Training

4.5.3.1 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 of 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 their driving they would be required to place and receive phone calls. They were instructed to answer the phone by saying, “hello.” The participant was instructed that during their drive 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 subject 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.

4.5.3.2 Working Memory Task Training

The participant was next presented with pre-recorded instructions for the working memory 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.

4.5.3.3 Driving Overview

The participant was shown video clips 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) along with a brief explanation by experimental staff. 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.

4.5.4 Driving

The participant was introduced to the in-vehicle experimenter, who took over at this point. The participant was escorted to the vehicle and seated, then given 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?"

4.5.4.1 Familiarization Drive

The participant was asked to drive the freeway route in its entirety to allow them to get familiarized with driving the simulator and the roadway scenarios. Participants experienced the car following scenario and were provided with guidance regarding the appropriate following distance to maintain.

4.5.4.2 Practice Drive

The participant completed one short practice drive during which he or she practiced answering and placing calls.

4.5.4.3 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 each of the drives, the participant was instructed as to which phone interface to hook up and use in the next drive.

4.5.4.4 End of Driving

After the driving trial was complete and the vehicle shifted into PARK, the Simulator Sickness Questionnaire 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.

4.5.5 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, NADS Wireless Phone Post-Drive Survey, and NADS Personal Wireless Phone Post-Drive Survey were administered. Finally, the experimenter asked the participant to sign the payment voucher, describing how compensation was related to driving performance. The participant was then escorted to the exit.

4.6 Phone Task Data Reduction

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 15.

Connecting (Answering/Dialing)	**Conversation Task (Baddeley)**	**Disconnecting** (Hanging Up)

Figure 15. 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 16 through 18.

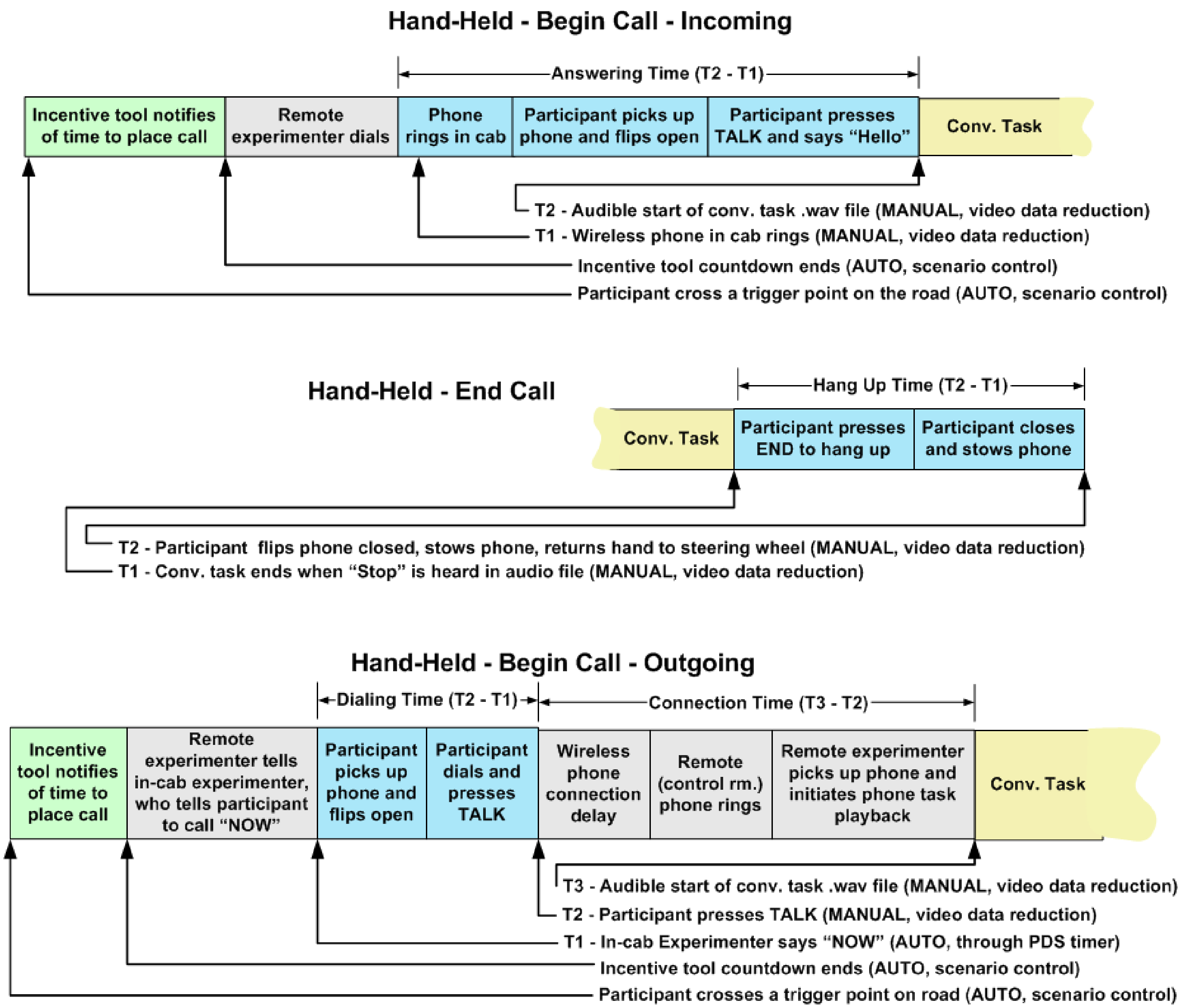


Figure 16. Components of Calls Using the HH Phone Interface.

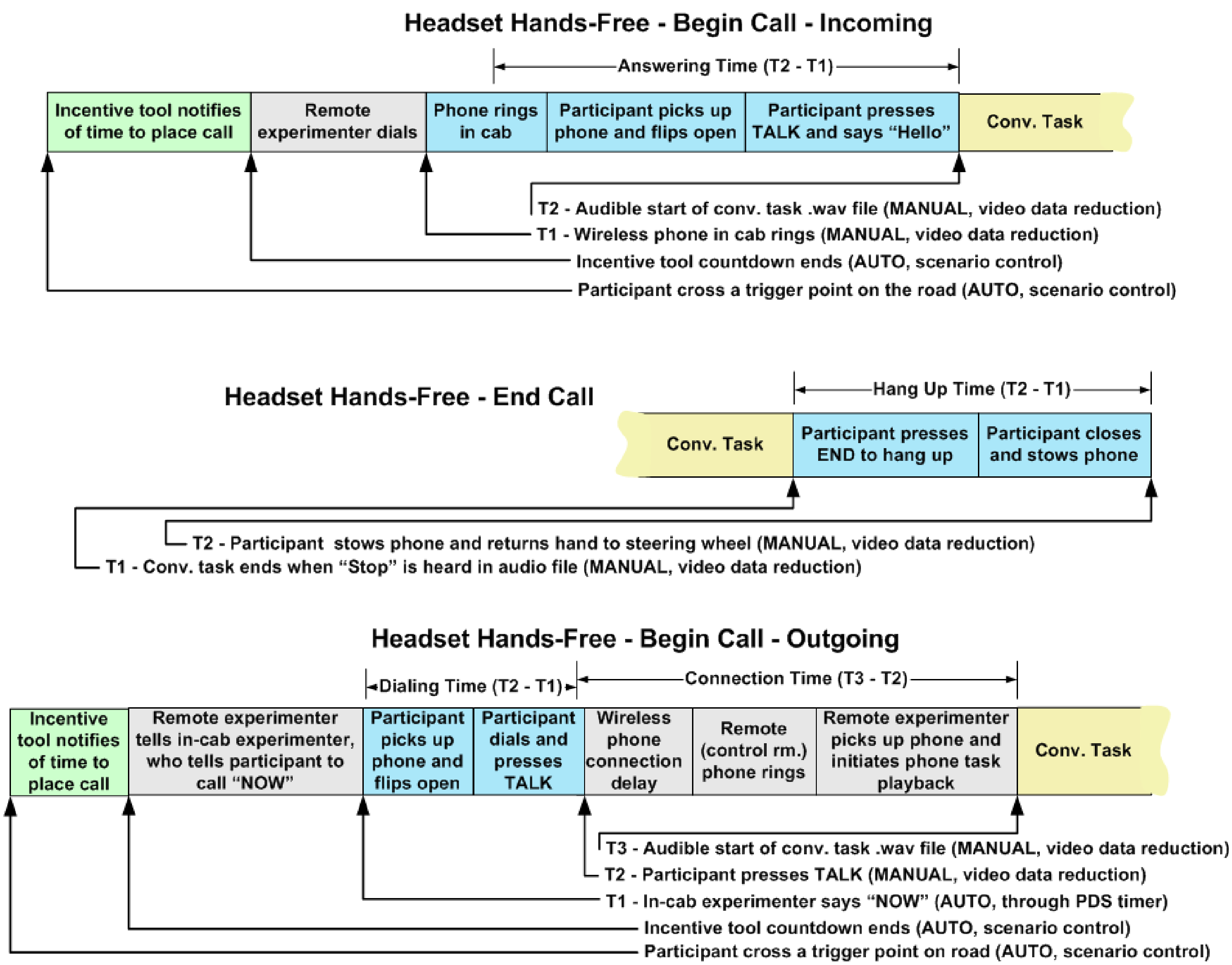


Figure 17. Components of Calls Using the HHF Phone Interface.

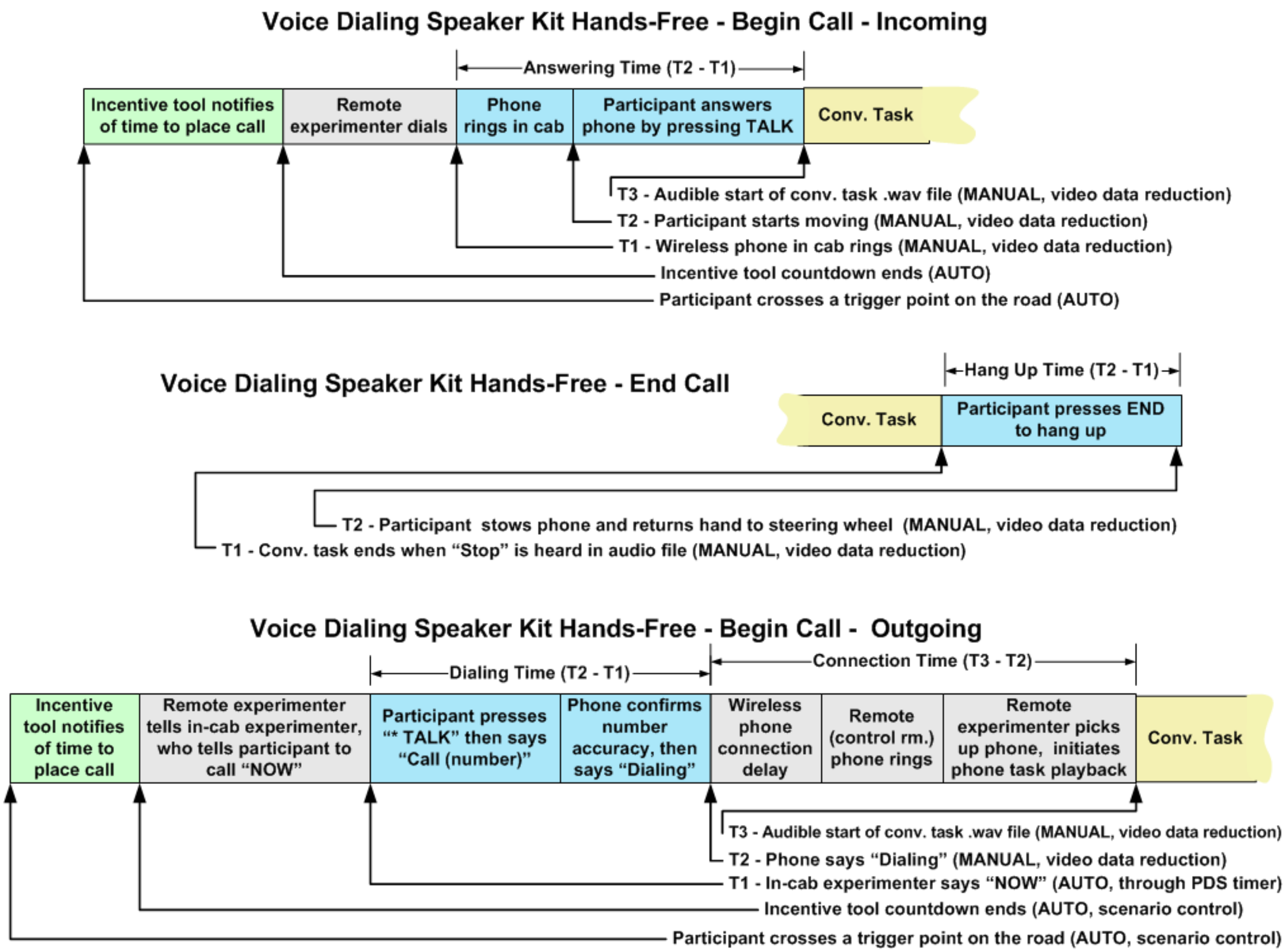


Figure 18. Components of an Outgoing Call Using the VSHF Phone Interface.

4.7 Pilot Data Review

Several activities took place following completion of the freeway pilot study data collection. Scenarios were reviewed in an effort to identify blatant scenario problems (cars hitting each other, events not happening, etc.) and to determine how to fix them for the main experiment. Video recordings of pilot participants' drives were analyzed to determine how events varied for different participants (e.g., car following events starting at different times due to delayed participant engagement in the event). An attempt was made to categorize the event variations in a way that made analysis possible. This examination of event variation required preliminary data reduction of the various events to be performed.

After discrete events were categorized and the analysis within categories was performed, an attempt was made to determine whether comparability of the event data could be improved by modifying the events prior to data collection for the main experiment.

5.0 FREEWAY PILOT TEST DETAILS AND EXAMPLE DATA

The pilot study was conducted to assess the adequacy of the experimental design, procedures, and data collection and reduction techniques prior to their large-scale use in the main experiment. This pilot study also allowed identification of problems with scenarios that required subsequent fine-tuning. In addition, the performance of wireless phone equipment selected for use in the experiment was tested to see if it operated sufficiently well in the NADS dome environment.

Preliminary analyses were conducted using data obtained from the 12 pilot participants. Data were first examined for the purpose of confirming that the quality of data collection channels and the adequacy of data reduction techniques developed for use in this study were acceptable. Once the quality of both raw and reduced data was confirmed, statistical analyses were performed to assess the sensitivity of dependent measures and quality of the design of events (e.g., cut-in, lead vehicle braking event). The analyses presented represent those that are planned to be performed on the data collected in the main experiment. Results presented below are provided for illustration purposes only, and are not intended to represent the definitive findings of this research.

5.1 Effect of Wireless Phone Interface on Car-Following Behavior

For most performance measures, two Analyses of Variance (ANOVAs) were computed using car-following parameters as dependent measures. The first ANOVA was intended to allow determination of whether the being involved in a phone conversation generally, independent of interface and type of phone call, influenced driving performance. For this analysis data were from incoming and outgoing phone calls were combined and collapsed across all three interface conditions, resulting in the set of trials involving any phone call. The three baseline conditions were combined separately to represent the set of trials with no phone call. Thus the single (within-subjects) factor in the model was the presence or absence of a phone conversation. The second analysis was intended to examine differences between interface conditions. For this analysis, data were combined across incoming and outgoing calls and the three baseline conditions were combined. Thus the single (within-subjects) factor in this analysis was phone interface condition (HH, HSHF, VSHF, Baseline). Driver age group was not included in either analysis model due to the small number of subjects in each age group.

Coherence values were extremely high overall, indicating that participants followed lead vehicle speed changes quite well (M = 0.98, SD = 0.02). The high coherence values also reflect the relatively close following distances. Specifically, the mean time headway during car following was 0.83 seconds (SD = 0.27, Min = 0.45, Max = 1.8). At 50 mph, this reflects a following distance of 61 feet. The results of statistical analyses revealed no effects of conversation or interface, indicating that coherence values remained relatively consistent across conditions.

Delay (seconds) was the main performance measure in the car following paradigm, reflecting the phase shift between the lead and following vehicle speeds. The first analysis revealed a significant difference between trials with and without a phone call, $F(1,11) = 6.70$, $p = .025$. This effect, which is shown in Figure 19, indicates that involvement in a conversation increased the delay by approximately 0.4 seconds, when data from all interface conditions are combined.

The results of the second analysis revealed no significant differences between interface conditions, $F(3,33) = 2.42$, $p = .08$.

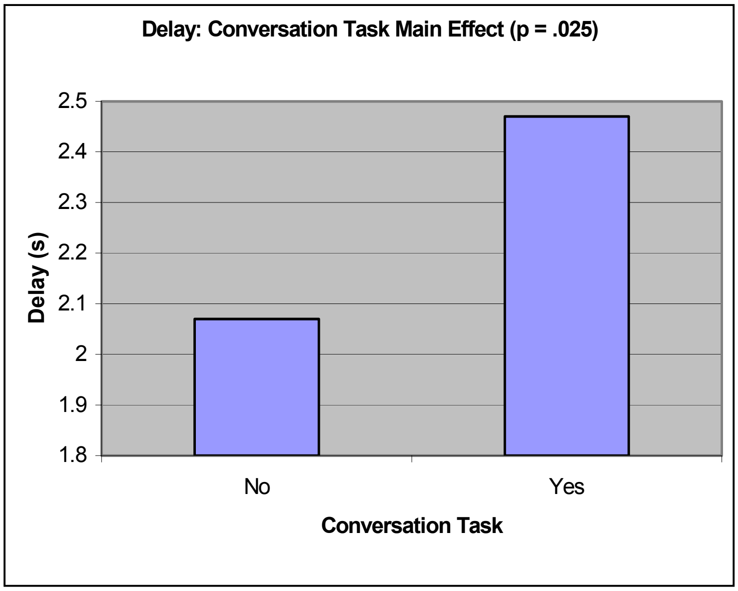


Figure 19. Main effect of Conversation Task on Car-Following Delay.

Modulus was the third parameter in the coherence paradigm, reflecting the gain associated with the following vehicle speed, relative to the lead vehicle speed. The overall effect of the conversation task, reflected in the conversation task main effect was significant, $F(1,11) = 9.94$, $p = .009$, as shown in Figure 20.

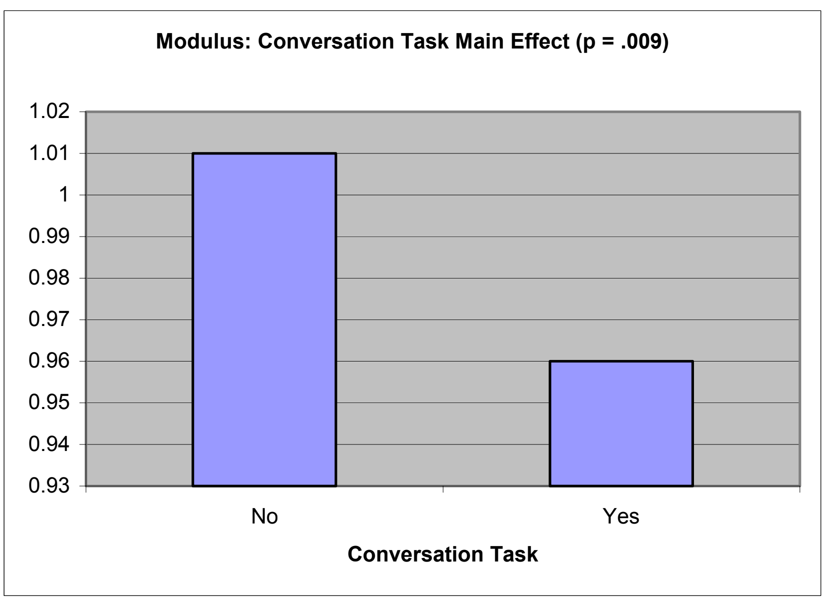


Figure 20. Main Effect of Conversation Task on Car-Following Modulus.

As stated previously, 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 overcorrection, typically resulting from aggressing following. Values less than 1 represent undercorrection, typically resulting from conservative following. Figure 23 shows that while involved in simulated conversations, drivers exhibited under-correction of a greater magnitude than the slight over-correction observed in the no-conversation condition. The results of the second analysis revealed significant differences between the interface conditions, $F(3,33) = 6.72$, $p = .001$ Specifically, the mean value for the Hand-Held conditions (M = .90) was significantly less than that associated with the Voice Dialing Speaker Kit Hands-Free (M = 0.98) or Headset Hands-Fee condition (M = 0.99), which suggests more conservative car-following when using the Hand-held phone.

Time headway was also examined. Although instructed to maintain a constant following distance, participants typically adjusted their following distances in an attempt to compensate for changes in driving/secondary task demands. Figure 21 shows that drivers generally increased their time headways during the conversation task, relative to the baseline trials. $F(1,11) = 4.48$, $p = .0578$. There were no differences between interface condition, $F(3,33) = 1.73$, $p = .18$.

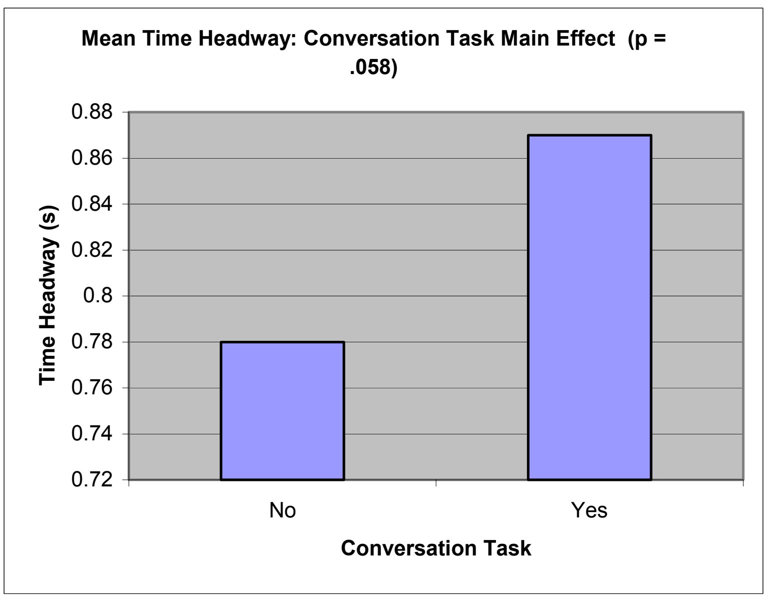


Figure 21. The Effect of Conversation Task on Time Headway During Car Following.

The effect of conversation task on the standard deviation of lane position is shown in Figure 22. Larger values of SDLP have traditionally been interpreted as reflecting impaired performance. As such, the results indicate that lane position performance was more impaired when participants were not on the phone than when they were involved in a conversation, $F(1,7) = 11.28$, $p=0.0121$. It should be noted, however, that the task instructions did not explicitly indicate that participants should attempt to minimize deviations in lane position.

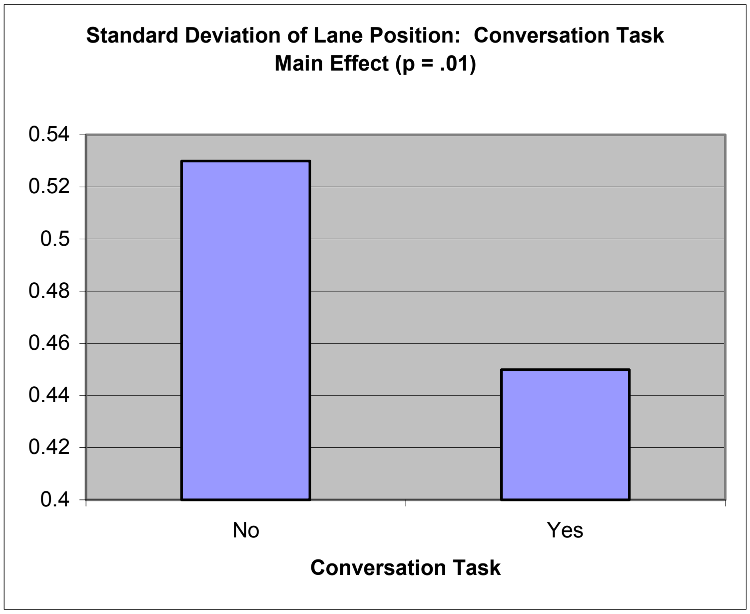


Figure 22. Effect of Conversation Task on Standard Deviation of Lane Position (SDLP) During Car Following.

One hypothesis concerning vehicle control performance is that participants trade resources between car-following and lane position. Specifically, when faced with a secondary task that requires diversion of attention from driving, the participant must either divert resources from car-following, which would be reflected primarily in increased values of delay (phase shift), or from lane maintenance, which would be reflected as increased SDLP values. To test this hypothesis the correlation between delay and SDLP with and without the conversation task was examined. A significant correlation was found between phase shift (delay) and SDLP during car-following segments with conversations ($r = 0.45$, $p = .0013$), but not during car-following segments with no conversations ($r = 0.18$, $p = .39$). The difference between correlations suggests that there was a relation between car-following delay and SDLP during conversations, but not otherwise during car following. The direction of the correlation was not consistent with the hypothesis that drivers trade lane maintenance for car following performance. Rather, the positive correlation indicates that impairment on one measure (e.g., increasing SDLP) increases with impairment on the other measure (e.g., increasing delay) during conversations.

5.2 Effect of Phone Interface on Merging Behavior

Participants completed three merge events in each scenario. Two merges were undertaken while the driver was engaged in a phone call and one was completed without the phone call. Each merge required the driver to exit from the main freeway at the posted speed limit and traverse the following three freeway interchange components: initial curve (1240 ft.), intermediate straight section (1060 ft.), curved section that merges with the new freeway segment (1700 ft.). The entire freeway interchange consisted of a single-lane, delineated road. For purposes of data analysis, the freeway interchange, or merge, event was divided into two components, referred to as Merge 1 event and Merge 2 event. The Merge 1 event included behavior during the curved road segment used to exit the freeway plus a portion of the second straight road section. The Merge 2 event included behavior during the latter part of the straight road section and in the entirety of the third geometric section of the merge, which was curved. The physical location marking the end of the Merge 1 event does not correspond to the beginning of the Merge 2 event. Rather, there was some portion of straight roadway between the end of the Merge 1 event and the beginning of the Merge 2 event.

5.2.1 Merge 1 Event

Vehicle travel speed and lane position (SDLP) during the Merge 1 event was examined to assess how drivers adjusted their speed and maintained their lateral position within the travel lane. Table 6 summarizes the Merge 1 performance measures for the phone call and no-phone call conditions.

Table 7. Merge 1 Event Performance Measures

Measure	**No phone call**		**Phone call**	
	M	**SD**	**M**	**SD**
Speed range (mph)	7.12	3.14	6.78	2.76
Mean speed (mph)	55.7	4.3	55.6	3.7
Std speed (mph)	1.94	0.90	1.88	0.87
STD lane position	2.09	0.50	2.12	0.54

Differences were very small and not indicative of performance impairment due to phone use. None of these differences was statistically significant. Similarly, there were no reliable differences between interface conditions.

5.2.2 Merge 2 Event

Conceptually, the beginning point for the Merge 2 event was the position at which drivers begin typically their tactical decision-making to determine how and when to enter the traffic stream. No objective basis exists for the selection of this point. However, the point may be based on a combination of roadway geometrics, sight distance, and individual differences among drivers. Additional details regarding the specification of this point will be provided in the final report for the main experiment.

Data from the Merge 2 event consisted of two summary measures (speed at beginning of event, speed at end of event), plus data sampled once per second during the event that includes the following measures: (1) ID numbers of vehicles forming the projected correct gap, referred to as the natural gap, (2) Velocity for two stream vehicles that comprise the current natural gap, (3) TTC values for the same two stream vehicles. These data were used to compute the measures listed below.

5.2.2.1 Natural Gap Stability

The number of samples for which the final gap remained the same varied between 1 and 11. The mean was 5.2 (SD = 2.77). The mean number of same samples while on the phone was 5.3 versus 4.5 when there was no phone call, which indicates higher stability during merges with phone calls than during merges with no phone calls, $F(3,31) = 2.94$, $p = .05$. Post hoc tests revealed there were no differences between interface conditions.

5.2.2.2 Time Required for Merging

The total number of samples varied from 10 to 16. The overall mean was 13.3 (SD = 1.4). There were no differences between trials with and without phone calls, $F(1,11) = 3.39$, $p = .09$.

5.2.2.3 Speed at Time of Merge

Vehicle speed at time of merge varied from 65.3 ft/sec to 107.8 ft/sec. The three slowest speeds were outliers, which may indicate significant problems in merging on some trials. The overall mean was 96.5 (SD = 6.7). The ANOVA results indicate that the main effect of phone call was not significant, $F(1,11) = 0.02$, $p = .88$, nor were the differences between interface conditions significant, $F(3,31) = 0.69$, $p = .57$.

5.2.2.4 Speed Differential at Time of Merge

The speed difference between the rear gap vehicle and participant vehicle was computed at the time of merge. The value of this speed difference ranged from –11.9 to 45.5 ft/sec. Negative values were observed for about 20% of the trials indicating that the merging drivers entered the traffic stream faster than the following vehicle on these trials. Overall, the speed difference was slightly greater on phone trials (M = 8.8) versus no-call trials (M = 8.6), but this difference was not significant, $F(1,11) = 0.10$, $p = .76$.

5.2.2.5 Time to Collision Values

Two values of TTC were computed at the point in time at which the merge event was completed. The TTC values were between the participant vehicle and the lead and following vehicles comprising the gap into which the driver merged.

The relevance of the different TTC values depends on the relative speeds between the participant vehicle and the lead or following vehicles. For example if the participant vehicle enters a gap and was traveling faster than both the lead and following vehicles, then the TTC to the lead vehicle was relevant, but the TTC to the following vehicle was not. Similarly, if the participant vehicle enters the traffic stream traveling slower than both the lead and following vehicles, then the TTC to the following vehicle has meaning, but the TTC to the lead vehicle does not.

The two subsets of trials with positive TTC values were examined at the time of merge, including (1) trials on which the participant vehicle was traveling faster than the lead gap vehicle, and (2) trials on which the participant vehicle was traveling slower than the rear gap vehicle. For the pilot study the merge stream vehicle speeds were not constant. Therefore, it was possible that some trials satisfied both conditions at the instant of the merge. Of 106 merge events, 24 (23%) satisfied the first criterion. Unfortunately for this group of trials, only two had sufficient information to compute TTC to the forward vehicle.

There were 85 (80%) trials that satisfied the second criterion. For this set of trials the mean TTC between the participant vehicle and the rear vehicle was 26.4 seconds (SD = 35.0), with a range of 4.7 to 244 seconds. This range included several obvious outliers; 95% of the gaps were less than 83 seconds. Assuming that TTC values of approximately 10 seconds or less reflect situations in which the driver of one vehicle may be influenced by the behavior of the other vehicle, it can be seen that approximately 25% of the selected trials have TTC values of 10.5 or less. This suggests that for the majority of trials, the merging driver was not influenced by the speed of the following vehicle.

An ANOVA was computed on this latter subset of 85 trials, for which the participant vehicle speed at time of merge was slower than the velocity of the rear gap vehicle. Rear vehicle TTC was used as the dependent measure. In this analysis, there was a large difference between phone-call trials (M = 23.9) and non-phone-call trials (M = 31.6), but due to the extremely high variability associated with variability of the gap size, this difference was not statistically significant. There were no differences between interface conditions.

With average speed differences of approximately 8.7 ft/sec (see above), the gap size between the participant vehicle and rear vehicle was approximately 208 ft for TTC of 23.9 (phone call trials) and approximately 275 ft for TTC of 31.6 (no-phone call trials).

5.2.2.6 Gap Sizes

Although the merge scenario was designed so that while approaching the merge point, the participant would encounter a continuous stream of regularly-spaced vehicles, inter-vehicle gap sizes appeared to vary more than was considered acceptable during the pilot study. In order for this event to be useful and results to be comparable across participants, the event must present an equal challenge (i.e., same gap size and same traffic stream speed) to all participants. As a result, an examination of gap size was performed to assess the variability of the scenario event.

Time to collision values and velocities of the front and rear vehicles comprising the gap were used to compute distances from the participant vehicle to the front and rear vehicles at the time of merge completion. The two distances were added, ignoring the participant vehicle length to compute gap size at time of merge completion. This value was not used as a dependent measure, but rather it represented a measure of scenario event consistency. Using this method, the average gap size was computed to be 372 ft (SD = 152). Gap sizes ranged between 82 and 739 feet. Due to this large variance in gap sizes, it was decided that additional efforts were needed to increase the consistency of this event for the main experiment.

5.3 Results for the Lead Vehicle Braking Event

Prior to analyzing the reaction time data for this event, an assessment of the consistency of event presentation was performed. The bumper-to-bumper distance (headway) between vehicles at the initiation of the lead vehicle braking event was examined. Distances ranged between 22.6 and 307.5 feet (M = 129.5, SD = 65.5). The relatively wide range of values suggests that data from different events would not be easily compared. It was therefore decided not to reduce the pilot data necessary for computation of driver response time to the braking events. As a result of the variability in this event, improvements to this event were deemed necessary to implement prior to the main experiment.

5.4 Results for the 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 are four performance measures associated with the cut-in events, brake reaction time and three measures of accelerator release time. 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. The accelerator drop uses the point at which the accelerator pedal reaches zero. The average method uses a criterion of a 66% reduction from the average pedal position value immediately preceding the start of the event. The third method, LMRT, uses a criterion of based on 10% of the minimum value it reaches after the event. First, the correlations among the three accelerator release variables were examined, plus brake response time. These correlations are summarized in the following table.

Table 8. Correlations Among Accelerator Release Measures and Brake Response Time for Cut-in Event

Measure	Accelerator drop	Accelerator average	Accelerator LMRT
Brake response time (s)	r = 0.60 (p < .0001)	r = 0.38 (p = .004)	r = 0.17 (p = .22)
Accelerator drop	---	r = 0.75 (p<.0001)	r = 0.11 (p =.39)
Accelerator average	---	---	r = 0.10 (p = .44)

Brake response time exhibited the strongest correlation with the accelerator drop measures, which most likely reflects the fact that complete release of the accelerator pedal would precede brake application.

Means and standard deviations for each of these measures are presented in the following table.

Table 9. Means and Standard Deviations for Accelerator Release and Brake Response Time Measures

Measure	Mean	SD
Brake response time (s)	3.03	1.00
Accelerator drop (s)	2.36	1.12
Accelerator average	2.09	0.97
Accelerator LMRT	1.32	1.16

ANOVAs were computed using each of the measures. Of particular interest were the effects of Phone call (Yes, No), Interface (HH, HSHF, VSHF), and the Phone call x Interface interaction. The results are summarized in Table 9.

Table 10. Summary of ANOVA Results for Accelerator Release and Brake Response Time Measures for Cut-in Events

Measure	Phone call	Interface	Phone call x Interface
Brake response time (s)	$F(1,11) = 25.06$, $p = .0004$	NS	NS
Accelerator drop	$F(1,11) = 3.89$, $p = .07$	NS	NS
Accelerator average	$F(1,1) = 3.52$, $p = .09$	NS	NS
Accelerator LMRT	NS	NS	NS

The main effect of phone call on brake response time was significant. Brake response times were considerably slower during phone calls (M = 3.43, SD = 0.98) than during baseline driving segments (M = 2.66, SD = 0.88).

The non-significant main effect of phone call for accelerator drop revealed slower accelerator drop during phone calls (M = 2.57, SD = 1.23) than during baseline driving segments (M = 2.15, SD = 0.96).

The accelerator average variable revealed a marginally non-significant main effect of phone call. Accelerator average release time was slower during a call (M= 2.38, SD = 1.05) than during baseline driving (M = 1.81, SD = 0.79).

For the Accelerator LMRT variable, there were no differences identified by statistical analysis.

5.5 Phone Use Performance Preliminary Analyses and Example Data

Preliminary analyses of dialing, answering, and conversation task performance were conducted using data obtained from the 12 pilot participants. Results are presented below.

5.5.1 Phone Dialing Speed

Values for this measure ranged from 15 to 278 seconds (M = 44.9, SD = 49.2). The large amount of variability was due to the existence of three outliers (278, 147, 129), all of which occurred in the Voice Dialing Speaker Kit Hands-Free condition. For exploratory purposes, outliers were removed on the assumption that dialing times greater than 2 minutes reflect a significant problem. This improved the normality of the distribution (M = 31.4, SD = 8.95, Min = 15, Max = 53). An ANOVA was computed on the resulting distribution and found a significant main effect of interface condition, $F(2,17) = 7.57$, $p = .0045$. Means and standard deviations are shown in the following table.

Table 11. Phone Dialing Speed for Each Interface Condition

Interface	Phone Dialing Speed	
	Mean	STD
Hand Held	25.8	4.7
Head Set Hands-Free	30.8	9.6
Voice Dialing Speaker Kit Hands-Free	38.8	7.2

Voice Dialing Speaker Kit Hands-Free dialing was considerably slower than dialing in the other two conditions.

5.5.2 Phone Answering Speed

Values for this measure varied between 3 and 17 seconds (M = 8.2, SD = 3.6). ANOVA results indicated a significant effect of interface condition, $F(2,20) = 19.09$, $p < .0001$. Means and standard deviations are shown in the following table.

Table 12. Phone Answering Speed for Each Interface Condition

Interface	Phone Answering Speed	
	Mean	**STD**
Hand Held	10.1	2.5
Head Set Hands-Free	10.0	3.3
Voice Dialing Speaker Kit Hands-Free	5.0	2.3

Answering was clearly fastest in the Voice Dialing Speaker Kit Hands-Free condition.

5.5.3 Baddeley Task Preliminary Analyses and Example Data

The present analyses address conversation task performance only; these results should be considered in light of driving performance, as it is possible that participants may have focused on one task to the detriment of the other.

Analyses were conducted to examine the effects of age, gender, phone interface, and practice on Baddeley task scores. Analysis of results of the Baddeley task sought to determine the following:

- Did performance on the task improve over the course of the study or was it steady? (i.e., this may help us understand if whether enough practice is being given to participants or if more is necessary prior to data collection.)
- Did performance vary within a call, and if so why? Was it scenario related, content related, and how can this be compared to the scenario events?
- Were there drop outs in the data where people abandoned the task completely? If so, when and why?
- What other trends appear in the data that are relevant to understanding the usefulness of the Baddeley task and interpretation of the data?

Two conversation task performance measures were considered; total judgment (total number of sentences correctly identified as sensible or nonsensical), and total recall (total number of key words correctly recalled). For each call, scores on each measure could range from 0 to 24.

5.5.3.1 Missing Data

Data from one participant (an older female) were missing for two calls due to technical difficulties. 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.

5.5.3.2 Practice Effects

The variable call allowed for examination of practice effects, in that each participant completed the calls in the same order and these were labeled 1 through 6. Analyses were conducted to determine whether performance improved over time; that is, across calls 1 through 6. Examination of call data revealed no significant differences in mean performance across calls for either dependent variable (judgment or recall). Participants' performance did not improve as a function of practice or familiarity with the task.

5.5.3.3 Interface Condition

No differences were found for interface condition, nor for the interaction of age, gender, and interface condition.

5.5.3.4 Age and Gender

For judgment, no differences were found between age or gender groups. Participants performed consistently well on this aspect of the task, with most scores falling between 21 and 24. For recall, significant differences were found for age and gender. Regarding gender, females recalled significantly more words (M = 18.41, n = 34) on average than did males (M = 16.03, n = 34). Follow-up analyses for age revealed that the young group recalled significantly more words (M = 21.21, n = 24) than did the middle (M = 15.96, n = 24) and older groups (M = 14.14, n = 22). These findings are illustrated in Figures 23-25.

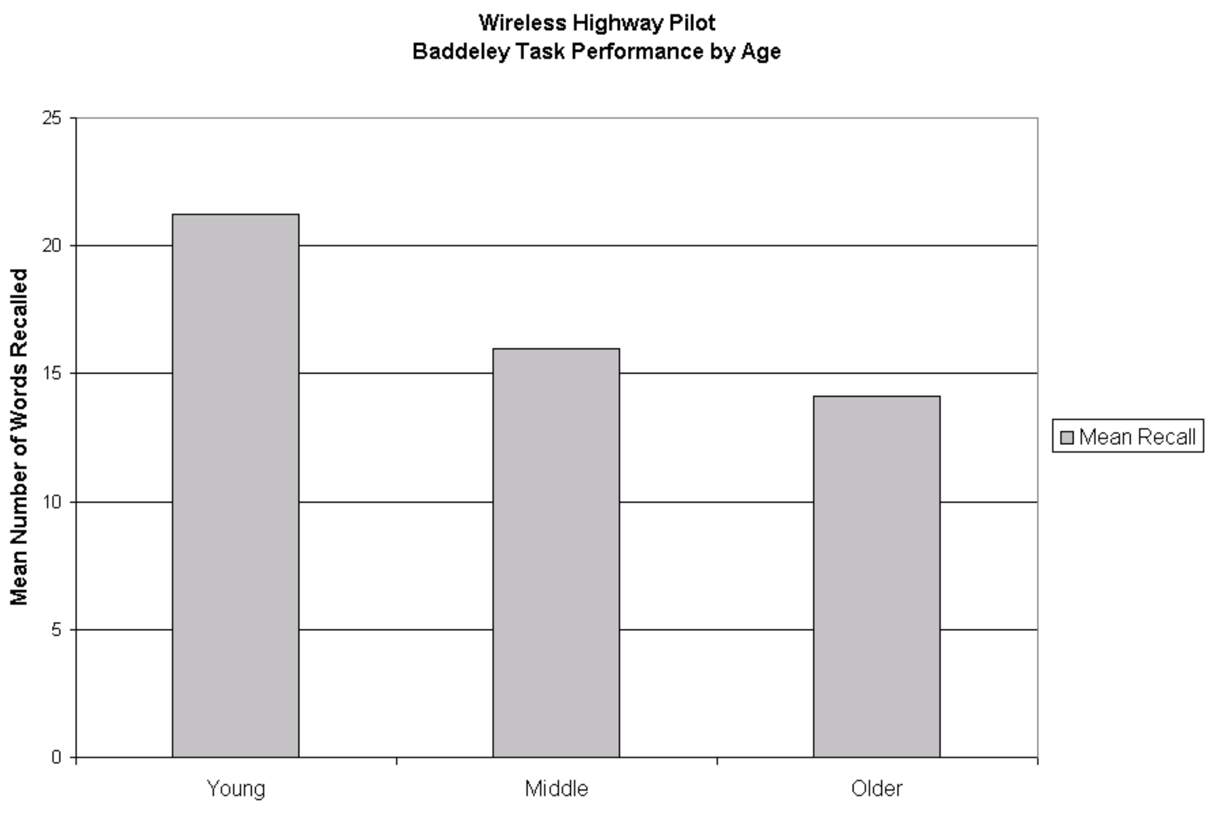


Figure 23. Baddeley Task Recall Performance by Age – Freeway Pilot

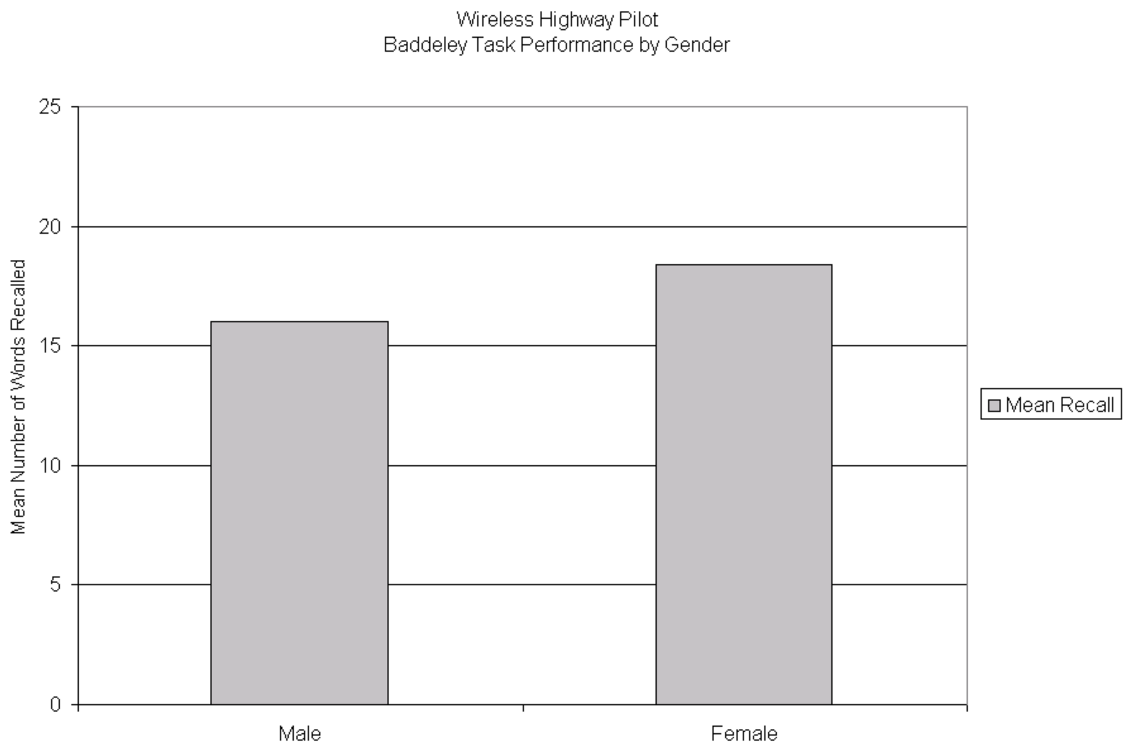


Figure 24. Baddeley Task Recall Performance by Gender – Freeway Pilot

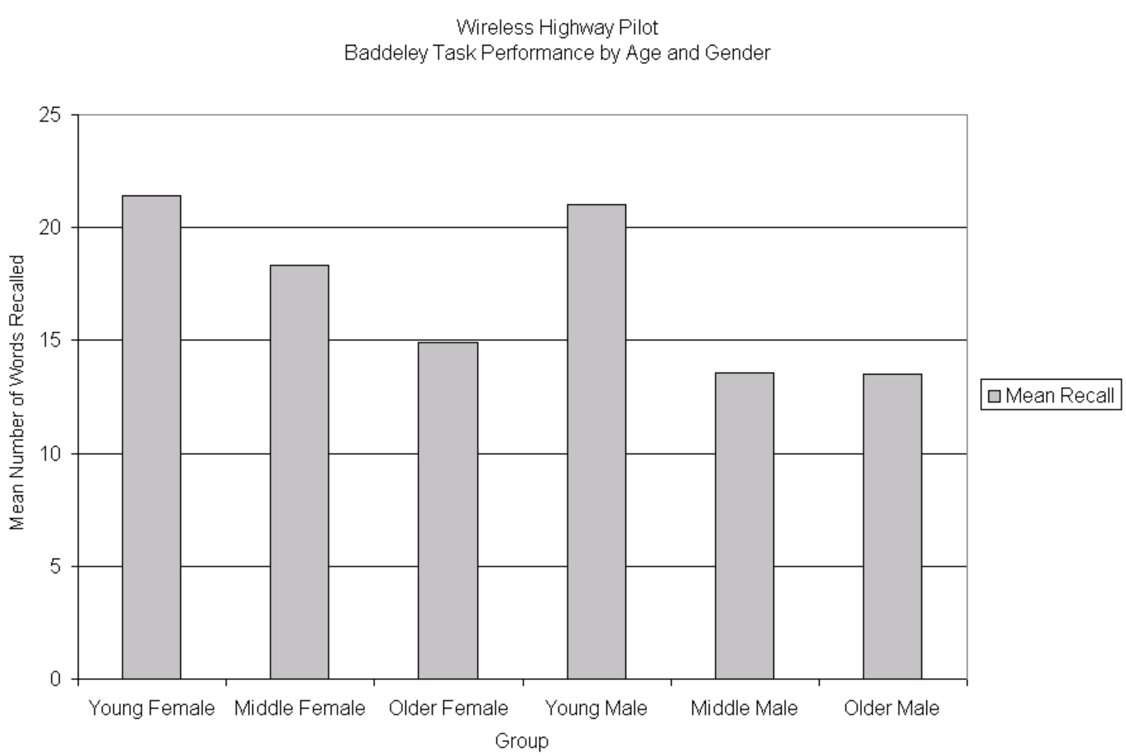


Figure 25. Baddeley Task Recall Performance by Age and Gender – Freeway Pilot.

5.6 Preliminary Driving Performance and Phone Task Performance Observations

One of the purposes of the pilot study was to collect data that could be examined to assess the quality of data and the extent to which the measures appeared to be sensitive. The following list summarizes the observations from the pilot study relating to driving performance measures. Detailed results and discussion of findings of the main study will be presented in a subsequent final report.

1. Coherence values were extremely high, which reflects good and consistent car following behavior.

2. The car-following delay main effect of phone call was consistent with the prediction of slower delay during a phone call, but the interaction with interface condition adds confusion to the interpretation, since effects are not consistent across interface conditions. Generally, one would predict that the no-phone call data for each interface condition in the conversation task by interface interactions would be approximately equal, since these data represent car-following episodes with no phone calls. However, in several of the measures, there were relatively large differences between these baseline (no conversation task) conditions. This created difficulties for interpretation.

3. Modulus differences suggest effect of hand-held (HH) condition on car following.

4. Time headway differences suggest a phone effect on HH condition in car following. Drivers increased headway during phone calls with this phone interface.

5. The effect of conversation on standard deviation of lane position (SDLP) was significant, but in the direction opposite that predicted. SDLP was available only during car following in the pilot study.

6. SDLP increases with delay during phone calls, but was not correlated during car following with no phone calls. Drivers do not trade SDLP for reducing delay in car following.

7. Phone use influences RMS error in car following in the HH condition. In the headset hands-free (HSHF) condition there was less RMS error during phone calls, which was difficult to interpret.

8. During Merge 1, drivers slowed most while in the hand-held condition, relative to the other interface conditions, but this effect reflects behavior both with and without phone calls.

9. Merge 2 events generally had too much variability to reveal patterns of distraction due to phone use. Speed difference between the participant vehicle and following vehicle appears to be most promising measure. In the HSHF condition, speed differentials were slower during phone call. But in the VSHF condition, the effect was in the opposite direction, namely slower speed differential without phone call.

10. TTC values at the time of merge were generally too large to indicate meaningful interaction between vehicles.

11. Cut-ins revealed the strongest most consistent effect of phone use. Brake response times were longer during phone calls, but no different among interface conditions.

12. Accelerator drop measures during lead vehicle cut-ins were less interpretable than brake response times.

13. The incentive parameters suggested some learning effect on ratings for car following and merging, but not on total points.

14. There were no differences in total incentive points between interface conditions.

15. Phone dialing speed was fastest with the hand-held interface. Hands free dialing was slowest.

16. Phone answering speed was fastest with the hands-free interface.

6.0 LESSONS LEARNED

Based on review of the video recordings of the pilot participants' drives as well as preliminary examination of the pilot data, a number of observations were made and issues requiring resolution were identified. Revisions to events, methods, and procedures were suggested, as appropriate. The issues and resulting modifications to scenario events and methods are described below.

6.1 Freeway Scenario Event Issues/Challenges

There were several challenges in designing and implementing the scenario and associated events. One challenge that applied to the overall scenario was ensuring that specific phone call sections, especially the shorter ones such as initiation and hang-up, consistently overlap the intended scenario events. Another challenge was to consistently identify and automatically log the points in time at which each of the conversation task subsections took place.

There were several challenges associated with specific events. These challenges and relating modifications to the events based on pilot data review are discussed below.

6.1.1 Lead Vehicle Braking Event

The implementation of the Lead Vehicle Braking Event turned out to be more problematic than originally anticipated. The biggest issue revolved around the case when the event takes place later in the scenario. During the setup time, the lead decelerating vehicle caused the driver to react much earlier than anticipated, no matter how slow the deceleration. The participant's slowdown in turn caused all other vehicles to slow down, in order to maintain the required density around the driver. When the initial condition was met, the speed of both vehicles was too slow for any meaningful braking reaction or the lead distance was small enough to qualify as the coupling threshold, in effect nullifying the event. Another problem occurred when participants reacted aggressively and maintained a lead distance that was larger than the coupling threshold. The lead vehicle kept slowing down, in effect creating a closed loop that again brought speeds to very low levels. A timeout provision in the scenario ensured that the lead vehicle eventually gave up and resumed the scenario, but the desired effect of the event was nullified.

Overall, the lead vehicle braking event was not repeatable enough in the pilot study to be analyzable. To deal with these problems, the event was modified to force a vehicle to change lanes in front of the participant at the desired braking distance, thus eliminating the need to slow down a vehicle in front of the driver during the setup phase. Furthermore, in order to keep the participant from predicting when the braking event would occur based on the preceding lane change, several additional lane changes were incorporated in front of the participant that did not result in a braking maneuver immediately afterward.

6.1.2 Car Following Event

The car following event posed quite a few challenges as well. The first challenge was ensuring proper timing for the creation of the car following vehicle (FV) and the subsequent lane change of the scenario vehicle (SV). Due to technical reasons, the time it took to create the FV varied in a non-predictable manner. As a result, the lane change would often take place before the FV had appeared. The delay in creating the FV was due to the time that it takes the simulator's image generator to create a vehicle once given the command to do so. The more vehicles that are queued for creation, the longer the IG would take to create all of them. The new scenario was designed to make sure that no other vehicles were queued for creation around the time when the FV needed to be created. This resulted in more constant creation times for the FV and thus eliminated the pop-up problems.

Another challenge relating to the car following event was ensuring that the scenario vehicles ahead of the FV would drive fast enough to ensure that the FV would not collide with them from behind. Since the speed of the FV was forced to the sinusoidal formula, the usual following controller that prevents rear-end collisions was intentionally inoperable. Similarly, SVs adjust their speed based on other vehicles ahead of them, not behind them. Given the high traffic density, it often occurred that the FV collided and penetrated their lead vehicle, in effect exposing the participant to another scenario vehicle. To deal with this problem, the velocities of the vehicles, in front of the FV, were forced to be the same as FV.

6.1.3 Merging Event

The merge event turned out to be the most challenging, for many reasons. The technical limitation on the maximum number of intelligent vehicles that can be active at any given time contradicted the need to have a steady flow of traffic in the merge lane that would be there at the moment when the driver was about to merge onto the next highway. This flow of traffic would have to be there regardless of the speed of the driver. Since the scenario was tuned to have this flow of traffic for a driver who operated at a normal velocity, aggressive drivers were able to beat the flow of traffic to the merge point thus completely avoiding the merge event. At the same time, if the participant drove much slower than expected, they would reach the merge point after all available scenario vehicles were created and had traveled past the merge point. Again, the limit on the total number of scenario vehicles dictated how long merge vehicles could be created to provide the continuous stream.

Another issue related to the merge was the inconsistency of inter-vehicle gaps within the platoon of vehicles. Analysis of merge event data from the pilot study was thus hampered by highly variable inter-vehicle gap sizes. The solution to this issue was to control the velocities of the merge vehicles to respond to the varying velocities that could be taken by the driver. The event was modified such that upon creation, the merge vehicles were forced to travel at a very slow velocity that helped them form a nice stream of evenly spaced traffic. When the driver exited onto the merge, the stream of merge vehicles was released to travel at their desired normal velocity. By the time the driver reached the merge point on the next highway, the stream of merge vehicles were traveling at their desired velocity and were evenly spaced apart. This ensured that the driver actually met the stream of merge vehicles regardless of his/her velocity and that the merge vehicles were evenly spaced apart. The resulting gap between the merge vehicles was 0.7 sec following distance.

6.1.4 Overall Scenario Event Issues

Consistency of event presentation was a major issue. Whereas the NADS provides the capability to create streams of vehicles that behave autonomously, this was found to introduce unwanted variability into the data collection events. Scenario vehicle behavior was relatively realistic and thus unpredictable, but this conflicted with the need for sufficient control to allow data from events to be compared. As a result, scenario vehicle behavior was modified, particularly with respect to the merge events, so that all simulator drivers would be faced with tasks of approximately the same difficulty. In addition, an attempt was made to improve event consistency by modifying event triggers such that they were "chained together," rather than independent of each other.

6.2 <u>Wireless Phone Issues (Equipment and Architecture)</u>

The following is a description of methodological issues identified and resulting revisions to methods or procedures, as appropriate.

<u>6.2.1 Headset Selection and Fit</u>

The headset hands-free condition in the pilot study created unanticipated problems for some drivers. The hands-free phone headset initially selected for use in the study was one that hooked over either ear and had a boom microphone with active noise cancellation feature. A headset that would fit more securely than an earbud was desired, and this style of headset was thought to secure fitting, as well as at least somewhat more prevalent than a headband style headset. The chosen headset (Plantronics M120) headset had two ways in which it could be made to "hold onto" the ear, as illustrated in Figure 29: the first was to clamp the ear between the ear piece and the "C" shaped piece that hooked over the ear, and the second was to change the shape of the "C" shaped piece to make it smaller or larger, depending on the size of the ear. Despite these available adjustments, the headset fit appeared to be poor and several participants in the pilot study were found to be holding onto the headset during calls and pressing it to their ears, thus increasing the demands of using the phone. Furthermore, due to the earpiece not being close enough to the ear due to poor fit, participants had trouble hearing the phone call. The act of holding onto the headset with one hand was considered to be a distraction to participants and, if nothing else, defeated the purpose of using a headset condition to achieve a "hands-free" condition. As a result, a replacement headset was chosen. The replacement headset (Plantronics M175), shown in Figure 30, had a headband that held the earpiece to the person's ear and provided a secure fit.

Figure 26. Illustration of headset adjustment features.

Figure 27. Replacement Phone Headset Selected for Use in the "Headset Hands-Free" Condition of the Main Freeway Experiment.

6.2.2 Distraction potential of third-party accessories

In examining various headsets and earbud devices for possible use in this research, it was observed that accessories could represent a significant distraction to drivers in and of themselves. Headsets or earbud devices that do not fit securely, or that do not provide sufficient volume, may cause the driver to manually adjust the device, or even hold it tightly to their ear during conversation. Such a poorly designed device is no longer "hands-free" and becomes a new source of distraction and annoyance.

6.2.3 Method of Pre-Recorded Call Creation: Computer-Generated Versus Actual Speech

In order to quickly produce the computer audio files needed for delivery of the conversation task, an attempt was made to use a commercial "text-to-speech" software program to create the files. The software would also have the added benefit of producing speech that would be at a standardized pace. Furthermore, using program commands the exact length of the pauses, during which the participants would respond verbally to the task, could be set to a specific number of seconds.

However, in trying out the calls in the NADS prior to the pilot study, it was found that the computer-generated sentences were not easily understood when used in the conversation task in the simulator cab. This may have been due to the ambient noise level present when driving in the NADS as well as due to mild distortion resulting from transmission of the recorded speech via wireless phone. While the computer-generated speech can generally be understood, some words are difficult due to emphases on wrong syllables, and occasionally, adjacent words that sound as though they are run together. This, together with the fact that half of the sentences were non-sensical combined to create difficulties in the simulator that were not experienced in the pre-pilot study conducted in a lab. It may be useful in future studies to compare the computer-generated voice with recorded speech, using material that is always meaningful and would thus allow the sentence context to be used to interpret words that may have been misunderstood initially.

6.3 General Tips for Designing NADS Scenarios

The experience of running the freeway pilot study highlighted areas where the efficiency and communication associated with the scenario development process could be improved. Strategies for designing successful scenario events were also devised.

6.3.1 Choosing Events Wisely

Use of events that require the participant to behave in a certain way are risky, since human behavior is frequently unpredictable and it is not possible to be sure that a subject will respond to instructions or a stimulus the desired way. Designing scenario events that have a limited set of possible responses will help ensure that the data recorded is comparable and analyzable.

For example, this pilot study found that, despite instructing participants to catch up to the lead vehicle in the car following event as quickly as possible, many participants did not catch up quickly enough to allow for a sufficiently long car following period (e.g., minimum of 60 seconds). One method of remedying this situation would have been to lengthen the section of simulated roadway on which the car following event was presented. This would allow sufficient opportunity for participants to engage the needed 60 seconds of the car following task at any point within the length of roadway.

6.3.2 Designing Events Efficiently

In working with scenario designers to develop events, sufficient detail and rationale for events must be provided early in the process in order to ensure clear communication of ideas and to expedite the development process. In the initial phases of scenario development, it is helpful to provide scenario designers with detailed information about an event to implemented, such as through a “timeline” of steps relating to the event, including preliminary ideas about scenario vehicle speeds, accelerations, etc. This added detail would allow developers’ time to be used most efficiently by reducing the number of iterations of scenario releases that must be developed.

7.0 SUMMARY

In summary, research to investigate the effects on driving performance and behavior of wireless phone use while driving as a function of interface design is currently being conducted by NHTSA using the National Advanced Driving Simulator (NADS). To date, performance of this research has required performance of the following steps:

1. Design and test freeway scenario (route) and events.
2. Establish digital wireless phone service in the NADS dome.
3. Develop an experimental design to examine effects of phone interface and driver age on driving performance while using a wireless phone.
4. Develop and test (pre-pilot) a conversation task to comprise wireless phone calls.
5. Conduct a pilot study to assess the adequacy of scenario events (in terms of drivers' response to them), methods and procedures, and preliminary data reduction.
6. Examine pilot study results for the purpose of identifying needed event and procedural changes.
7. Implement necessary changes to events and procedures in preparation for main freeway experiment.

Experimental details and results of the main freeway experiment will be provided in a subsequent report.

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9.0 APPENDIX A: INFORMED CONSENT FORM