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13. ABSTRACT Existing driver distraction guidelines for visual-manual device interface operation specify traditional manual radio tuning as a reference task. This project evaluated the radio tuning reference task through two activities. The first activity consisted of a static evaluation of the features and layouts of 12 original equipment vehicle radios. The second activity consisted of an experiment in which naïve participants drove five models of vehicles on a test track while performing manual radio tuning tasks. Driving performance measures and eye glance behavior were examined during radio tuning and baseline (no secondary task) periods. Results showed differences between task and baseline periods in most measures as a function of radio design.

Results of the test track radio running experiment were evaluated along with experimental data for radio tuning obtained in a driving simulator by NHTSA. Similar results were found for most eye glance measures. The data suggest the following visual demand acceptability criteria based upon driver 85th percentile radio tuning performance:

- Individual eye glances away from the forward road scene should not exceed 1.3 seconds, and
- Total eyes-off-road time to perform an entire task should not exceed 12.1 seconds.

For compatibility with occlusion testing, these time values should be rounded off to multiples of 2.0 seconds. This gives task acceptability criteria of individual eye glances away from the forward road scene not exceeding 2.0 seconds and total eyes-off-road time to perform an entire task not exceeding 12.0 seconds.

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EXECUTIVE SUMMARY

The National Highway Traffic Safety Administration is developing guidelines to reduce driver distraction associated with performance of electronic device tasks using visual-manual driver interfaces. NHTSA's guidelines draw from the base of knowledge contained in the earlier Alliance of Automobile Manufacturer's *Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In-Vehicle Information and Communication Systems*, referred to as the "Alliance Guidelines" (Driver Focus-Telematics Working Group, 2006).

Principle 2.1 of the Alliance Guidelines specifies a radio tuning reference task. A reference task in this context is one that, albeit carrying a certain amount of crash risk when performed concurrently with driving, is societally acceptable. The reference task provides acceptability criteria against which newer tasks and in-vehicle communication and information systems maybe evaluated to determine if they are acceptable for the driver to perform while driving. Tasks that are found not to distract the driver more than the specified reference task are considered acceptable for the driver to perform while driving. The radio-tuning reference task in the Alliance Guidelines is based on radios that were considered "conventional" prior to 2000. The radio-tuning reference task used a simple, generic radio design with rotary tuning knobs or push-button tuning controls.

Alliance Guidelines' Principle 2.1 A used visual demand as its metric for determining task acceptability. The 85th percentile driver eye glance characteristics of a "typical" radio tuning task determined from past research were used to establish recommended visual demand criteria. Thus, the Alliance Guidelines acceptability criteria were defined, for Principle 2.1 A, as a "benchmark," not a moving value that changes with technology. The Principle 2.1 A's acceptability criteria were that individual driver eye glances to the device interface while performing a task should not exceed 2.0 seconds and that the total glances to task time should not exceed 20.0 seconds. (This is referred to as the 2/20 rule.)

Alliance Guidelines' Principle 2.1 B used lane exceedances and headway variability as its metrics for determining task acceptability. The number of lane exceedances and headway variability while performing a "typical" radio tuning task was statistically compared to values measured while performing a candidate task to determine task acceptability. Measurement of the number of lane exceedances and headway variability for both the candidate task and the radio tuning were performed for each test participant. Thus, the Alliance Guidelines acceptability criteria for Principle 2.1 B were a moving value that changes with technology.

This study was intended to assess driver performance, according to Alliance Principle 2.1, while the driver was performing the Alliance radio tuning reference task using modern automobile radios. Modern car radios have a great variety of functions and many different control types (e.g., steering wheel controls and voice commands) are becoming more common in vehicles. There is a perception that newer radio interfaces have changed in complexity and may impose different demands on drivers than conventional (prior to 2000) radios.

The main goal of this investigation was to understand the extent to which newer radio designs meet the existing radio tuning criteria. Data to support this goal were obtained through measures that assessed the driver's visual demand and through lane exceedances and headway variability as suggested by the Alliance Guidelines. To accomplish these comparisons, the reference task itself was used in two activities: (1) comparing the extent to which older and newer radio systems could qualify for use as the Alliance-stipulated reference task and (2) testing naïve participants on a representative subset of these systems to see how driver performance compared with the Alliance-stipulated criteria for performance.

In addition to the above, further project's objectives were to:

- Assess the extent of visual demand and vehicle performance differences due to radio tuning (versus just driving),
- Assess the extent of visual demand and vehicle performance differences due to the type of radio tuning method employed,
- Assess the extent of visual demand and driving performance differences due to lead vehicle behavior during radio tuning,
- Estimate the visual demand thresholds suggested by these new data, and
- Compare these test track results with NHTSA radio tuning data from an earlier driving simulator study.

This project included two different experimental phases plus a comparison with radio tuning data from a previously-conducted NHTSA driving simulator study. The first phase, which was performed in a static setting, consisted of a survey of the characteristics of a wide variety of radio systems, especially the feasibility of using them to perform an Alliance reference radio tuning task. The second phase tested a subset of these radios in a dynamic experimental test involving driving while following a lead vehicle and manually tuning a radio.

The survey covered original equipment radio systems on the following vehicles.

- 2011 Ford Edge with MyFord Touch premium infotainment system
- 2011 Infiniti M37x
- 2010 Chevrolet Impala
- 2010 Toyota Prius with premium infotainment system
- 2006 Cadillac STS with premium infotainment system
- 2006 Infiniti M35
- 2005 Ford Escape Limited
- 2005 Mercedes Benz R350
- 2003 BMW 530i
- 2001 BMW 330i
- 1996 Buick Century
- 1995 Mercury Sable

The survey of radio system features showed that the infotainment options available to drivers have changed greatly over the span of the 16 model years spanned by the test vehicles examined. The methods through which these options are accessed and controlled have changed even more dramatically. However, with only a few exceptions, most Alliance specifications for the reference radio tuning task were met in all 12 vehicles used for this evaluation. The controls that were most commonly absent were separate buttons for adjusting tuning frequency.

A range of static completion times was found across the 12 evaluated systems. The most salient effects in average static task completion time were not observed between newer and older systems, but rather between systems using different types of controls. The systems that included separate buttons for adjusting radio frequency tended to show longer completion times than those that only provided a knob control for tuning. The mean completion time for radios using knob tuning (7.9 s.) was almost half of the mean time for one using button tuning (14.6 s.).

Driving performance tests used a subset of four of the vehicles used for the survey on a test track (the VTTI Smart Road). Additionally, a Toyota Prius used in the NHTSA driving simulator study was also tested during the second VTTI test phase, making a total of five vehicles tested on the test track.

Test participants were recruited from members of the general public. A total of 43 participants between the ages of 45 and 65 years were tested. They drove normally (i.e., while not performing radio tuning or any other secondary task, also referred to as baseline driving), and while performing radio tuning tasks with the different vehicles. A lead vehicle was present while performing all radio tuning tasks. For some tests the lead vehicle was driven at a constant speed while for other tests its speed was varied according to a predetermined profile. In both lead vehicle speed scenarios, the test participant was instructed to follow the lead vehicle at a test participant-decided, constant, distance.

Results were evaluated along with driving simulator radio tuning task data collected by NHTSA's Vehicle Research and Test Center. Quite similar results were found for the eye glance measures. As a result, the VTTI test track eye glance data and the NHTSA driving simulator eye glance data were pooled together for analyses to determine visual demand based task acceptability criteria. Quite different results were found for the driving performance variable evaluated. Therefore, the VTTI and NHTSA kinematics variable data were not pooled.

The data indicate that visual demand based task acceptability criteria, based on this pooled data set, using driver 85th percentile (the same percentile as used in the Alliance Guidelines) radio tuning performance would be: individual eye glances away from the forward road scene should not exceed 1.3 seconds and total eyes-off-road time to perform an entire task should not exceed 12.1 seconds.

NHTSA is interested in using both driving simulator testing and occlusion testing to determine the acceptability of tasks for performance while driving. Occlusion testing would be performed as specified in ISO 16673:2007, "Road Vehicles – Ergonomic Aspects of Transport Information and Control Systems – Occlusion Method to Assess Visual Demand due to the use of In-Vehicle Systems." This standard specifies a viewing interval (shutter open time) of 1.5 seconds followed by an occlusion interval (shutter closed time) of 1.5 seconds. As this standard indicates, each 1.5-second unoccluded period corresponds to 2.0 seconds of driving simulator eyes-off-road time. Therefore, specified acceptance criteria involving eyes-off-road time should be a multiple of 2.0 seconds.

For compatibility with occlusion testing, the above listed individual eye glances away from the forward road scene not to exceed time of 1.3 seconds and total eyes-off-road time to perform an entire task not to exceed time of 12.1 seconds are rounded off to the nearest multiple of 2.0 seconds. This gives task eye glance acceptability criteria of individual eye glances away from the forward road scene not exceeding 2.0 seconds and total eyes-off-road time to perform an entire task not exceeding 12.0 seconds. (This is referred to as the 2/12 rule.)

The data obtained helped provide the following answers to the research questions:

- **Were there any differences in driver-vehicle performance between when performing manual radio tuning and the corresponding baseline driving?** – There were sizeable, statistically significant, differences for four out of five eye glance measures between radio tuning tasks and their associated baselines. The values for Total Glance Time to Task, Total Eyes-Off-Road Time, Glance Rate, and Duration of Longest Glance to the System all differed significantly from their baseline values during radio tuning. However, the Average Duration of Single Glances to the System did not change significantly during task performance.

  The driving performance variables evaluated (Lane Exceedances, Standard Deviation of Lane Position, Standard Deviation of Distance Headway, and Standard Deviation of Time Headway) generally did not exhibit significant differences from their associated baselines.

  These findings indicate that the eye glance measures were more sensitive to radio tuning task performance than were the driving performance variables evaluated.

- **Were there differences between different vehicle's radios or different methods of tuning the same vehicle's radio?** – Yes, some eye glance variables showed sizeable differences between tuning with a knob and tuning with a button. Button tuning was typically more visually demanding than knob tuning.

  There was no statistically significant difference in tuning methods for the Average Duration of Single Glances to the System and the Duration of Longest Glance to the System. This finding suggests that these differences are based on the generally longer task durations required by button tuning. The characteristics of the glances to the system appear to not be altered between tuning methods, but rather by the overall effect of the longer task duration.

- **Were there differences between conditions with constant lead vehicle speed versus a variable lead vehicle speed?** – With the exception of one distance headway condition, there were no significant or marginally significant differences between constant and variable lead vehicle speed conditions for any measure in any condition. This suggests that the variance in headway in the variable lead vehicle speed condition was not severe enough to draw drivers' resources away from the tuning task any more than does following a constant-speed vehicle. However, the relatively short task durations tested may have not provided enough time for the eye glance measures to be sensitive to differences between these two following situations.

- **What conclusions can be drawn about the tested interface modalities?** – The more complex radio interfaces tended to be associated with longer task durations, larger values for total glance time to task and total eyes-off-road time, more deviation in lane position, and higher headway deviation.

GLOSSARY OF TERMS

Alliance	Alliance of Automobile Manufacturers
DAS	data acquisition system
HVAC	heating, ventilation, and air conditioning (system)
LCD	liquid crystal display
mph	miles per hour
NHTSA	National Highway Traffic Safety Administration
RSME	Rating Scale Mental Effort

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CHAPTER 1. INTRODUCTION

PROJECT BACKGROUND

The National Highway Traffic Safety Administration is developing interface guidelines to reduce driver distraction due to the operation of electronic devices with visual-manual driver interfaces. The Alliance of Automobile Manufacturers has previously developed a set of electronic device interface guidelines (*Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In-Vehicle Information and Communication Systems*, 2006 version, commonly known as the Alliance Guidelines) to reduce driver distraction (Driver Focus-Telematics Working Group, 2006).

Principle 2.1 of the Alliance Guidelines identifies radio tuning as their selected reference task. A reference task is one that, albeit carrying a certain amount of crash risk when performed concurrently with driving, is societally acceptable. The concept behind using a reference task to establish task acceptability criteria was that new tasks which are enabled in telematics and advanced information systems, if they are acceptable for the driver to perform while driving, should not distract the driver more than the reference radio-tuning task specified in the Alliance Guidelines. The radio-tuning reference tasks described and used in the Alliance Guidelines are based on radios that were considered “conventional” in the era prior to 2000. These radio-tuning reference tasks used simple radios with rotary tuning knobs or push-button tuning controls. Specifically, the radio tuning task described in the Alliance Guidelines required powering on the radio (or switching from another “function” to the radio), switching from the AM to the FM band (or vice versa), and tuning to a specified frequency that was at least 40 steps above or below the starting frequency.

Alliance Guidelines’ Principle 2.1 A used visual demand as its metric for determining task acceptability. The 85th percentile driver eyeglance characteristics of a “typical” radio tuning task determined from past research were used to establish recommended visual demand acceptability criteria. Thus, the Alliance Guidelines acceptability criteria were defined, for Principle 2.1 A, as a “benchmark,” not a moving value that changes with technology. The Principle 2.1 A’s acceptability criteria were that individual driver eye glances to the device interface while performing a task should not exceed 2.0 seconds and that the total glances to task time should not exceed 20.0 seconds. (This is referred to as the 2/20 rule.)

Alliance Guidelines’ Principle 2.1 B used lane exceedances and headway variability as its metrics for determining task acceptability. The number of lane exceedances and headway variability while performing a “typical” radio tuning task was statistically compared to values measured while performing a candidate task to determine task acceptability. Measurement of the driver lane exceedances and headway variability for both the candidate task and the radio tuning were performed for each test participant. Thus, the Alliance Guidelines acceptability criteria for Principle 2.1 B were a moving value that changes with technology.

Questions have emerged about the extent to which the demand level of “typical” tasks in today’s modern radios is represented by the Alliance reference tuning task. Modern car radios have a great variety of functions and many different control types (e.g., steering wheel controls and voice commands) are becoming more common in vehicles. There is a perception that newer radio interfaces have changed in complexity and may impose different demands on drivers than conventional (prior to 2000) radios.

The main goal of this investigation was to understand the extent to which newer radio controls and faceplates could substantially impact the complexity of the radio tuning reference task. Data to support this goal were obtained through measures that directly assessed the driver's visual demand and through lane exceedances and headway variability as suggested by the Alliance Guidelines. To accomplish these comparisons, the reference task itself was used in two activities: (1) comparing the extent to which older and newer radio systems could qualify for use as the Alliance-stipulated reference task and (2) testing naïve participants on a representative subset of these systems to see how driver performance compared with the Alliance-stipulated criteria for performance.

In addition to the above, further project's objectives were to:

- Assess the extent of visual demand and vehicle performance differences due to radio tuning (versus just driving).
- Assess the extent of visual demand and vehicle performance differences due to the type of tuning used by a radio.
- Assess the extent of visual demand and vehicle performance differences due to lead vehicle behavior during radio tuning.
- Assess the effects of testing multiple repetitions of the same radio tuning task.
- Estimate the visual demand thresholds suggested by this new data.
- Compare these test track results with those previously obtained in a driving simulator environment.

This project included two different experimental phases plus a comparison with radio tuning data from a previously conducted NHTSA driving simulator study. The first phase, which was performed in a static setting, consisted of a survey of the characteristics of a wide variety of radio systems, especially the feasibility of using them to perform an Alliance reference radio tuning task. The second phase tested a subset of these radios in a dynamic experimental test involving driving while following a lead vehicle and manually tuning a radio. This second phase included two sub-phases: (1) testing with a constant lead vehicle speed, and, (2) testing in which the lead vehicle varied its speed using a predefined speed profile.

In a previous data collection (Ranney, Baldwin, Parmer, Martin, & Mazzae, 2011), NHTSA's Vehicle Research and Test Center (VRTC) conducted a simulator-based study addressing the distraction potential of several types of secondary tasks, including the standard radio tuning task, while drivers followed a variable-speed lead vehicle. As part of this study, they analyzed their data to obtain both eye glance and kinematics metrics. This report will integrate the results of that study with the current results from the VTTI on-road study, and will compare findings where appropriate.

The methodology and results for these evaluations are described in the next two chapters.

CHAPTER 2. SURVEY OF RADIO SYSTEMS

METHODS

In order to assess on a qualitative basis the differences between diverse "generations" of infotainment systems, a survey of different original-equipment vehicle radios was conducted. This survey was expected to provide initial information on where large differences may be observable for the test track studies, as well as suggest potential reasons for those differences.

The survey of different radios involved one surveyor who accessed and collected the data for all radios that were tested. The vehicles evaluated were selected mainly on the basis of their availability to the experimental team, with consideration provided to achieving a diverse sample (e.g., not having all vehicles from the same brand). The sample included two vehicles from model year 2011 (the newest available at the time of this survey), two vehicles from model year 2010, eight vehicles from model years 2001-2006, and two older vehicle models from the mid-1990s. The vehicles surveyed included various types of infotainment functions available at the time they were manufactured. The vehicles analyzed for the static evaluation were:

- 2011 Ford Edge with MyFord Touch premium infotainment system,
- 2011 Infiniti M37x,
- 2010 Chevrolet Impala,
- 2010 Toyota Prius with premium infotainment system,
- 2006 Cadillac STS with premium infotainment system,
- 2006 Infiniti M35,
- 2005 Ford Escape Limited,
- 2005 Mercedes Benz R350,
- 2003 BMW 530i,
- 2001 BMW 330i,
- 1996 Buick Century, and
- 1995 Mercury Sable.

Audio system features and functions evaluated for this effort are listed below, and summarized separately for each vehicle (a full matrix of data collected for the static evaluation can be found in Appendix A):

- Tuning control methods,
- Number of hard keys and soft keys,
- Size of smallest digit on display,
- Radio bands available,
- Minimum step between station frequencies,
- Availability of alternative control methods, such as voice commands,
- Description of tuning methods in owner's manual, and
- Additional embedded functions.

In addition to noting these characteristics for each system, the surveyor himself completed the Alliance reference task in each vehicle (only the tuning task by itself while the vehicle was stationary), and recorded the amount of time necessary to complete that task using a stopwatch.

Three repetitions of the closest approximation of the reference tuning task possible in each system, all performed by the surveyor, were averaged.

RESULTS

The survey showed that the infotainment options available to drivers have increased greatly over the span of the 16 model years covered within this evaluation. The methods through which these options are accessed and controlled have changed even more dramatically. However, with only a few exceptions, most Alliance specifications for the reference radio tuning task (e.g., separate buttons for radio function and band selection, 5mm minimum digit size, white noise between stations) were met in all 12 vehicles used for this evaluation. The controls that were most commonly absent were separate buttons for tuning frequency up and down. Of the 12 vehicles evaluated, 5 were missing these controls. No system analyzed for this evaluation exactly met the Alliance guideline regarding the minimum step between radio frequencies (5 kHz for AM band, 0.1 MHz for FM) for a verification-test radio. All systems tested showed minimum steps of 10 kHz for the AM band, and 0.2 MHz for the FM band. Lack of adherence to this test-system requirement, however, proved to be of little or no consequence to test outcomes; both frequency bands still provided well over the 40 minimum steps between start and end frequencies specified in the Alliance guidelines. Therefore, though a minor detail, perhaps the radio frequency specification in the Alliance document needs updating to the 10 kHz steps used in production radios for the AM band, and 0.2 MHz steps used in production radios for the for the FM band.

The two oldest models analyzed for this evaluation (i.e., the 1996 Buick Century and the 1995 Mercury Sable) relied greatly on hard-key controls. In fact, no soft-key controls were observed in the Century. Of the 10 other vehicles tested, only 3 had only hard key controls: the 2010 Toyota Prius (with advanced infotainment system), the 2010 Chevrolet Impala (with base audio system), and the 2001 BMW 330i. The remaining seven systems had either a balanced presence of hard and soft key controls, or a greater reliance on soft key controls.

A majority of the vehicles evaluated had steering wheel controls for the audio system. These were mainly prevalent in vehicles of model year 2001 and newer, with 8 of 10 such vehicles including some type of control on the steering wheel. In most vehicles with steering wheel controls for the audio system, manipulation of these controls would adjust simple functions such as volume. However, in a few cases (most notably in the 2011 Ford Edge), a variety of functions could be accessed from the steering wheel using a multi-directional control. In the Edge, two four-direction pads with center select button were available on the steering wheel.

A range of static completion times was noted across the 12 evaluated systems. The systems that included separate buttons for tuning frequency up and down (as recommended by the Alliance description of the system to be used for the radio tuning reference task) tended to show longer completion times than those that only provided a knob control for tuning. Systems using knob controls elicited completion times of 10 s. or less. With the exception of the Mercury Sable[1], all

[1] The Mercury Sable was an exception because it allowed push-and-hold scrolling, which the other vehicles did not have. Therefore, one could scroll faster by pushing and holding the buttons, negating the need for multiple repeated button pushes. Due to this "push and hold" mode, the scrolling in the Sable was much faster than for other button tuning vehicles.

button-controlled systems elicited static completion times of greater than 13 s., as illustrated in Figure 1.

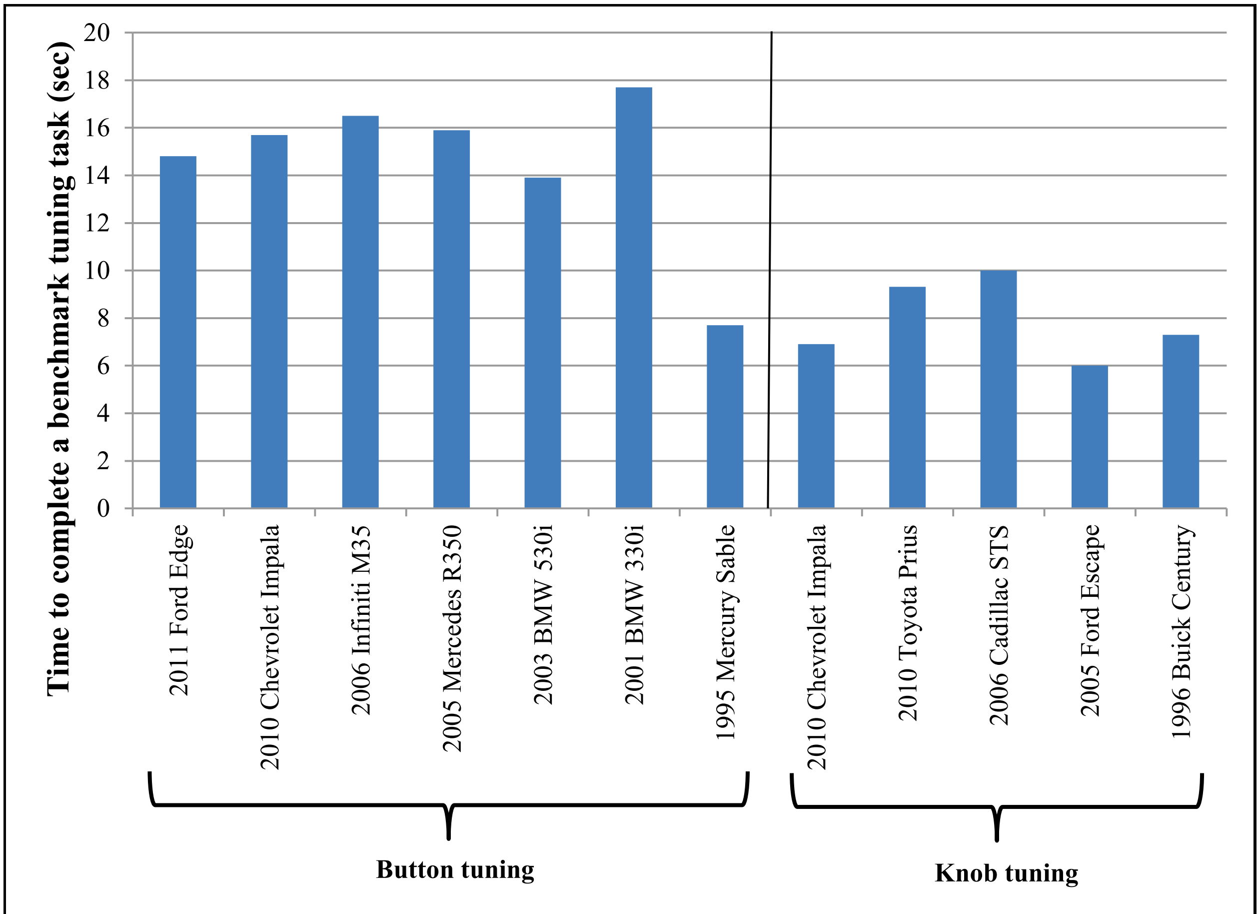

Figure 1. Completion Times for Alliance Radio Tuning Tasks During the Survey (note that these times are based on multiple trials for a single subject, constant across vehicles).

2011 Ford Edge

The 2011 Ford Edge used for this evaluation was equipped with the MyFord Touch interface system, as illustrated in Figure 2 and Figure 3. This system used multiple LCD screens (including a touch-sensitive screen on the center console) to control the audio system, climate control system, Bluetooth-connected phone, and information/navigation settings. A close-up of the home screen, illustrating these four main functions, is shown in Figure 4. Visual-manual methods, as well as vocal commands, could be used to submit a variety of commands to the system. While a large number of hard keys were available as steering wheel controls, the MyFord Touch system relied heavily on soft key functions.

From the "home screen" (see Figure 4), the audio system could be activated by touching the bottom left corner of the screen. Radio tuning could be accomplished several different ways:

- A vocal command could be used (e.g., "Tune FM 87.7").

- The "Direct Tune" function allowed the user to enter a station directly on a keypad.
- Incremental tuning (the method used for the Alliance reference task) was accomplished using small touch-sensitive buttons on the console below the screen (visible in the lower right corner of Figure 2).

The presence of separate buttons for tuning radio frequency up and down was consistent with what the Alliance guidelines call for in a test reference task.

Figure 2. 2011 Ford Edge Instrument Panel, Steering Wheel, and Center Console

Figure 3. 2011 Ford Edge MyFord Touch Radio Interface

Figure 4. 2011 Ford Edge MyFord Touch Home Screen

2011 Infiniti M37x

The 2011 Infiniti M37x's instrument panel used for this evaluation is shown in Figure 5. This vehicle was equipped with an infotainment system (see Figure 6) using a screen at the top of the center console, and controls for the audio, HVAC, phone, and navigation systems. Most controls dedicated to radio functions were located at the bottom of the console, as illustrated in Figure 7. Controls were evenly distributed among soft keys and hard keys.

The audio system was activated by pressing the left knob. A separate “AM/FM” button allowed for frequency band selection. (A third button allowed for selection of “XM.”) Tuning to a particular frequency required the use of the tuning knob (on the right side of the console).

The availability of separate buttons for radio function and frequency band selection was consistent with Alliance guidelines. However, the knob was the sole available method for tuning; separate buttons to move frequency up or down were not available. Static completions of the tuning task were not performed in this vehicle.

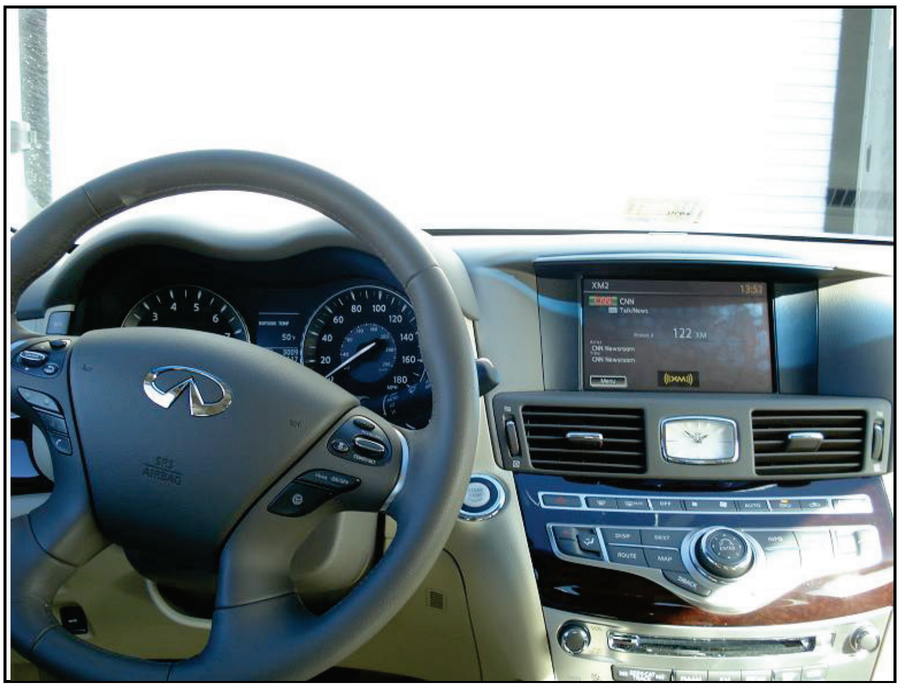

Figure 5. 2011 Infiniti M37x Instrument Panel, Steering Wheel, and Center Console

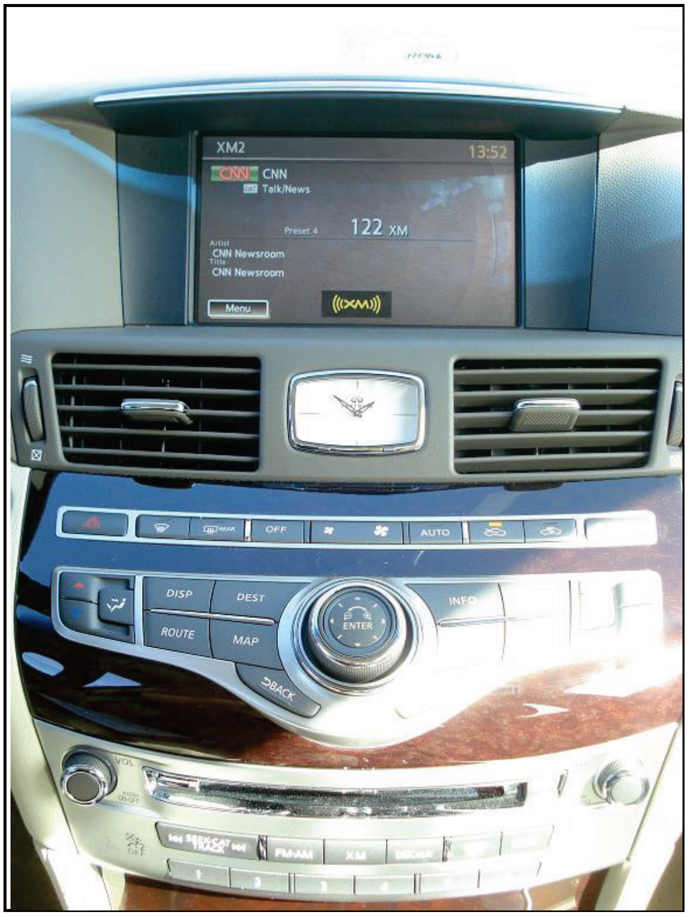

Figure 6. 2011 Infiniti M37x Infotainment System

Figure 7. 2011 Infiniti M37x Infotainment System Lower Console

2010 Chevrolet Impala

The 2010 Chevrolet Impala's instrument panel used for this evaluation is shown in Figure 8. This vehicle was equipped with a base audio package that had no steering wheel controls and relied on hard keys for most functions (see Figure 9). Of the 23 keys available with this system, only 4 could be classified as soft keys (4 CD controls could also be used for radio functions).

A large button in the center of the console could be used to turn on the radio and adjust volume. A single "band" button was used to switch among the AM band and two sets of FM presets. Tuning could be accomplished one of two ways: via the knob on the upper right of the console, or by using the buttons labeled "REV" and "FWD" (normally used when the radio is in CD mode). The owner's manual instructs users to use the knob for tuning tasks, and does not mention the alternative functionality of the "REV" and "FWD" buttons. The tuning knob elicited a much faster static completion time for a reference tuning task (6.89 s., versus 15.7 s. for button-tuning). This difference could be attributed to the slow response of the system to input from the buttons during the button-tuning task. The presence of separate buttons for tuning radio frequency up and down was consistent with Alliance guidelines for setting up a reference task, although this method was not described in the owner's manual.

Figure 8. 2010 Chevrolet Impala Instrument Panel, Steering Wheel, and Center Console

Figure 9. 2010 Chevrolet Impala Base Audio System

2010 Toyota Prius

The 2010 Toyota Prius' instrument panel used for this evaluation is shown in Figure 10. This vehicle was equipped with an advanced infotainment system, which included audio functions and navigation capability. This system consisted of a large touch-sensitive screen, and a number of hard key controls located on the center console and the steering wheel. A close-up of the center console display and controls is shown in Figure 11.

Pressing the left knob would turn the audio system on. Two different methods were available to switch frequency bands. The user could either push one of the three dedicated hard keys on the left side of the screen, or touch one of the three soft keys available at the radio function screen. The knob to the right of the screen was used for incremental tuning. The knob was the sole available method for tuning; separate buttons to move frequency up or down were not available.

Figure 10. 2010 Toyota Prius Steering Wheel and Center Console

Figure 11. 2010 Toyota Prius Premium Infotainment System

2006 Cadillac STS

The 2006 Cadillac STS's instrument panel used for this evaluation is shown in Figure 12. This vehicle was equipped with an advanced entertainment and navigation system, using a touch-sensitive screen on the center console, shown in Figure 13. Controls were balanced among hard and soft keys, including six hard keys on the steering wheel.

The audio system was activated by pressing the left knob. The frequency band could be selected by touching a soft key on the screen, or by pressing a hard key on the console below the screen. Tuning to a particular frequency required the use of the tuning knob (the upper-right knob in Figure 13).

The availability of separate buttons for radio function and frequency band selection was consistent with Alliance guidelines for setting up a reference task. Separate buttons for tuning radio frequency up and down were missing from this system.

Figure 12. 2006 Cadillac STS Instrument Panel, Steering Wheel, and Center Console

Figure 13. 2006 Cadillac STS Infotainment System

2006 Infiniti M35

The 2006 Infiniti M35's instrument panel used for this evaluation is shown in Figure 14. This vehicle was equipped with an infotainment system using a screen at the top of the center console, and controls for the audio, HVAC, phone, and navigation systems (see Figure 15). Most controls dedicated to radio functions were located at the bottom of the console (see Figure 16), although a few were located in the middle portion. The majority of controls were soft keys, and the few observed hard key controls were dedicated to functions such as controlling volume or ejecting a compact disc.

The audio system was activated by pressing the left knob. Unlike the 2011 Infiniti M37x, the 2006 M35 did not include dedicated buttons for frequency band selection. The quickest way to select a specific frequency band was to press the "RADIO" button twice. Pressing RADIO once activated the radio menu screen, consisting of the group of preset stations most recently viewed (and these presets could include multiple bands). Pressing RADIO a second time would change the frequency band. Tuning to a particular frequency required the use of the tuning knob (on the right). However, at the location where the static evaluation was completed, the "SEEK" button could be used to incrementally tune, as the SEEK function was so sensitive that a station was detected at almost every frequency.

The availability of separate buttons for radio function was consistent with Alliance guidelines, as was the method for frequency band selection. However, the knob was the sole available method for tuning; separate buttons to move the frequency up or down were not available (but, again, note that the SEEK buttons could be used to simulate frequency buttons in the area where testing occurred).

Figure 14. 2006 Infiniti M35 Instrument Panel, Steering Wheel, and Center Console

Figure 15. 2006 Infiniti M35 Infotainment System

Figure 16. 2006 Infiniti M35 Lower Console

2005 Ford Escape

The 2005 Ford Escape's instrument panel used for this evaluation is shown in Figure 17. This vehicle was equipped with the "Limited" model audio system, which had a 6-CD changer, a small LCD display, and controls, as illustrated in Figure 18. Pressing on the left knob would turn the radio on, and separate buttons were available for selection of the AM or FM band. The tuning knob on the right was used to locate particular frequencies.

The availability of separate buttons for radio function and frequency band selection was consistent with Alliance guidelines regarding set up of a reference task. However, the knob was the sole available method for tuning; separate buttons to move frequency up or down were not available.

Figure 17. 2005 Ford Escape Limited Steering Wheel and Center Console

Figure 18. 2005 Ford Escape Limited Audio System With 6-CD Changer

2005 Mercedes R350

The 2005 Mercedes R350's instrument panel used for this evaluation is shown in Figure 19. This vehicle was equipped with a screen for the entertainment system on the center console, illustrated in Figure 20. This screen was not touch-sensitive, but had columns of soft keys lining the left and right edges of the screen. A 10-digit keypad was also available for radio and phone-related tasks.

The audio system could be accessed by pressing the "PWR" button on the left side of the console, although a 5.6 s. lag time existed between button engagement and the presentation of the radio screen. AM/FM selection was possible using a soft key. Radio tuning used a directional toggle control on the right side of the console, under the keypad. Moving the toggle incrementally left or right (or holding it down) would manually tune frequency down or up, respectively. Moving the toggle up and down would move the radio among preset stations.

The presence of separate buttons for radio function and frequency band selection was consistent with Alliance guidelines for setting up a reference task, as was the availability of separate toggle positions to move radio frequency up and down.

Figure 19. 2005 Mercedes R350 Instrument Panel, Steering Wheel, and Center Console

Figure 20. 2005 Mercedes R350 Infotainment System

2003 BMW 530i

The 2003 BMW 530i's instrument panel used for this evaluation is shown in Figure 21. This vehicle was equipped with a long, narrow audio system with an LCD display, illustrated in Figure 22. The 530i had a balanced number of soft key controls and hard key controls. The controls used to program and recall presets were also used for other functions (e.g., audio equalizer settings). Pressing on the left knob would turn the radio on. One pair of soft keys controlled AM/FM band selection when in radio mode (rather than dedicated hard keys). Seeking (via two arrow keys) was the default tuning method, and manual tuning required pressing the

"M" button before manipulating the arrow keys. Quick tuning (i.e., holding down the arrow keys to move the frequency band up or down) was not available with this system.

The presence of separate buttons for radio function and frequency band selection was consistent with Alliance guidelines for setting up a reference task. The availability of separate buttons to move radio frequency up and down was also consistent with the guidelines, although the approach required one additional button push.

Figure 21. 2003 BMW 530i Instrument Panel, Steering Wheel, and Center Console

Figure 22. 2003 BMW 530i Base Audio System

2001 BMW 330i

The 2001 BMW 330i's instrument panel used for this evaluation is shown in Figure 23. This vehicle was equipped with a long, narrow audio system using two side-by-side LCD displays, one longer than the other (see Figure 24). Unlike the 2003 BMW 530i tested in this evaluation, the 2001 330i system relied heavily on hard key controls (only two soft keys were observed). Similar to the 530i, pressing down on the knob would turn the radio on. Unlike the 530i, separate hard key controls were available to activate the AM and FM frequency bands. Tuning controls were identical to the 530i (seeking via the arrow keys was the default tuning method; however, manual tuning was available by pressing the M button before manipulating the arrow keys). Quick tuning (i.e., holding down the arrow keys to move the frequency band up or down) was not available with this system.

The presence of separate buttons for radio function and frequency band selection was consistent with Alliance guidelines for setting up a reference task. The availability of separate buttons to move radio frequency up and down was also consistent with the guidelines, although the approach required one additional button push.

Figure 23. 2001 BMW 330i Instrument Panel, Steering Wheel, and Center Console

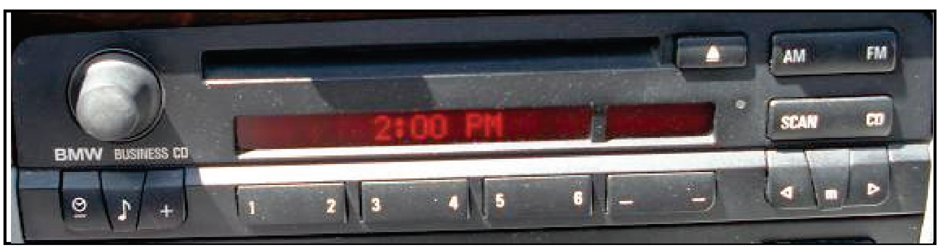

Figure 24. 2001 BMW 330i Base Audio System

1996 Buick Century

The 1996 Buick Century's instrument panel used for this evaluation is shown in Figure 25. This vehicle was equipped with a base audio system (see Figure 26). This system consisted entirely of hard keys on the center console (with no soft keys) and a digital display. The radio was turned on by pressing the upper knob. Pressing the lower knob changed frequency bands, and turning the knob was used to choose radio stations.

The presence of separate buttons for radio function and frequency band selection was consistent with Alliance guidelines for setting up a reference task. However, the knob was the sole available method for tuning; separate buttons to move frequency up or down were not available.

Figure 25. 1996 Buick Century Steering Wheel and Center Console

Figure 26. 1996 Buick Century Base Audio System

1995 Mercury Sable

The 1995 Mercury Sable's instrument panel used for this evaluation is shown in Figure 27. This vehicle was equipped with a base audio system (see Figure 28). This system was heavily reliant on hard keys. The volume and seek buttons were the only controls classified as soft keys, as they could also control audio settings or incremental tuning in different modes. The radio was turned on by pressing a dedicated POWER button. A single button also controlled the selection of the desired frequency band. Seeking was the default tuning method. To incrementally tune, the user pressed the AMS button, then manipulated the SEEK buttons to tune up or down. This mode would time out after 5 s. of inactivity. Frequencies could also be changed quickly in AMS mode by holding down the right or left SEEK buttons. Although incremental tuning was not the default setting for this system, separate buttons are available to achieve it.

The presence of separate buttons for radio function and frequency band selection was consistent with Alliance guidelines for setting up a reference task. The availability of separate buttons to move radio frequency up and down was also consistent with the guidelines, although the approach required one additional button push.

Figure 27. 1995 Mercury Sable Steering Wheel and Center Console

Figure 28. 1995 Mercury Sable Base Audio System

DISCUSSION

The main goal of this survey was to determine whether differences in technology had implications related to implementation of the Alliance reference tuning task (in particular, Verification Alternative B of Principle 2.1). Of course, manufacturers which use the Alliance document have a choice between verification alternatives A or B for determining whether visual demand limits have been met (as part of Principle 2.1), and only some of them use alternative B. Also, provisions exist for creating a simulation prototype radio with which to uniformly administer the reference radio tuning testing in vehicle evaluations. Nonetheless, what was of interest here was whether radios in modern vehicle systems could be configured for use as the reference task for testing. The 12 surveyed vehicles illustrated that radio interfaces in new and old vehicles differ in a number of important ways. Alternative functionalities (e.g., touch screens, navigation systems) and alternative control methods (e.g., soft keys, voice commands) are far more prevalent in newer vehicles. However, because basic tuning controls (using a knob or a set of buttons) are still available in these newer vehicles, meaningful departures from the specification in the Alliance document for the setup of a reference radio tuning task appear to be limited. This means that all of the radios could be used to configure the reference task for testing, if that were necessary – instead of using a simulated prototype for uniform testing.

In fact, the most salient effects in average static task completion time were not observed between newer and older systems, but rather between systems using different types of controls. As illustrated in Figure 1, the mean completion time for knob tuning (7.9 s.) was almost half of the mean time for button tuning (14.6 s.). While all of the observed completion times fell within the 20 s. threshold outlined in the Alliance Guidelines, such a marked difference between control types could differentially affect results of any relative comparisons performed, as described in Alternative B of Principle 2.1 of the Alliance Guidelines.

The question remains, however, how these observations, obtained in a static setting, translate to a situation where the driver is diverting some attention from the driving task to a radio-tuning task. Data to answer this question were collected as part of a separate experimental effort, which is described in the next chapter.

CHAPTER 3. DYNAMIC STUDIES

INTRODUCTION

The results of the survey suggested that some differences between systems would be observed in the dynamic studies. Radios with different characteristics were selected for inclusion in this part of the investigation. The objective for the dynamic tests was to determine if measurable differences existed between different radios. It is important to note that the different radios, and to some extent the tuning methods, were unique to each vehicle. Rather than try to isolate these effects in a very unbalanced fashion, it was deemed preferable to use the term "scenario" to refer to each unique instance of radio, tuning, method, and vehicle. Testing occurred in two phases (Table 1), mainly distinguished by the additional testing of one vehicle and by the addition of a variable lead vehicle speed profile to the experimental treatments.

Table 1. Study Design: Two Task Repetitions Were Analyzed for Each Cell, Although Some Participants Completed More Than Two Repetitions

<table>
<tr><th rowspan="2">Phase</th><th rowspan="2">Vehicle (quasi-randomized order)</th><th colspan="4">Number of Task Repetitions</th></tr>
<tr><th colspan="2">Baseline drive</th><th colspan="2">Tuning task</th></tr>
<tr><td rowspan="5">Phase I (Constant lead vehicle speed, at least 20 participants completed all vehicles)</td><td>2005 Mercedes R350</td><td colspan="2">2-4</td><td colspan="2">2-4</td></tr>
<tr><td>2006 Cadillac STS</td><td colspan="2">2-4</td><td colspan="2">2-4</td></tr>
<tr><td>2006 Infiniti M35</td><td colspan="2">2-4</td><td colspan="2">2-4</td></tr>
<tr><td>2010 Chevrolet Impala (knob tuning)</td><td colspan="2">2-4</td><td colspan="2">2-4</td></tr>
<tr><td>2010 Chevrolet Impala (button tuning)</td><td colspan="2">2-4</td><td colspan="2">2-4</td></tr>
<tr><td rowspan="4">Phase II (Constant and variable lead vehicle speeds, at least 20 participants completed all vehicles)</td><td>Lead vehicle speed
(random order within each task) --></td><td>Static</td><td>Variable</td><td>Static</td><td>Variable</td></tr>
<tr><td>2010 Chevrolet Impala (knob tuning)</td><td>2-4</td><td>2-4</td><td>2-4</td><td>2-4</td></tr>
<tr><td>2010 Chevrolet Impala (button tuning)</td><td>2-4</td><td>2-4</td><td>2-4</td><td>2-4</td></tr>
<tr><td>2010 Toyota Prius</td><td>2-4</td><td>2-4</td><td>2-4</td><td>2-4</td></tr>
</table>

METHOD

Test Track Evaluation (Virginia Tech Transportation Institute)

Equipment

A subset of five vehicles used in the survey were used for the dynamic evaluation.

- 2005 Mercedes R350
- 2006 Cadillac STS

- 2006 Infiniti M35
- 2010 Chevrolet Impala
- 2010 Toyota Prius

Four of the five vehicles used for the dynamic evaluation were equipped with advanced audio systems with features including large multi-color screens and navigation systems. The only exception was the 2010 Chevrolet Impala, which featured a basic radio package with a comparatively smaller digital display.

Evaluations took place on a portion of the Virginia Smart Road. The Smart Road is a 2.2-mile two-lane test track closed to public traffic, with large turnarounds at each end, and two smaller intermediate turnarounds. The route used for this evaluation is illustrated in Figure 29. All testing was performed during daylight hours in good pavement conditions without other vehicles present. Dynamic evaluations used the portion of road between Turnaround 1 (Upper Turnaround) and Turnaround 3 (Lower Turnaround). The Smart Road Bridge and large lower turnaround were not used.

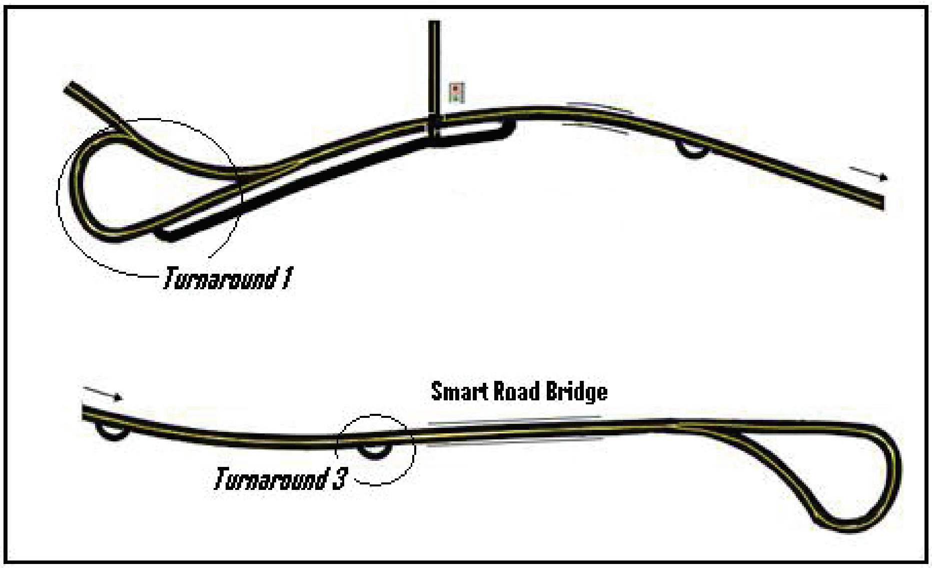

Figure 29. Diagram of Virginia Smart Road

Instrumentation

Data acquisition systems (DAS), with hardware similar to that used for the SHRP 2 Naturalistic Driving Study (Antin, Lee, Hankey, & Dingus, 2011), were installed in all vehicles used for the dynamic evaluation. All data collection equipment was installed and securely mounted such that it would not move under normal operating conditions. All of the video cameras installed in the vehicle were inconspicuously mounted to avoid impeding the driver's field of view. The DAS collected video and driving performance data continuously.

The digital video for this study was collected from four different video cameras. The first camera was positioned to show the driver's face. The second camera was placed over the driver's right shoulder to show the center console. The third and fourth cameras showed the forward and rear driving scenes, respectively. All four views were multiplexed into one video stream (as illustrated in Figure 30) for later observation and coding by trained reductionists.

Figure 30. Sample Video Screen

Performance data collected within the DAS included vehicle speed, brake activation status, following behavior, lane keeping performance, and longitudinal and lateral acceleration. Video and driving performance data were stored in digital format in a removable hard drive. Video and driving data were synched, and then analyzed at a rate of 10 Hz. Reductionists coding the video indicated the location of eye gaze at that 10 Hz rate. These location time series were used to calculate the eye glance dependent measures.

Participants

A total of 43 participants 45 to 65 years old (the age range specified in the Alliance Guidelines) took part in this study. This participant pool was comprised of two separate participant groups, as data collection occurred in two phases with separate experimental parameters. Invalid data points were removed, yielding 20 participants with complete data for each phase of data collection as well as some participants with missing data. Each participant group was comprised of approximately equal numbers of male and female participants. The mean age for participants in each phase was roughly 54 years old (Phase I: 53.7; Phase II: 54.2).

Procedure

Study procedures for each phase of data collection were described and listed in Table 1. In each phase, a given driver tested all of the vehicles in that phase. The presentation order of the vehicles was quasi-randomized. Fully randomized orders were generated and adjusted so that the last vehicle tested with the previous participant was always the first vehicle for the next participant. This allowed for all vehicles to have a similar number of instances in which they were the first vehicle tested. The presentation order of the lead vehicle speed conditions within each task of Phase II was counterbalanced within each vehicle (for the Impala, which had two different tuning tasks, both tasks were completed for one speed condition at a time).

Phase I

Upon entering the Smart Road while driving the first vehicle in the experimental order, participants completed one lap without a lead vehicle present, and without performing a task, at a speed of 45 miles per hour (mph). This lap was used to familiarize participants with the test track and current road conditions; it was only completed one time for each driver at the beginning of the experimental session, and was not repeated for the remaining vehicles.

For the next lap (the "baseline drive"), participants were instructed to follow a lead vehicle (driven by a second experimenter) at a safe and comfortable following distance. No instructions were provided regarding participant speed, although the lead vehicle maintained a constant speed of 45 mph. This baseline drive was completed for all experimental vehicles prior to the presentation of any experimental conditions.

Upon completion of the baseline drive, the experimenter instructed the participant to stop the vehicle at the upper turnaround. The participant was then trained on the Alliance reference radio tuning task (i.e., powering the radio on, changing frequency, and tuning to a prescribed station at least 40 steps up or down) while the vehicle was stationary. The experimenter described and demonstrated the task as many times as desired, then the participant practiced the task until stating to the experimenter that he/she would feel comfortable completing that task (or a similar task) while driving.

The experimenter then briefly contacted the lead vehicle driver, and instructed the participant to begin driving at a safe following distance behind the lead vehicle. As was the case for the baseline drive, no instructions were provided regarding participant speed, although the lead vehicle maintained a constant speed of 45 mph.

Once the lead and participant vehicles were traveling at a constant speed and following distance, the experimenter instructed the participant to begin a task. If the participant completed the first task on a run within a short enough period of time, a second iteration of the same type of task was assigned during the same lap. Upon reaching the lower turnaround, the participant was instructed to drive back towards the starting point; up to two similar radio tuning tasks were completed during this trial. Therefore, a minimum of two (and a maximum of four) tasks were completed for each lap. As not all participants completed equal numbers of second task iterations (before or after reaching the lower turnaround), analyses were only conducted on the first trial per run towards or back from the lower turnaround. The first trial used exactly the same task used to train the participant. The remaining trials varied the frequencies and bands. All tuning tasks required a minimum of 40 frequency steps between start and end points.

Post hoc, a segment of the baseline drive matching the duration and starting location of each task was selected and used for pairwise analyses. Further discussion of this manipulation can be found in the Data Analysis section.

When the task lap was complete, the participant was instructed to park the vehicle in the turnaround at the top of the road, power the vehicle down, and move to the next vehicle in the experimental order. The baseline lap was then repeated, followed by stationary training on the new tuning task, and then the experimental conditions. Because the Impala had two tuning modalities, the tuning task lap (as well as the training preceding it) was completed twice, resulting in one baseline drive and two tuning task laps (rather than one tuning task lap) for that vehicle. In each case, the button mode of tuning was tested before the knob modality.

Once baseline and task drives were complete in all vehicles, participants returned to the main building, where they were compensated, thanked for their time, and dismissed.

Phase 2

Upon entering the Smart Road while driving the first vehicle in the experimental order, a new group of participants completed one lap without a lead vehicle present, and without performing a task, at a speed of 45 mph. This lap was used to familiarize participants with current road conditions, was only completed one time at the beginning of the experimental session, and was not repeated for all vehicles.

For the second lap (the “baseline drive”), participants were instructed to follow a lead vehicle (driven by a second experimenter) at a safe and comfortable following distance. No instructions were provided regarding participant speed. The lead vehicle would either maintain a speed of 45 mph or vary speed between 40 and 50 mph, depending on the prescribed experimental order.

The variable speed profile used for this study is described below, and illustrated in Figure 31:

1. Lead vehicle accelerated to 40 mph.
2. Lead vehicle maintained a speed of 40 mph for up to 2 s.
3. Lead vehicle accelerated from 40 mph to 50 mph over the course of 10 s.
4. Lead vehicle maintained a speed of 50 mph for up to 2 s.
5. Lead vehicle decelerated from 50 mph to 40 mph over the course of 10 s.
6. Steps 2-5 were repeated until the lead vehicle approached a turnaround.

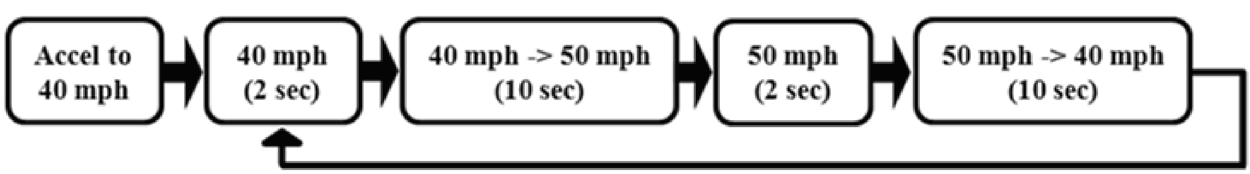

Figure 31. Variable Speed Profile Used for Phase 2 of Dynamic Evaluations

Upon completion of the baseline drive, the experimenter instructed the participant to stop the vehicle. The participant was then trained on the Alliance reference task (powering the radio on, changing frequency, and tuning to a prescribed station at least 40 steps up or down) while the vehicle was stationary. The experimenter described and demonstrated the task as many times as desired, then the participant practiced the task until they stated to the experimenter that they would feel comfortable completing that task (or a similar task) while driving.

The experimenter then briefly contacted the lead vehicle driver, and instructed the participant to begin driving at a safe following distance behind the lead vehicle. No instructions were provided regarding participant speed, although the lead vehicle would maintain the same speed profile used in the baseline drive.

Once the lead and participant vehicles were traveling at 40 mph in the variable speed condition or 45 mph in the constant speed condition, the experimenter instructed the participant to begin a task. If the participant completed the first task on a run within a short enough period of time, a second iteration of the same type of task was assigned. Upon reaching the lower turnaround, the participant was instructed to drive back towards the starting point; up to two similar radio tuning tasks were completed during this trial. Therefore, a minimum of two (and maximum of four) tasks were completed for each lap. As not all participants completed equal numbers of second task iterations (before or after reaching the lower turnaround), analyses were only conducted on the first trial per run towards or back from the lower turnaround. The first trial used exactly the same task used to train the participant. The remaining trials varied the frequencies and bands. All tuning tasks required a minimum of 40 frequency steps between start and end points.

Post hoc, a segment of the baseline drive matching the duration and starting location of each task was selected, and used for pairwise analyses. Further discussion of this manipulation can be found in the Data Analysis section.

When the task lap (or laps, in the case of the Impala) was complete, a second baseline drive was completed, with the lead vehicle changing its behavior (i.e., if the first baseline and task laps used a constant vehicle speed profile, then a variable speed profile was used for the second set, and vice versa). Once this second baseline drive was complete, the task laps were run again, using this new lead vehicle behavior.

When all tuning modalities (as applicable) and speed behaviors had been tested in the first vehicle, the participant was instructed to park the vehicle in the upper turnaround, power the vehicle down, and move to the second vehicle in the experimental order. Once baseline and task drives were complete in the second vehicle, participants returned to the main building, where they were compensated, thanked for their time, and dismissed.

Dependent Variables

Several measures were analyzed from the data available. Task duration was combined with vehicle performance and eye glance behavior measures, as described below:

- Task Duration (s.): Calculated as the time elapsed from the experimenter instruction of "Now" until the task was complete, as indicated by the participant saying "Done." This is somewhat different from the definition of Task End presented by the Alliance.

In that definition, the task end is defined as the "last control input to the task." However, the Alliance allows it to be measured as "when the participant says 'Done' in the test procedure."

- Vehicle Performance Measures: The Alliance formally defines Lane Exceedances and Standard Deviation of Time Headway as part of its Verification Alternative B procedures.
    - Lane Exceedances: The number of times that the outside edge of a tire crossed the outside edge of a lane marker, as determined by a proprietary machine-vision algorithm.
    - Standard Deviation of Lane Position (m.): Variation of lane keeping, measured from the distance from the center of the lane (provided by a proprietary machine-vision algorithm). Algorithm confidence levels were monitored, and only data points associated with confidence levels over 97.5 percent were analyzed.
    - Standard Deviation of Distance Headway (m.): Range from the subject vehicle's front bumper to the rear end of the lead vehicle, as measured by radar. Only data points where the radar algorithm determined the presence of a lead vehicle were included in the analysis.
    - Standard Deviation of Time Headway (s.): The Distance Headway, as described above, divided by the subject vehicle's speed.
- Eye Glance Behavior Measures: All of these were focused on glances to the system of interest. Average values were compared statistically, and 85th percentiles were calculated for the sample. Only Total Glance Time to Task and Average Duration of Single Glances to the System are formally defined by the Alliance, as part of Verification Alternative A.
    - Total Glance Time to Task (s.)
    - Total Eyes Off-Road Time (s.)
    - Average Duration of Single Glances to the System (s.)
    - Glance Rate (glances per minute)
    - Duration of Longest Glance to the System (s.)

Data Analysis

Trials were classified in terms of task outcome, and any incomplete or incorrectly performed trials were removed from further analysis. Dependent variables were extracted from their source, organized in a database using custom software developed in Matlab, and analyzed using a general linear model in SAS. Significant main effects were further analyzed using Tukey-corrected paired comparisons to obtain a family-wise error of 0.05. Statistical significance for all other analyses was also established at a Type I error level of 0.05. Baselines were included in the analyses for all dependent measures except task duration. As not all participants completed a second task repetition while driving towards or returning from the lower turnaround, therefore, data analyses only included the first trials for each leg.

Matched-duration baseline epochs were calculated for all trials based on the duration of each individual trial. As discussed above, data for baseline conditions for each tuning task were obtained by allowing the participant one non-task lap in each vehicle, where they were only asked to follow the lead vehicle. A segment of baseline driving was selected for each tuning task by matching to a segment of baseline driving for duration and approximate starting location.

The following experimental factors and their interactions were used in data analysis:

- Scenario (combinations of radio/vehicle and tuning method; each scenario included a matched-duration "just driving" condition for comparison)
  - Phase I included five different task conditions – Impala-Knob, Impala-Button, Cadillac-Knob, Infiniti-Button, and Mercedes-Button (the first part of the name indicates the vehicle model, the second part indicates the tuning method used). All analyses except that for Task Duration also included the matched baseline conditions as additional scenarios, for a total of 10 different Scenario levels.
  - Phase II included Prius-Knob-Constant, Prius-Knob-Variable, Impala-Knob-Constant, Impala-Knob-Variable, Impala-Button-Constant, and Impala-Button-Variable (the first part of the name indicates the vehicle model, the second part indicates the tuning method used, and the third part indicates whether the lead vehicle maintained a Constant or a Variable speed). All analyses except that for Task Duration also included the matched baseline conditions as additional scenarios, for a total of 12 different Scenario levels.
- Trial Number: Included two levels, one representing the first trial (heading towards the lower turnaround), and one representing the second trial (heading back from the lower turnaround).

Simulator Study (NHTSA's Vehicle Research and Test Center)

The radio tuning task was run as a baseline condition within a larger data collection effort aimed at studying experimental methods for measuring driver distraction. Data were collected using the VRTC simulator described below. The following method section is edited to restrict focus to the radio tuning task portions of the study; full methods can be found in the final NHTSA report (Ranney, Baldwin, Parmer, Martin, & Mazzae, 2011) for this effort.

Laboratory

For this experiment, a temporary enclosure was assembled inside a larger laboratory to provide a controlled environment in which to set up the fixed-base driving simulator. Figure 32 shows a drawing of the simulator enclosure with the relative dimensions and layout of the vehicle and equipment inside.

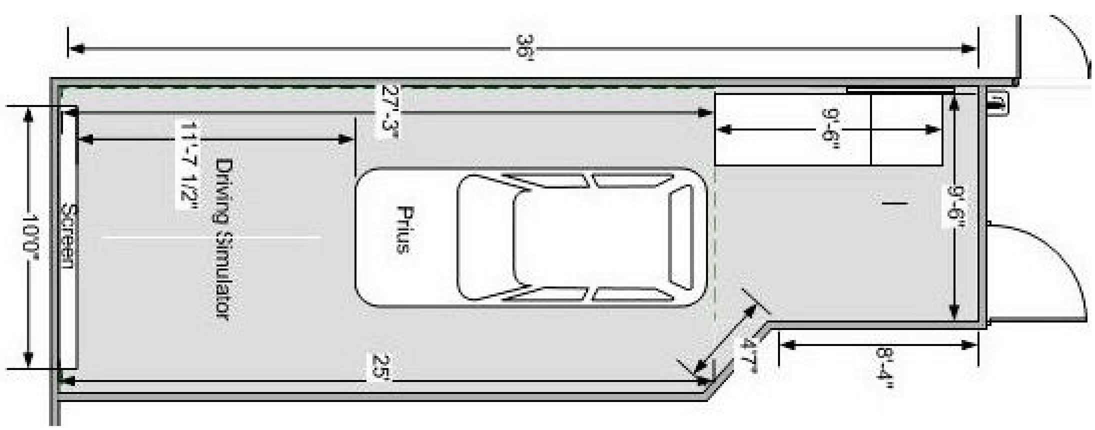

Figure 32. Dimensions and Basic Layout of Simulator Environment

The enclosure's structure consisted of materials from two portable canopies made of interlocking aluminum poles with white tarps for covering the roof and sides. While the canopy tarps provided basic simulator cover, additional materials were added to the roof and walls to permit better experimental control of both light and sound. The wall panels can be seen in Figure 33.

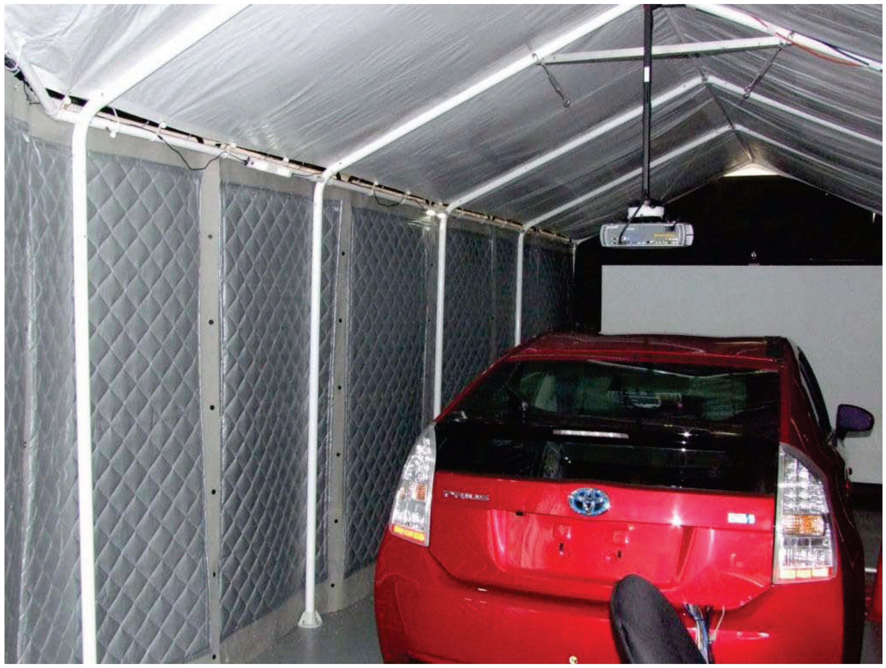

Figure 33. Simulator Enclosure, Roof and Wall Construction Materials

The wall panels were free-standing modular acoustical screens with a noise reduction coefficient of 0.75. These acoustical screens were each 4 feet wide by 8 feet tall. Each screen had a black tubular steel frame that was attached to the canopy frame and the frames of other screens to form the desired light and sound barrier for the simulator walls. Acoustic foam was then placed on top of the roof of the canopy, supported by the canopy frame and white tarps. Thus, the canopy's frame supported both the acoustic foam panels above the roof tarp and the acoustic screens used for the walls.

Once the structure was complete, accent lighting was added to the junction of the wall and ceiling to provide a lighted path to the driver's side of the vehicle. As seen in Figure 32, a door was placed at the end of the structure behind the vehicle. This door was made of one of the acoustical screens and frame, in which a hinge was fabricated to attach the door to the canopy frame. A wheel was mounted under the door frame to allow it to open and close easily.

Driving Simulator

Inside the simulator enclosure, components of the fixed-base simulator included a production test vehicle (2010 Toyota Prius), an Intel Pentium 4 computer, a ceiling-mounted digital projector (1024 x 768) positioned above the vehicle, and a forward projection screen (10 ft. x 10 ft.). The STISIM drive simulator software was used.

The roadway scene consisted of a four-lane rural highway with two (12 foot wide) lanes in each direction, separated by double yellow lines. After an initial curve, all secondary tasks were performed on straight-road sections. There were no cross roads and lighting was selected to simulate daytime driving conditions. Single oncoming vehicles were programmed to appear approximately every 1300-1600 feet (i.e., once every 15-20 seconds), with varying speeds and lateral positions in the nearest oncoming lane. Scenario, roadway, and vehicle parameters are described in the original report (Ranney, Baldwin, Parmer, Martin, & Mazzae, 2011).

A touch screen was installed inside the vehicle and was connected to a separate computer, which was used to generate visual stimuli for secondary tasks (see Figure 34). The simulator computer, secondary task computer and other experimenter materials were located at a control station located behind the vehicle on the passenger side. From there, two experimenters could operate all the equipment and communicate with a participant using a speaker and microphone system.

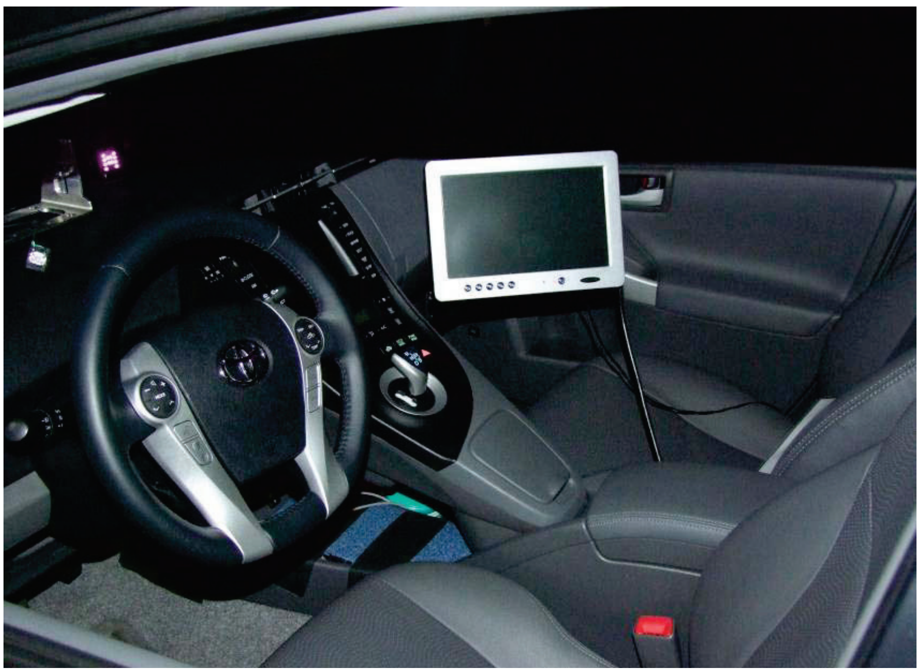

Figure 34. Prius Interior and Touch Screen

Sensors that recorded steering, accelerator and brake inputs were attached temporarily to the test vehicle. Specifically, a bracket (see Figure 35) was developed to couple either front tire of the test vehicle to a turn plate on the ground while the vehicle tires were off the ground (vehicle supported by 5 jack stands). The bracket and turn plate assembly mounted to the front tire provided steering inputs to the driving simulator when the participant moved the steering wheel, allowing the simulator to run without the vehicle being turned on.

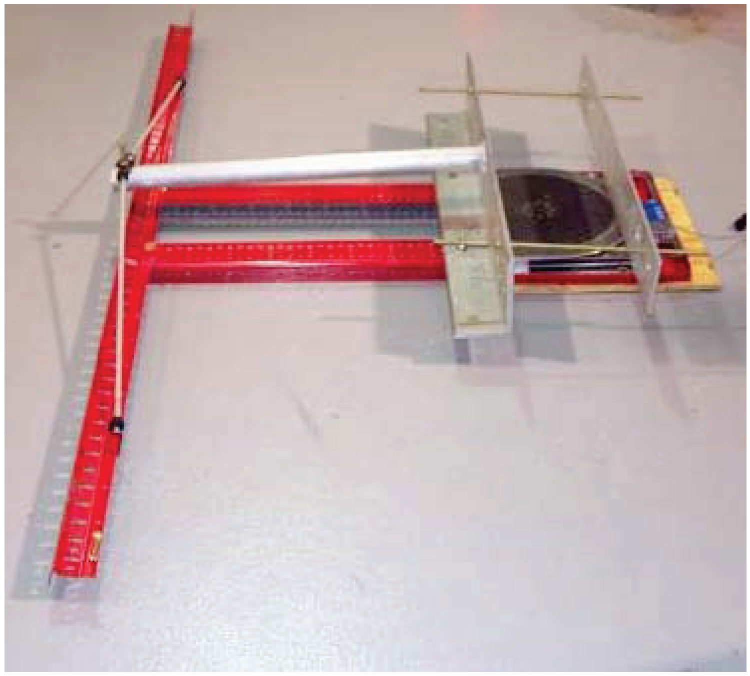

Figure 35. Apparatus for Recording Steering Wheel Movement

A Seeing Machines FaceLAB eye tracking system was used to record the driver's head pose and gaze. Head pose used three parameters to define position and three parameters to define orientation.

FaceLAB output the direction in which each eye is looking. Each eye looked along a "gaze ray." Each gaze ray had an origin at the center of the respective eye and pointed toward the object being looked at. Each gaze ray was represented by pitch and yaw angles. The pitch and yaw angles were transformed into a direction vector. Dual gaze was converted into a single gaze vector. The system used two stereo cameras mounted on the dashboard and was relatively unobtrusive. To assist the system in tracking facial features, participants applied five latex target stickers to their faces during system calibration.

The vehicle data acquisition system was configured to collect steering wheel position, brake and throttle inputs, and participant responses to the target detection task. That system also collected video data from multiple camera locations, in addition to collecting timing data from the various systems (STISIM, FaceLAB, and the secondary task computer) to provide time syncing of all the data in post processing routines. In addition, the STISIM simulation computer collected data for its respective performance measures. The primary data channels are displayed in Table 2.

Table 2. Data Collection Channels

Data Channel	Description	Units	Resolution
Vehicle Speed	STISIM	km/h	1 km/h
Range	Distance to the lead vehicle, STISIM	m	.5 m
Range-Rate	Relative velocity between the vehicles, STISIM	m/s	.1 m/s
Lateral Position	Lateral position in reference to the simulated lanes, STISIM	cm	2 cm
Hand Wheel Position	Angular position of the steering wheel (0 degrees = straight)	degree	.1 degree
UTC Time	Time of day	HH:MM:SS	1 s
Event Task	DT button press response	0 or 1	1/30th s

Participants

One hundred drivers participated in the experiment. Ages ranged between 25 and 60 years. Approximately half of the participants in each age category were female, half male. Participants were active drivers with a valid driver's license and a minimum of 7,000 miles driven per year. All participants reported having experience using a wireless phone while driving. Wireless phone use was considered to be a surrogate for multi-tasking experience; we expected drivers who were experienced phone users to be more representative of drivers who would chose to perform various secondary tasks while driving. Most of the participants were active users of text messaging and most were comfortable constructing text messages while driving. Fifty-seven percent of the participants reported some previous experience with a navigation system. Data for this experiment were collected in October through December of 2010.

Driving Task

A dynamic car-following paradigm modeled after that used by Brookhuis and colleagues (Brookhuis, Waard, & Mulder, 1994), was programmed into the scenario run on the STI simulator. This task required participants to maintain a constant following distance behind a lead vehicle, which changed speed according to a predefined complex waveform (see Figure 36). Note that this is the same lead vehicle speed profile as was used during second phase of testing on the VTTI Smart Road.

Participants were required to follow a simulated lead vehicle's speed changes on straight road segments. Prior to testing, drivers were given training and feedback about the range of following distances considered acceptable. During the experiment, participants received feedback and, if they were part of the Incentive Group, monetary incentives based on their ability to maintain an acceptable following distance. Feedback included the average and standard deviation of the distance between the vehicles, and the percentage of time the participant stayed within an acceptable range (120 ft. ± 60 ft.). An auditory warning system was used to encourage drivers to maintain a fairly close following distance. When drivers exceeded a pre-defined criterion (200 ft.), an audible tone sounded once every five seconds until the driver returned to an acceptable following distance.

Figure 36 presents the lead vehicle speed signal that was created for this experiment. The signal is a modification of a signal that had been used previously. The modification involved increasing the y-axis scaling of the previous signal around its mean, which had the effect of retaining the same relative frequency components while increasing the amplitude. The original construction of the complex signal is described in an earlier study (Ranney, Mazzae, Baldwin, & Salaani, 2007, pp. 93-98).[2]

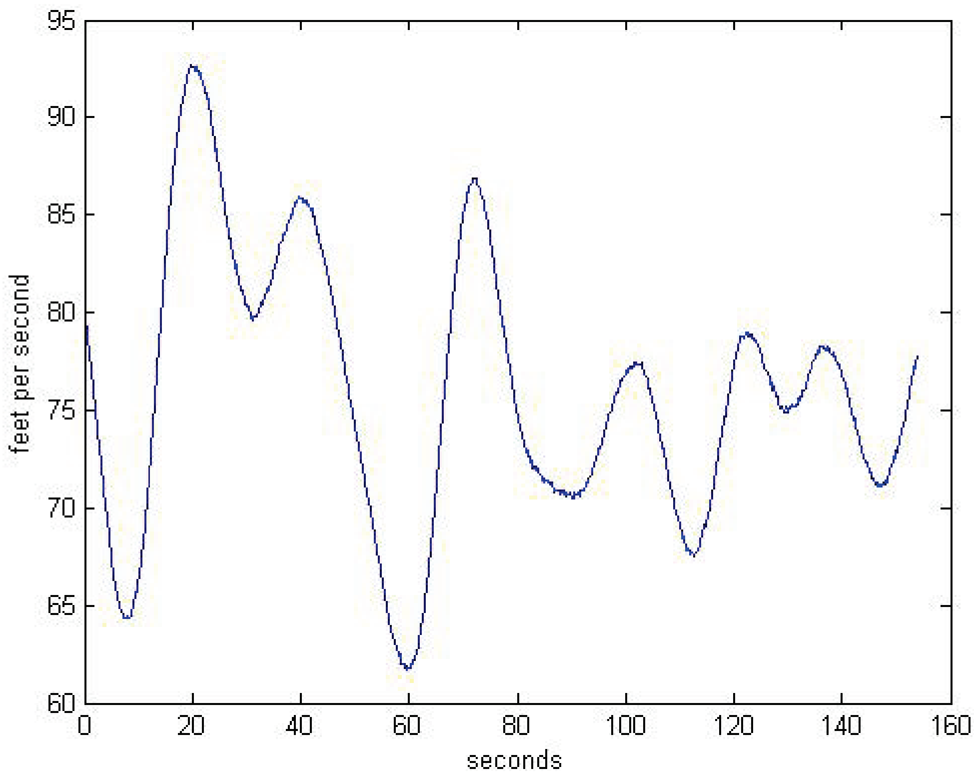

Figure 36. Lead Vehicle Car-Following Speed Signal

[2] The lead vehicle speed profile's shape was obtained by band pass filtering a white noise signal having a Gaussian distribution. The band pass filter frequencies were set to [0.02 – 0.45] Hz, based on the assumption that this range corresponds approximately to the behavior of vehicles in traffic. The random signal can have many shapes, each derived from a different seed. Based on visual inspection of a variety of windows selected from a long random signal, a single shape was selected which appeared to represent multiple periods and a variety of amplitudes. Pilot testing was used to ensure that the signal could be adequately followed without requiring excessive acceleration or deceleration. The standard deviation of acceleration for the selected signal was 0.03g.

Visual Target Detection Task

The visual target detection task was a modification of the original Peripheral Detection Task (PDT) (Harms & Patten, 2003). Instead of LEDs reflected off the windshield, the targets were computer-generated, red-colored circles intended to approximate the size of the reflected LEDs in the traditional PDT. Targets appeared one at a time at one of six locations on a single horizontal line near the horizon in the driving scene as shown in Figure 37. The targets subtended a visual angle of approximately 1 degree, based on an approximated average driver's eye location. Figure 38 shows the locations of the targets with respect to an average driver's seated position. Participants responded to targets by pressing a button attached to their left index finger. The button was connected by wire to a transmitter box that was worn on the wrist.

One target appeared every 3-5 s.; the inter-stimulus interval (ISI) durations were sampled from a uniform distribution of times within this range. The target appeared on the roadway display for 1.5 s. or until the participant pressed the response button. The subsequent ISI was initiated either by the participant's response (for correct trials) or 0.5 s. following target disappearance (for miss trials). Targets not responded to within 1.5 s. were considered misses.

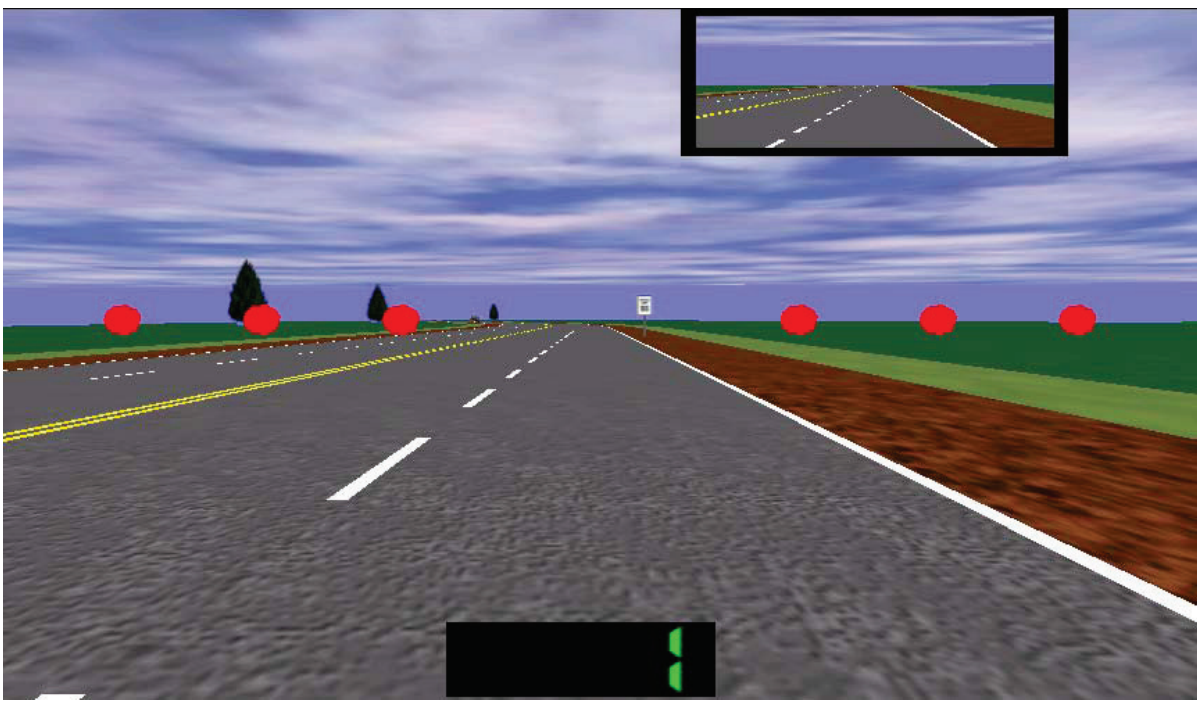

Figure 37. Visual Detection Task

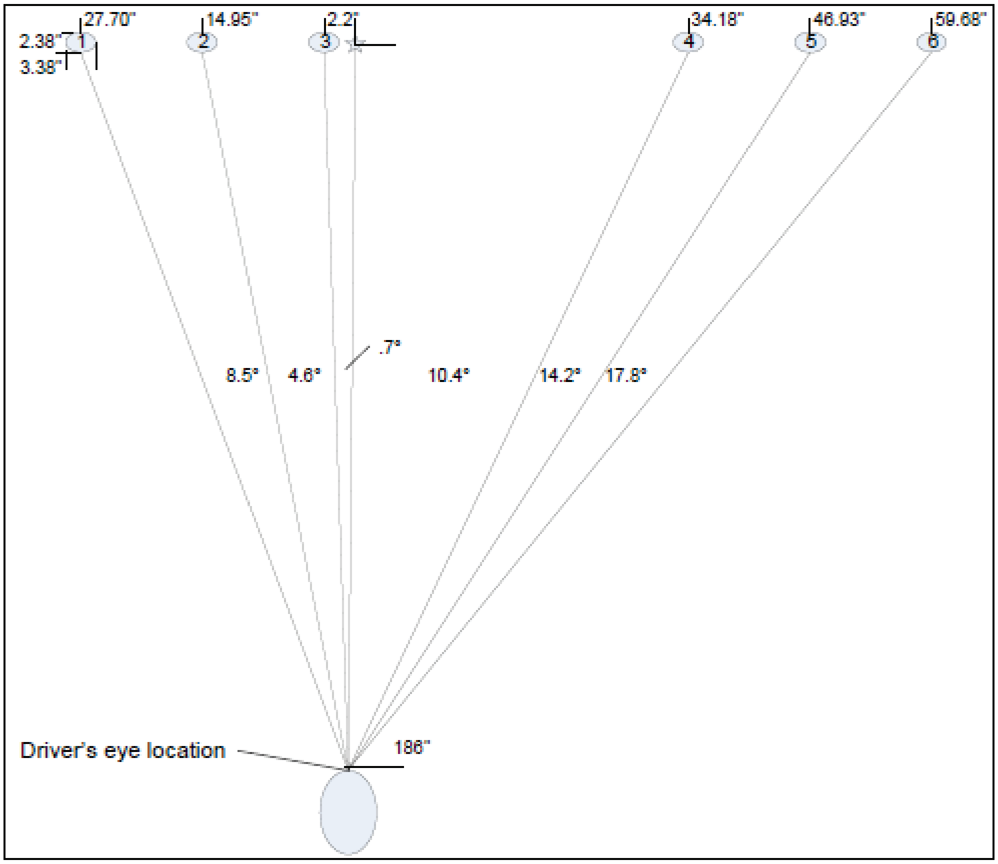

Figure 38. Detection Task Target Size and Location

Procedure

Each participant completed one session, which lasted approximately four hours. All testing was done in a single vehicle. Upon arrival, the participant was asked to read and sign the Participant Information Summary, thereby giving informed consent to participate in the study. Participants were then asked to generate a list of familiar phone numbers that they could dial from memory. Examples included their home phone, their cell phone, their partner's cell phone, phone numbers of friends and family members, and other numbers frequently called. Verbal tags (e.g., "Call Home") were created for these numbers and used as stimuli in the experiment. The use of visual tags was intended to ensure that participants needed only one glance to the stimulus screen to identify and recall the number to be dialed.

The participant was then escorted to the experimental vehicle and given an overview of the vehicle controls and displays, including adjusting the seat position. This was followed by an explanation of the monetary performance incentive system (if appropriate) and the Rating Scale Mental Effort (RSME), which was used after each trial to record participants' subjective assessment of mental workload. The participant was then asked to affix latex stickers to his or her face for eye tracker calibration. During this procedure, the experimenter instructed the participant concerning head position and point of gaze and made adjustments to a head/eye model. A test of the model was conducted to determine whether calibration was successful. If necessary, several calibration steps were repeated and a second model test performed.

Next, the participant was given instructions and practice for the driving task components, including car following and target detection. The desired following distance was demonstrated and participants were advised that a warning signal would sound if their following distance increased beyond an acceptable range. Participants were given practice with the combination of car following and target detection, followed by performance feedback (see Table 4 and Table 5). The participant was then given an opportunity to ask questions about any aspect of the protocol.

Data collection consisted of four separate blocks, as shown in Table 3. To minimize carryover effects due to the requirement that participants perform tasks using multiple devices, the presentation order of the secondary tasks was balanced within age groups.

Table 3. Structure of Experimental Session

Task Block	Secondary Task Conditions (within Ss)
1	Benchmarks - Address entry (DFD protocol) - Radio tuning (Alliance 2.1)
2	Hard button portable phone - 10-digit dialing - Dialing via contact list - Text message
3	Touch screen portable phone - 10-digit dialing - Dialing via contact list - Text message
4	Baseline driving

Training on the secondary tasks began following a break. Training, practice, and testing were completed for each block in the order assigned to a particular participant.

The experiment had nine main driving trials, eight of which involved concurrent performance of the secondary tasks shown in Table 7, plus approximately ten practice drives. Participants performed a practice trial before each main trial. Participants could ask to repeat the practice trial as much as was necessary to achieve a certain level of confidence with performing the combination of primary and secondary tasks.

Each main driving trial lasted approximately three minutes. After each trial, the participants were asked to complete the RSME and were provided performance feedback, if appropriate. The experimenter then provided the participant with training and stationary practice for the next trial and secondary task. The participant was offered a break after each secondary task block. The experimenters were positioned at a control station behind the vehicle during data collection. Communication with the participant was accomplished by a speaker and microphone system.

At the completion of data collection, the participant was asked to complete a simulator sickness questionnaire to determine if rest was required before being allowed to drive home. The participant was also asked to complete a post-test questionnaire.

The participant was then given compensation, which consisted of the total of three amounts: (1) Base pay ($31 per hour) for participation, (2) Performance incentive pay or completion bonus, and (3) mileage reimbursement for travel to and from the test facility. The performance incentive or completion bonus was computed for each trial based on the amounts shown in Table 4. The completion bonus pay was determined in exactly the same manner as the performance incentive pay; participants just did not know any details about the completion bonus until their participation was complete.

Table 4. Monetary Incentive/Performance Bonus Amounts per Trial Performance

Task	Priority	Good	Acceptable	Poor
Car Following / Target Detection	1	$2.60	$1.30	$0.0
Secondary Task	2	$1.40	$0.70	$0.0
Total		$4.00	$2.00	$0.0

On each trial, the participant had the opportunity to earn $4.00 in addition to the base pay. Thus, for consistently good performance on each of the nine main trials, the participant could earn an additional $36.00. The performance for each trial was determined subjectively by the experimenter based on the general criteria presented in Table 5.

Table 5. Task Performance Incentive Criteria

Task	Good Performance	Acceptable Performance	Poor Performance
Car Following	Maintains close following distance consistently with minor deviations	Maintains close following distance mostly with some noticeable deviations	Generally fails to maintain close following distance
Target Detection	Consistently attentive to target detection, detecting most targets	Moderate number of targets not detected	Fails to detect significant number of targets
In-Vehicle Secondary	Performs secondary task continuously with minimal errors	Performs secondary task either intermittently or with moderate number of errors	Performs secondary task with considerable difficulty, slowly, and with moderate number of errors

Subjective criteria were established during pilot testing to differentiate among the three performance categories.

The experimenter answered any participant questions and then accompanied the participant to his or her personal vehicle.

A separate small-scale pilot test was conducted to observe how many of each task type could be completed in a static setting. Following training and practice, six participants performed each of the secondary tasks five times (with no driving).

RESULTS

Test Track Evaluation (Virginia Tech Transportation Institute) – Phase I

The results of the first phase are shown in Table 6. As participants in the NHTSA simulator study followed a variable-speed lead vehicle, those results will be presented alongside the Phase 2 results.

The effects of Scenario were significant for all measures except Lane Exceedances, while the Trial Number and the Scenario X Trial Number interaction were significant for a subset of them. Detailed information about the post hoc test results are provided later in the discussion, organized based on their relevance to the research questions.

Table 6. Statistical Outcomes for Eye Glance Variables' ANOVAs for the First Phase

Variable	Scenario	Trial Number	Scenario X Trial Number
Task Duration	$p<0.0001$	$p<0.05$	
Lane Exceedances			
Standard Deviation of Lane Position	$p<0.0001$		
Standard Deviation of Distance Headway	$p<0.001$	$p<0.05$	$p<0.05$
Standard Deviation of Time Headway	$p<0.0001$	$p=0.05$	$p<0.05$
Total Glance Time to Task	$p<0.0001$	$p=0.0078$	$p<0.0001$
Total Eyes Off-Road Time	$p<0.0001$		$p<0.0001$
Average Duration of Single Glances to the System	$p<0.0001$	$p=0.0368$	
Glance Rate	$p<0.0001$		$p=0.0181$
Duration of Longest Glance to the System	$p<0.0001$		

Task Duration

Mean task durations for all control input scenarios are presented in Figure 39, with error bars representing standard error. There were main effects for Scenario and Trial Number, but no significant interaction between Scenario and Trial Number.

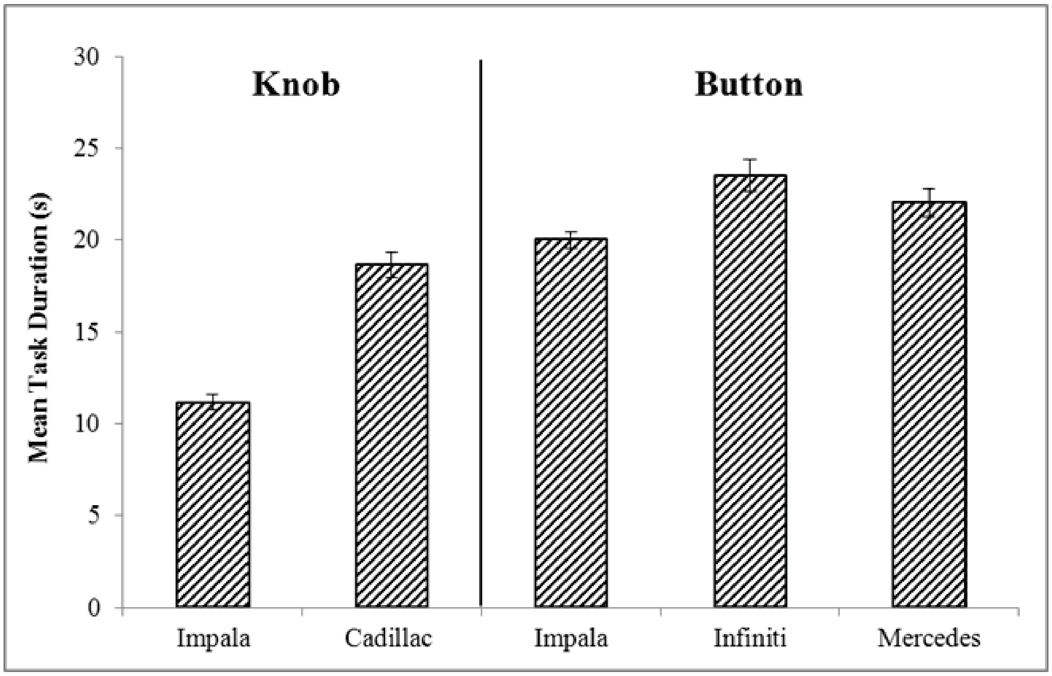

Figure 39. Mean Task Durations for Phase I

Lane Exceedances

Figure 40 presents the mean number of lane exceedances for each scenario and their standard errors. As can be seen, there were very few excursions in Phase I, which led to both low frequency and high variability. The low resultant statistical power prevented any further analysis of this variable.

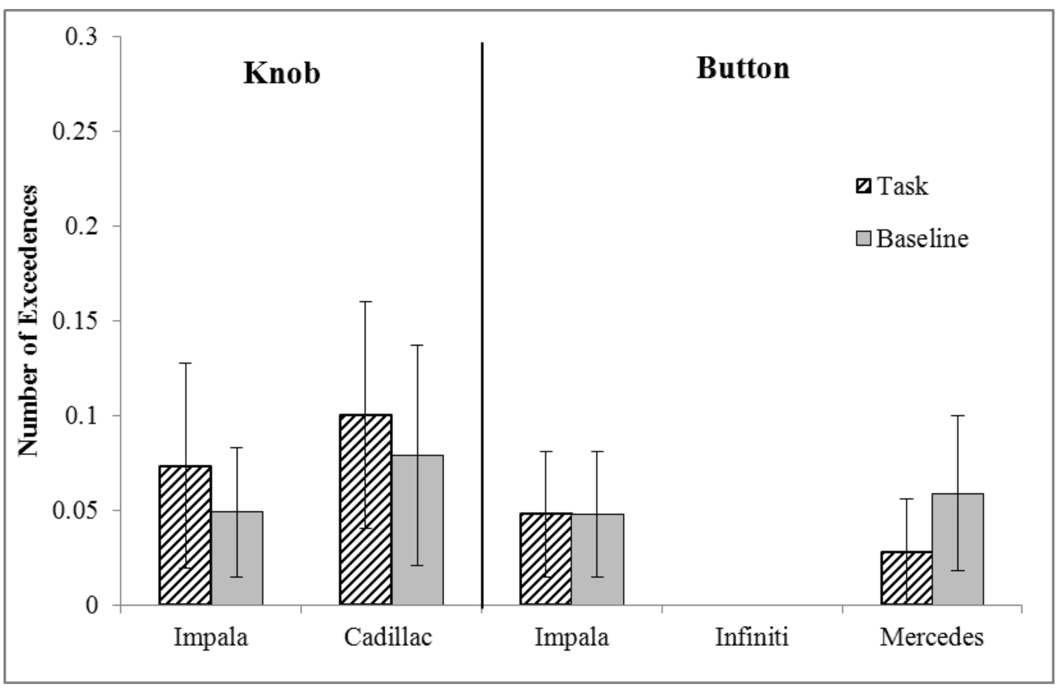

Figure 40. Mean Number of Lane Exceedances for Phase I

Standard Deviation of Lane Position

Mean standard deviations and standard errors of lane position for all scenarios are presented in Figure 41. There was a main effect for Scenario.

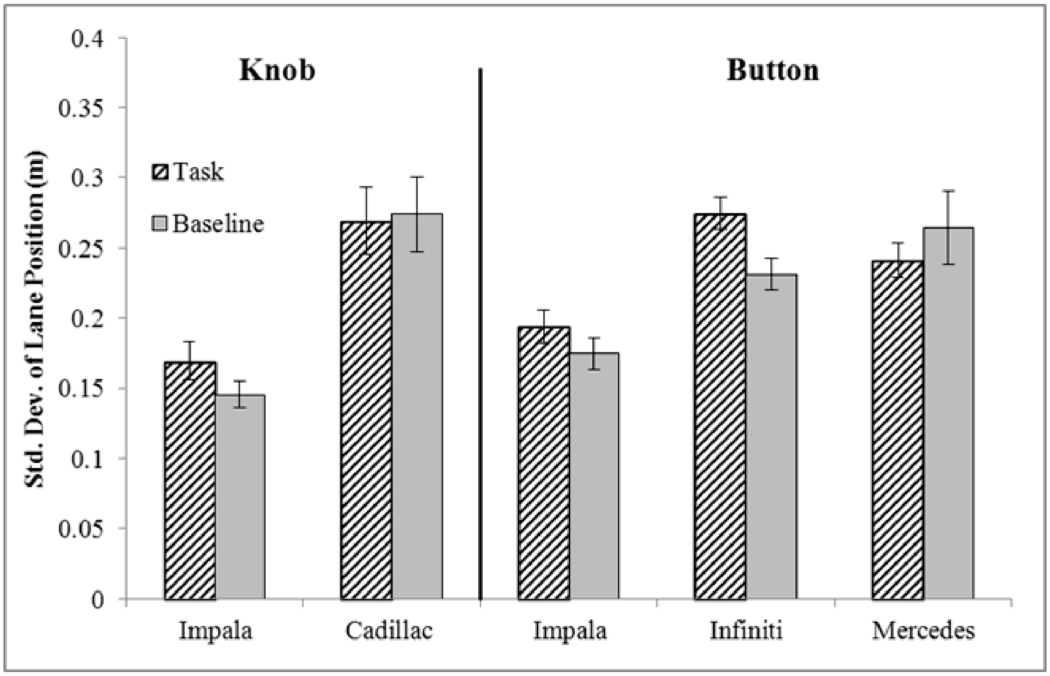

Figure 41. Standard Deviation of Lane Position for Evaluation 1

Headway Measures

Mean standard deviations of distance headway and associated standard errors for all conditions are shown in Figure 42. There were significant main effects for Scenario and Trial Number, as well as an interaction between Scenario and Trial Number.

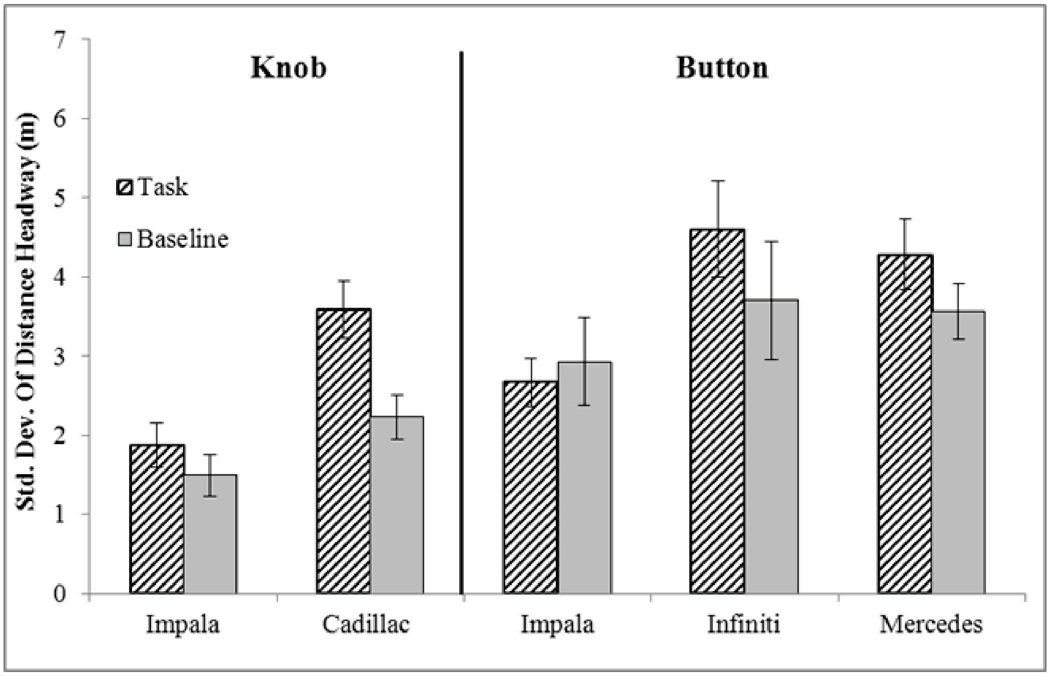

Figure 42. Standard Deviation of Distance Headway for Phase I

Figure 43 presents the mean standard deviation of time headway and standard errors for all scenarios. There was a main effect of Scenario, a marginal effect of Trial Number, and a significant Scenario x Trial Number interaction.

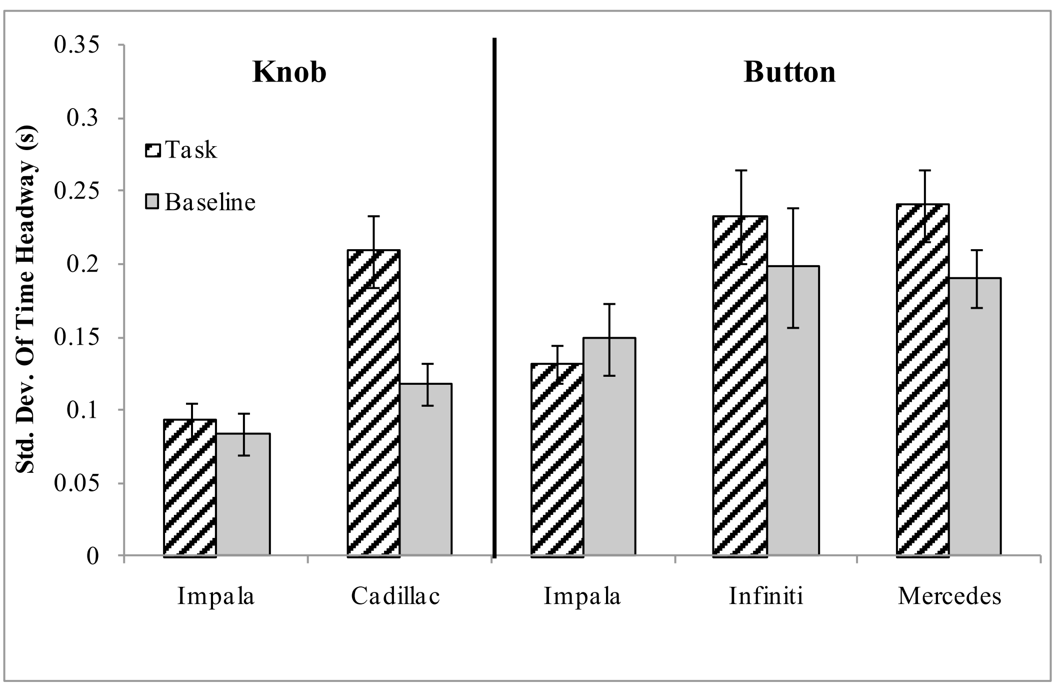

Figure 43. Standard Deviation of Time Headway for Phase I

Eye Glance Measures

The mean Total Glance Time to Task is illustrated in Figure 44. The main effects of Scenario and Trial Number, and the Scenario X Trial Number interaction effect were statistically significant. These are mean total glance times to the task, not 85th percentile values. The Alliance criteria for visual demand in Verification Alternative A call for 85 percent of the drivers in a test sample to each produce a total glance time to task that meets the stipulated criteria ($\leq$ 20 seconds).

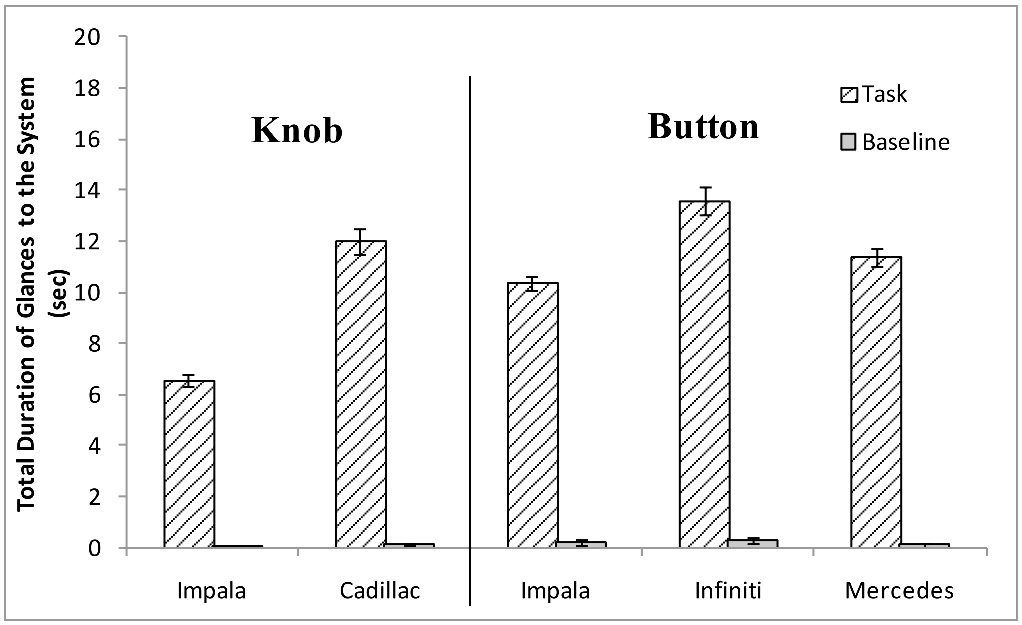

Figure 44. Total Glance Time to Task for Phase I

Figure 45 shows the mean Total Eyes-Off-Road Time. The main effects of Scenario and Trial Number were significant for this measure.

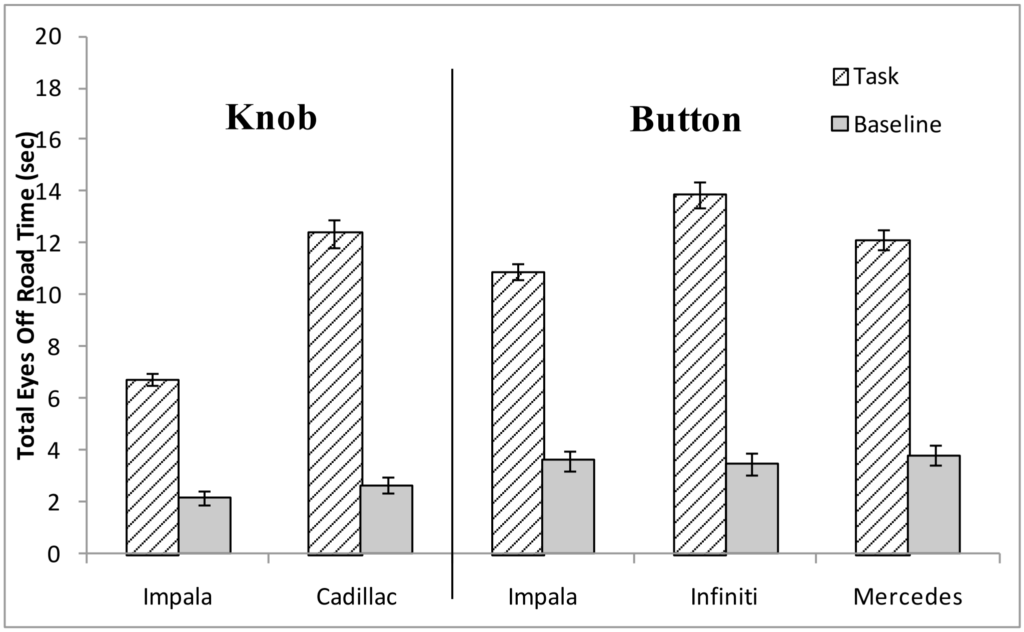

Figure 45. Total Eyes-Off-Road Time for Phase I

The mean Average Duration of Single Glances to the System was significantly affected by the Scenario and the Trial Number (Figure 46). Again, these are mean durations of single glances to the task, not 85th percentile values. The Alliance criteria for visual demand in Verification Alternative A call for 85percent of the drivers in a test sample to each produce a mean duration of single glance time to task that meets the stipulated criteria (≤2 seconds).

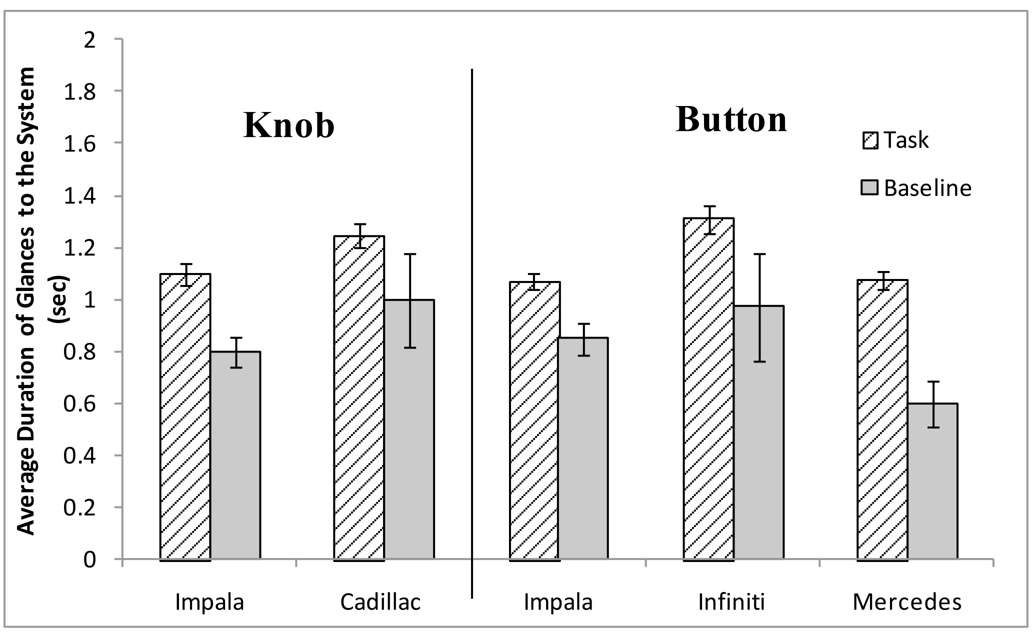

Figure 46. Average Duration of Single Glances to the System for Phase I

Figure 47 shows the mean glance rate, which was significantly affected by Scenario and Trial Number. No significant effect was observed by the interaction of these two factors. This glance metric is not called for in the Alliance Guidelines, but has been related to event detection (in the CAMP Driver Workload Metrics project; Angell et al., 2006). Therefore, it was examined here as a point of interest.

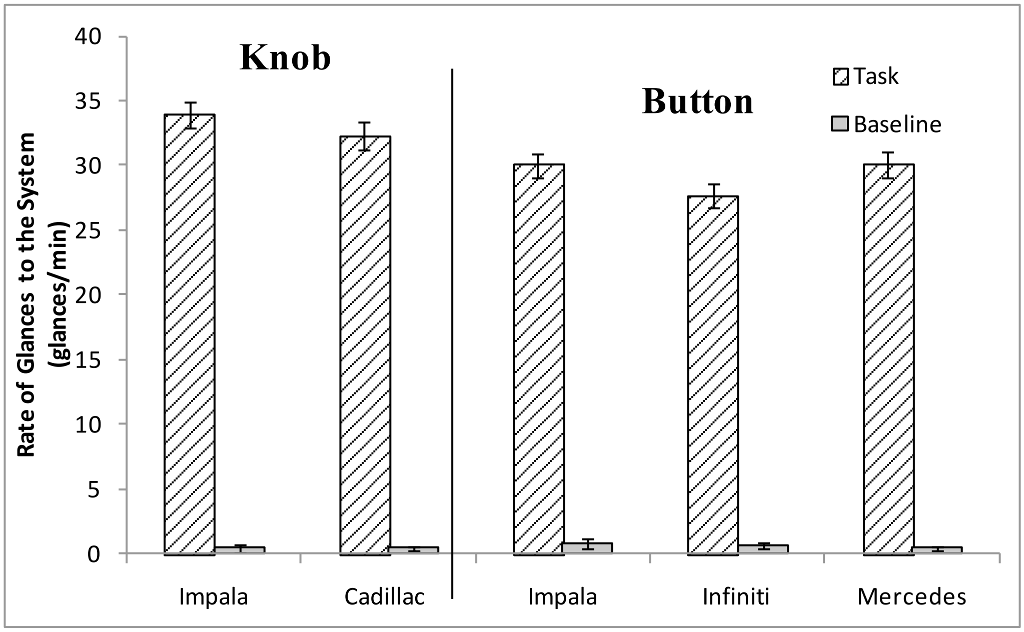

Figure 47. Rate of Glances to the System for Phase I

The mean Duration of Longest Glance to the System is illustrated in Figure 48. The Scenario factor had a significant effect on this measure. This metric is not identified in the Alliance Guidelines, but is reported here due to the fact that the presence of very long glances (particularly, many long glances for a task) can raise risk of missing events or conflicts that may be developing on the road ahead. Whether a single very long glance (e.g., in excess of 2 s.) is sufficient to be of concern is unknown (since such long glances can occur as 'outliers' that are not repeatable and are unassociated with task design or device operation). It may also be that some observed frequency of long glances across a sample provides a more robust metric.

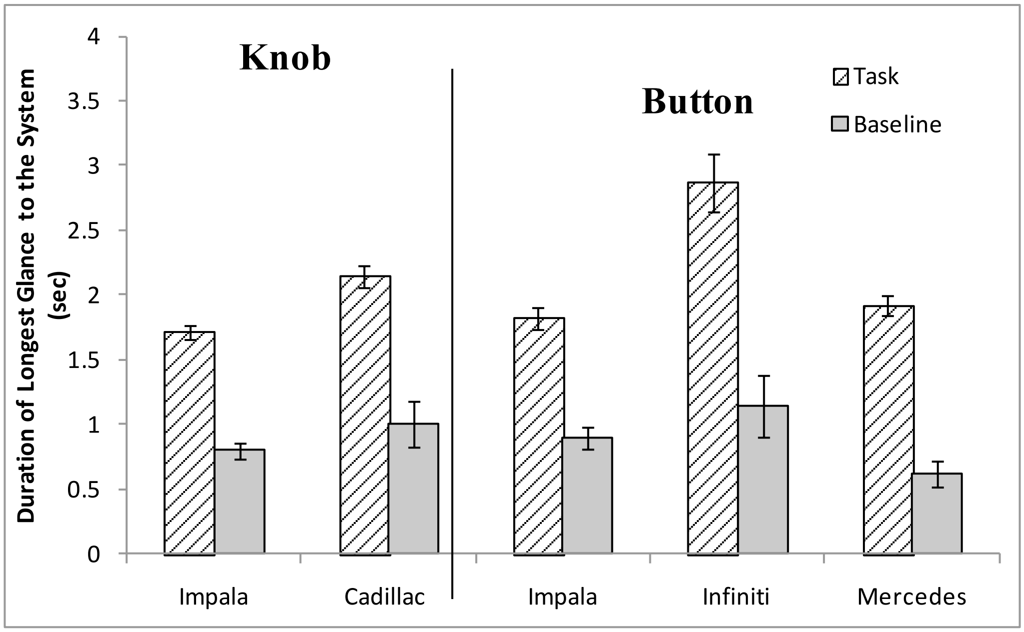

Figure 48. Duration of Longest Glance to the System for the First Evaluation

Combined Test Track Evaluation (VTTI; Phase II) and Simulator Study (VRTC)

This section presents the combined results of Phase II of the VTTI study and the NHTSA study, as both involved participants following a variable-speed lead vehicle. The NHTSA data (labeled DFD for Dynamic Following Detection test since that was the type of test being performed by NHTSA; see Ranney, Baldwin, Parmer, Martin, J& Mazzae, 2011, for additional information) will be compared below with the VTTI data. To enable a fair comparison to the two trials used in the VTTI study, only the first trial of NHTSA data for each analysis type will be included below. Since the NHTSA simulator used a Toyota Prius as its base vehicle, and the radio tuning task used the vehicle’s installed radio, comparisons are best drawn between the simulator results and the Prius on-road results. Since baselines were not matched as they were in the on-road study, they will not be included for the simulator study results.

The results of Phase II of the VTTI study are shown in Table 7. The effects of Scenario were significant for most measures, while the Trial Number and the Scenario X Trial Number interaction were significant for a small subset of them. Detailed information about the post hoc test results are provided later in the discussion, organized based on their relevance to the research questions.

Table 7. Statistical Outcomes for Eye Glance Variables' ANOVAs for the Second Evaluation

Variable	Scenario	Trial Number	Scenario X Trial Number
Task Duration	$p<0.0001$		
Lane Exceedances			
Standard Deviation of Lane Position		$p<0.05$	
Standard Deviation of Distance Headway	$p<0.0001$	$p<0.05$	
Standard Deviation of Time Headway	$p<0.01$		
Total Glance Time to Task	$p<0.0001$		
Total Eyes Off-Road Time	$p<0.0001$		
Average Duration of Single Glances to the System			$p=0.0073$
Glance Rate	$p<0.0001$	$p=0.0113$	$p=0.0023$
Duration of Longest Glance to the System	$p<0.0001$		

Task Duration

Mean durations and standard error bars for all task scenarios in the VTTI Phase II are presented in Figure 49 below. There was a main effect for Scenario, but no main effect for or interaction with Trial Number. Mean task durations varied substantially between the VTTI and NHTSA Driving Simulator studies: 13.3 s. for the on-road trial versus 19.7 s. for the simulator study.

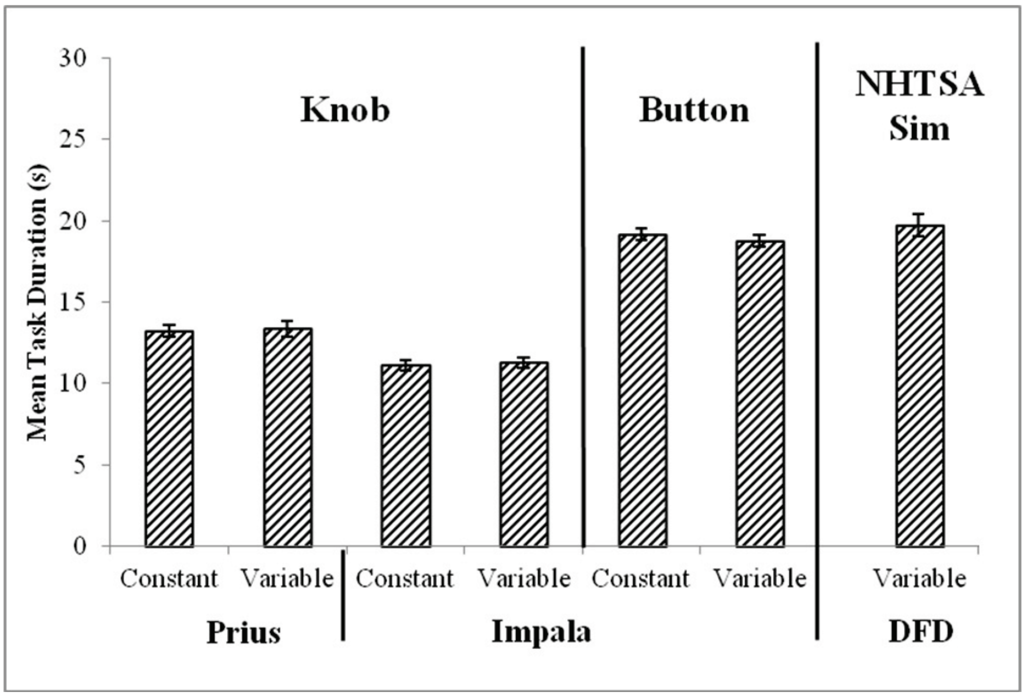

Figure 49. Mean Task Durations for Phase II

Lane Exceedances

Figure 50 presents the mean number of lane exceedances for all conditions, with standard error bars. As for Phase I, there were very few exceedances, and these were not analyzed further. For the NHTSA study, the driving simulator had a higher number of lane exceedances than all test track conditions.

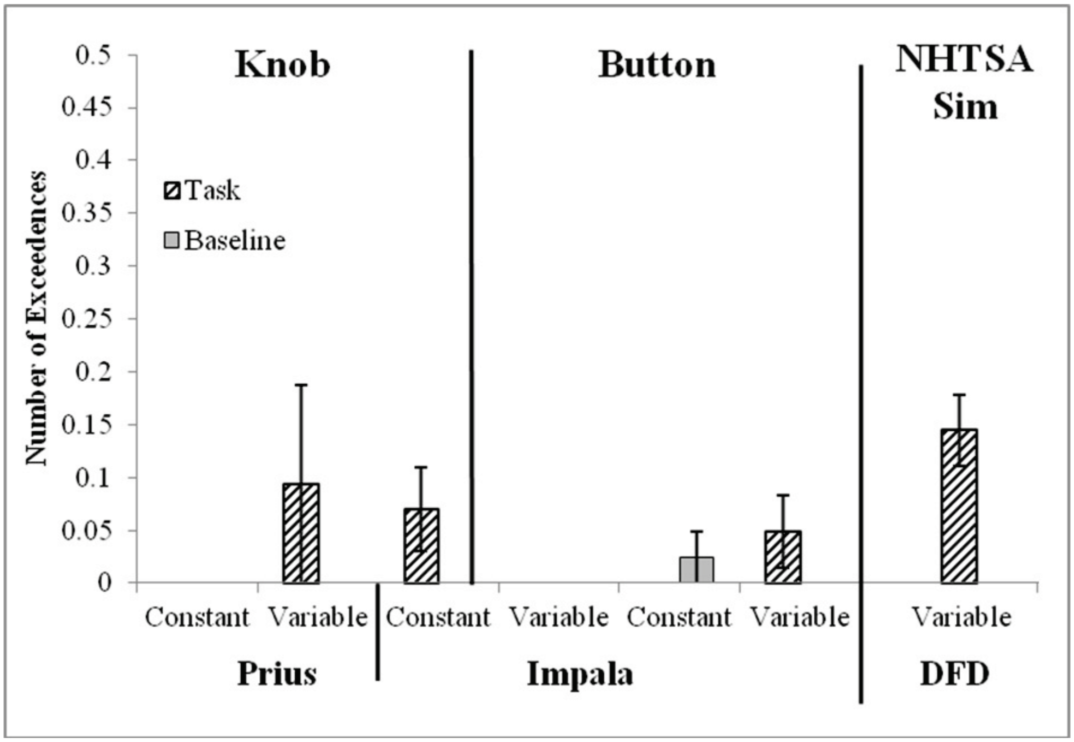

Figure 50. Mean Number of Lane Exceedances for Phase II

Standard Deviation of Lane Position

Mean standard deviation of lane position and standard error bars for all conditions in the VTTI Phase II study are presented in Figure 51. There was no main effect for Scenario, although there was a main effect for Trial Number. The standard deviations of lane position for NHTSA simulator results were similar to those found in the test track study, but slightly higher.

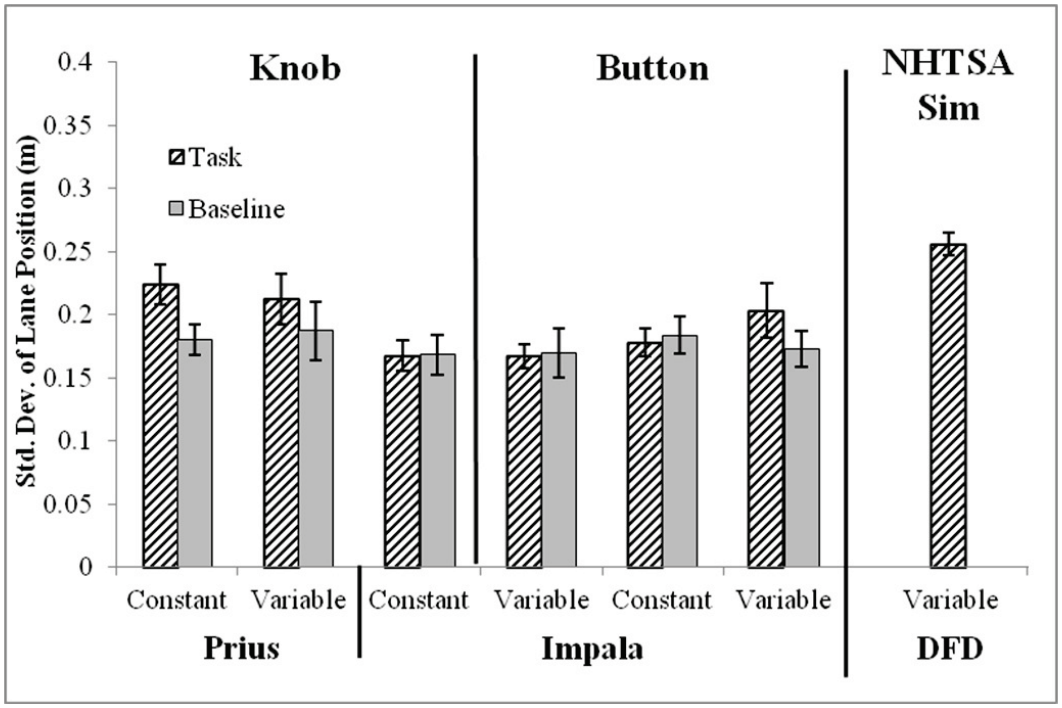

Figure 51. Standard Deviation of Lane Position for Phase II

Headway Measures

Mean standard deviation of distance headway and standard errors for all conditions in the VTTI Phase II study are presented in Figure 52. Main effects were found for Scenario and Trial Number. As the NHTSA simulator study did not use standard deviation of distance headway as a dependent measure, it is not provided here for comparison.

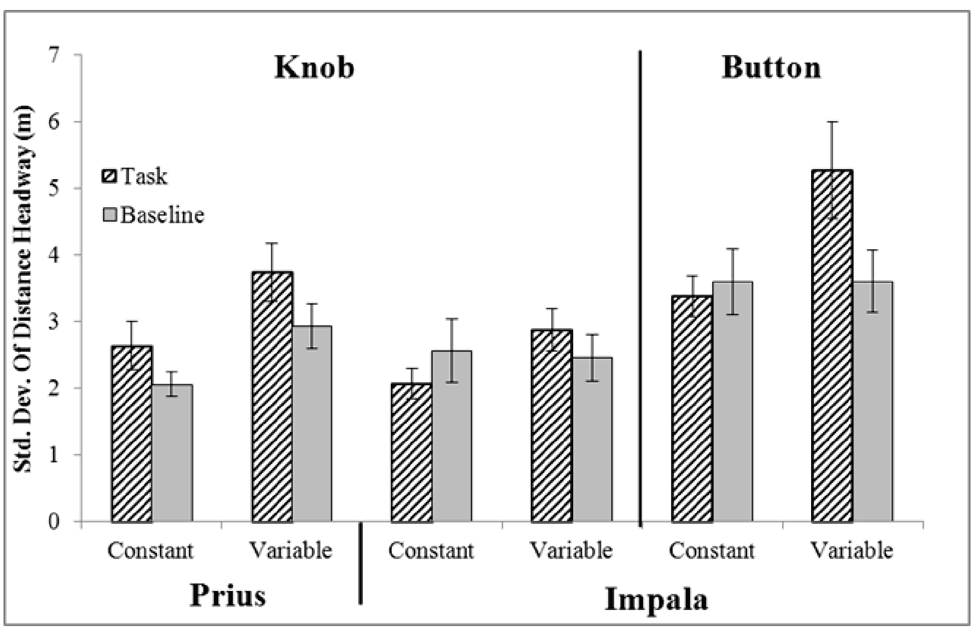

Figure 52. Standard Deviation of Distance Headway for Phase II

Figure 53 presents the mean standard deviations of time headway for the VTTI Phase II study, with standard error bars. There was a significant main effect for Scenario. The NHTSA driving simulator time headway variance is substantially higher than that found on the test track.

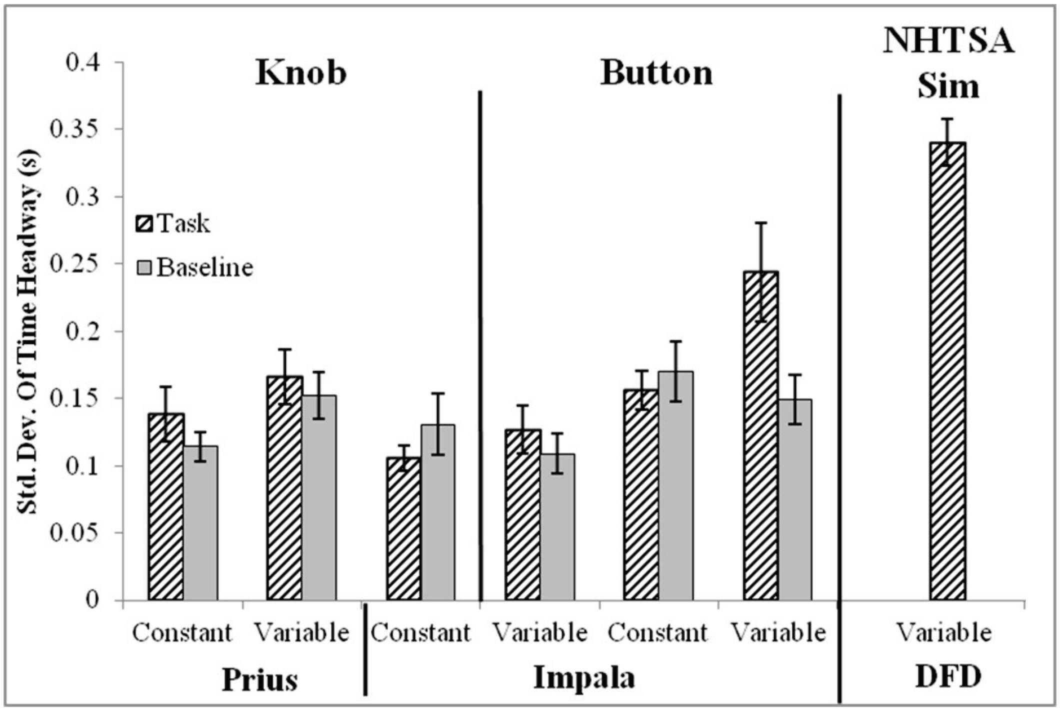

Figure 53. Standard Deviation of Time Headway for Phase II

Eye Glance Measures: VTTI On-Road Testing

For illustrative purposes, the variables in this section include data from both NHTSA and VTTI testing whenever possible. The mean Total Duration of Glances to the System is illustrated in Figure 54. The main effect of Scenario was statistically significant. These are mean total glance times to the task (not 85th percentile values). The Alliance criteria for visual demand in Verification Alternative A call for 85 percent of the drivers in a test sample to each produce a total glance time to task that meets the stipulated criteria (≤ 20 s.).

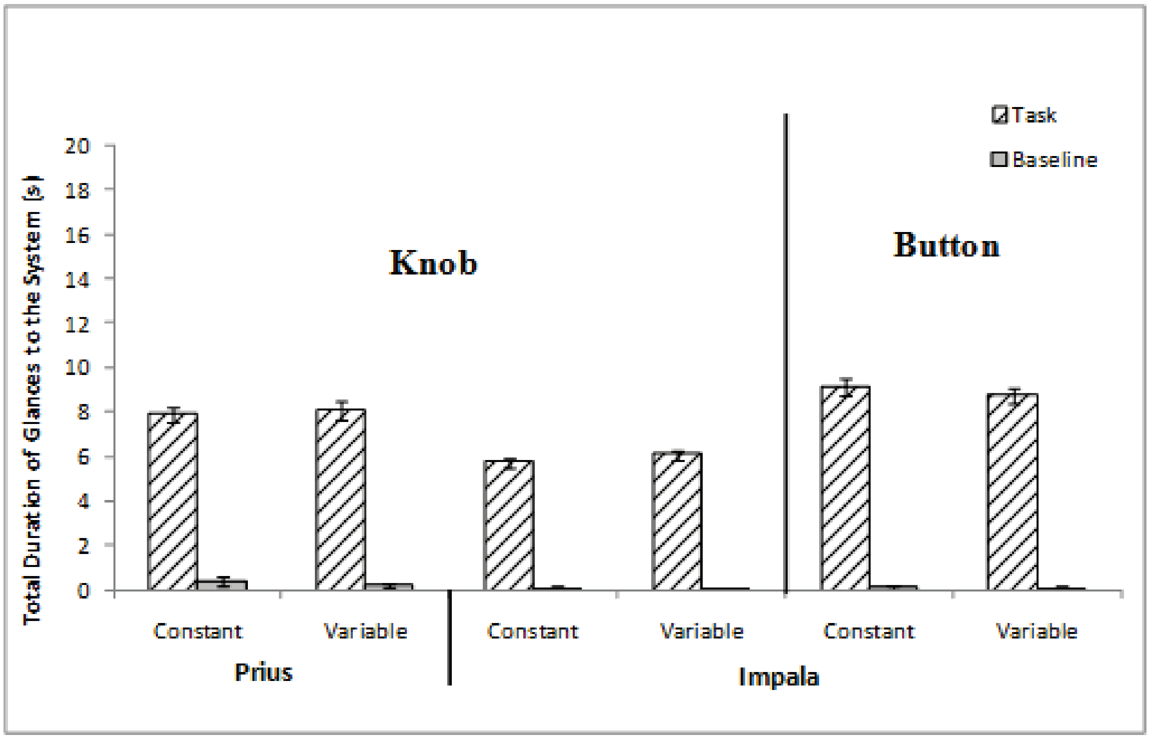

Figure 54. Total Glance Time to Task for Phase II

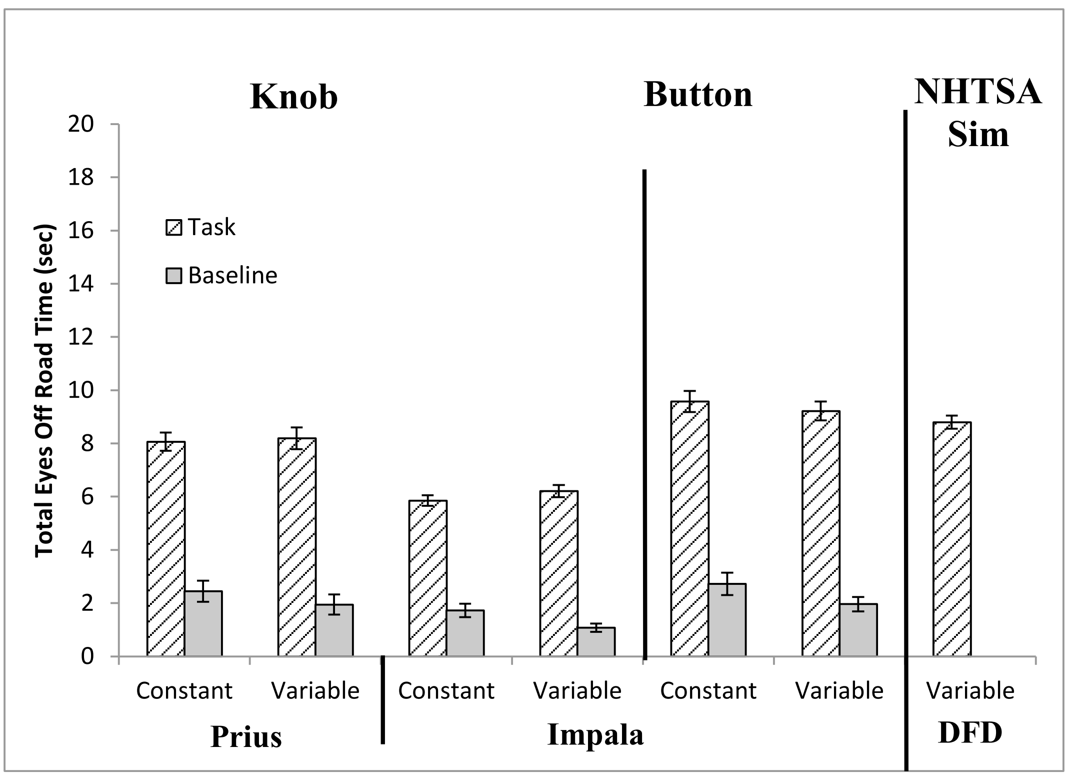

Figure 55. Total Eyes-Off-Road Time for Phase II

Figure 55 shows the mean Total Eyes-Off-Road Time. The main effect of Scenario was significant for this measure. The NHTSA mean Eyes-Off-Road time was greater than that found for the Prius in on-road testing (8.8 s. versus 8.0 s.) for the variable-headway test track condition.

The mean Average Duration of Glances to the System was significantly affected by the interaction of Scenario and Trial Number (Figure 56). Again, these are mean durations of single glances to the task (not 85th percentile values). The Alliance criteria for visual demand in Verification Alternative A call for 85 percent of the drivers in a test sample to each produce a mean duration of single glance time to task that meets the stipulated criteria (≤2 s.). The NHTSA eyeglance reduction value is presented in the graph with the underlying assumption that all glances outside the forward roadway were directed to the system of interest. The mean value for the NHTSA effort, 0.77 s., is less than with the mean for the on-road variable-headway Prius condition (1.16 s.).

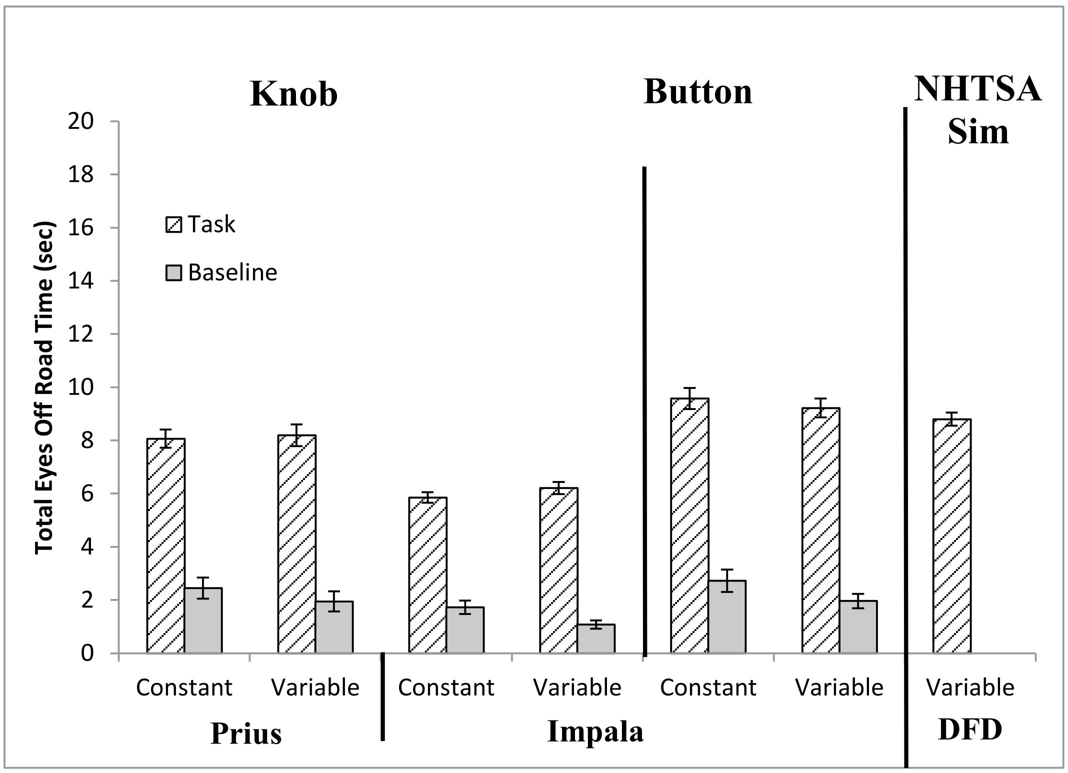

Figure 56. Average Duration of Single Glances to the System for Phase II

Figure 57 shows the mean glance rate, which was significantly affected by Scenario, Trial Number, and their interaction. This glance metric is not called for in the Alliance Guidelines, but has been related to event detection (in the CAMP Driver Workload Metrics project; Angell et al., 2006). Therefore, it was examined here as a point of interest. Again, the NHTSA eyeglance reduction value is presented in the graph with the underlying assumption that all glances outside the forward roadway were directed to the system of interest. The mean value for the NHTSA effort was 43.7 glances per minute, which was higher than the on-road equivalent for the variable-headway Prius condition (32.2 glances per minute).

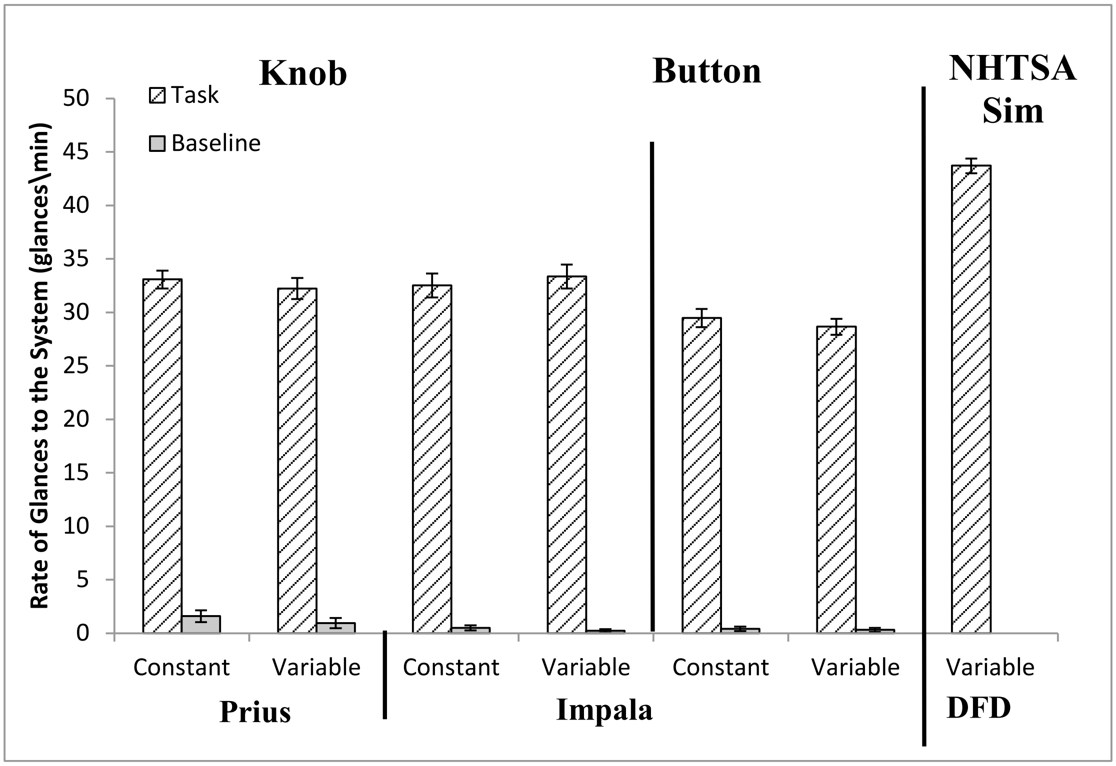

Figure 57. Rate of Glances to the System for Phase II

The mean Duration of Longest Glance to the System is illustrated in Figure 58. The Scenario factor had a significant effect on this measure. This metric is not identified in the Alliance Guidelines, but is reported here due to the fact that the presence of very long glances (particularly, many long glances for a task) can raise risk of missing events or conflicts that may be developing on the road ahead. Whether a single very long glance (e.g., in excess of 2 s.) is sufficient to be of concern is unknown (since such long glances can occur as 'outliers' that are not repeatable and are unassociated with task design or device operation). It may also be that some observed frequency of long glances across a sample provides a more robust metric. The mean value for the NHTSA eyeglance data was 1.6 s., which was lower than the on-road equivalent for the variable-headway Prius condition (2.0 s.). Note that the assumption was still made that all glances outside the forward roadway in the NHTSA study were directed to the system of interest. Since the mean duration for both experiments was relatively close, this difference could be an artifact of the eye-tracker device, or it could be indicative in differences between the subject populations, which were not assessed for equivalence.

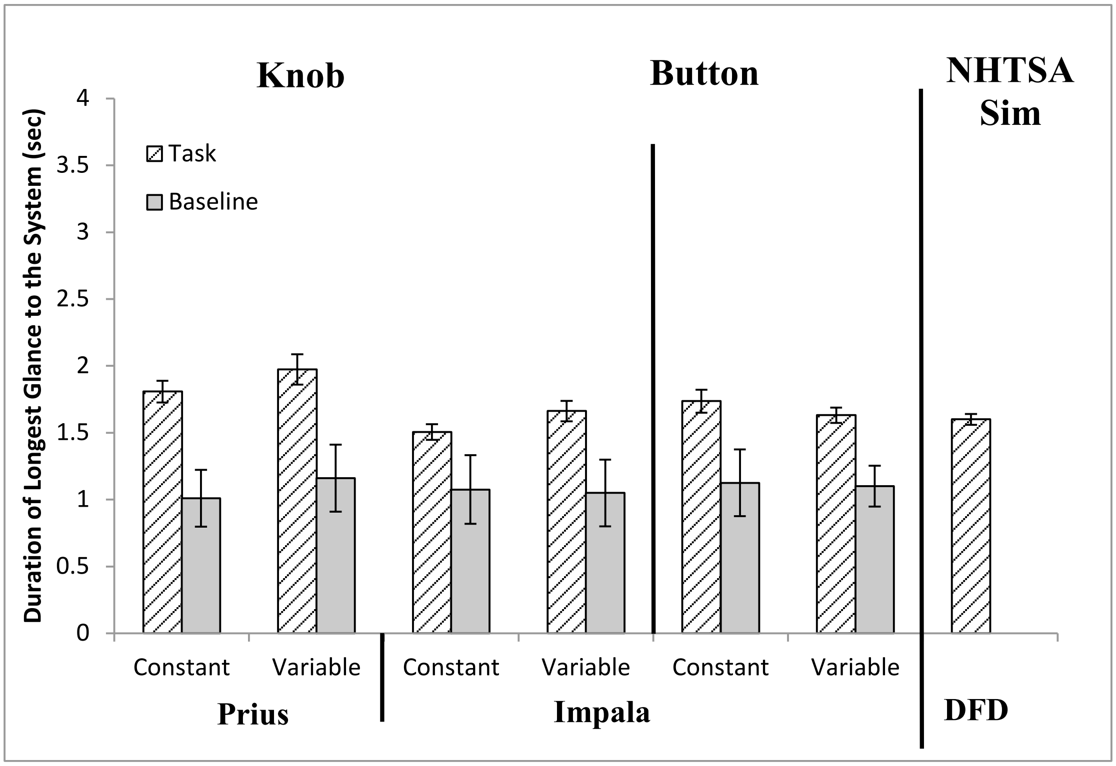

Figure 58. Duration of Longest Glance to the System for Phase II

A statistical comparison between the common Phase I and II eye glance results was also conducted. Significant differences were observed in the Total Glance Time to Task (p=0.0070) and the Total Eyes-Off-Road Time (p=0.0095). The average Total Duration of Glances to the System for Impala drivers during the first phase was 8.48 s.; drivers in the second evaluation looked away 7.38 s. or ~1.1 s. less. A similar difference was found in Total Eyes-Off-Road Time (8.87 s. versus 7.67 s.).

Table 8 lists the 85th percentiles for the different vehicles and tuning method combinations, based on the samples available for both the VTTI and the NHTSA studies. Percentiles were calculated based on a single value per participant, using the first of the two task repetitions (or multiple task repetitions, in the case of the NHTSA simulator data) that were analyzed for each participant. The Impala Button Tuning (Constant Lead Vehicle Speed) condition is boldfaced and italicized because it was the closest to the reference task as described in the Alliance Guidelines, and on which the 2/20 thresholds are presumably based. If this Impala condition were to be used to establish these thresholds based on the results of this study, those thresholds would be 1.2 s. for Average Duration of Single Glances to the System and 11.6 s. for the Total Eyes-off-Road Time, much smaller values than the 2 s. and 20 s., respectively, currently specified in the existing criteria used by the Alliance. These values would change to 1.0 s. and 12.0 s. if the NHTSA data are used, and 1.3 s. and 12.1 s. if both datasets are fully combined.

Table 8. 85th Percentiles for the Eye Glance Measures, Based on the Study Sample

Vehicle – Tuning Method – Lead Vehicle Speed Profile	Total Glance Time to Task (seconds)	Total Eyes-Off-Road Time (seconds)	Average Duration of Single Glances to the System (seconds)	Rate of Glances to the System (glances per minute)	Duration of Longest Glance to the System (seconds)	Total Number of Data Points
Cadillac - Knob Tuning – Constant Speed	15.3	15.8	1.5	38.0	2.7	19
Impala - Button Tuning - Constant Speed	***11.7***	***12.6***	***1.2***	***36.7***	***2.1***	***39***
Impala - Knob Tuning - Constant Speed	7.8	8.0	1.2	41.5	1.9	40
Impala - Button Tuning - Varied Speed	11.2	11.4	1.1	33.2	2.1	19
Impala - Knob Tuning - Varied Speed	7.6	8.0	1.3	43.4	2.0	20
Infiniti - Button Tuning - Constant Speed	14.9	15.2	1.4	34.6	3.2	20
Mercedes - Button Tuning - Constant Speed	11.9	13.6	1.2	36.4	2.4	22
Prius - Knob Tuning - Constant Speed	9.5	9.5	1.4	37.5	2.2	19
Prius - Knob Tuning - Varied Speed	10.9	10.9	1.4	38.2	2.5	20
NHTSA Simulator	NA	12.0	1.0	43.7	2.1	90
All VTTI Data	11.6	12.1	1.3	37.8	2.4	218
All Data	NA	12.1	1.3	39.5	2.3	308

Additional NHTSA Simulator Study Results

In addition to the results compared above with the VTTI test track results, several other variables were analyzed in the NHTSA study that were not computed for the test track data. The interested reader is directed to Ranney, Baldwin, Parmer, Martin, & Mazzae, 2011, for further details.

CHAPTER 4. DISCUSSION

The data presented in the previous two chapters were used to attempt to address a number of research questions that were pertinent to this investigation. Those research questions are answered in this chapter, to the extent possible from the data collected.

WERE THERE ANY DIFFERENCES BETWEEN DRIVING WHILE USING THE SYSTEMS AND "JUST DRIVING"?

There were sizeable, statistically significant, differences for four out of five eye glance measures between radio tuning tasks and their associated baselines. The values for Total Glance Time to Task, Total Eyes-Off-Road Time, Glance Rate, and Duration of Longest Glance to the System all differed significantly from their baseline values during radio tuning. However, the Average Duration of Single Glances to the System did not change significantly during task performance. These findings were as expected, as few glances to the system were predicted in the baseline conditions, during which the system was turned off and throughout which no driver interaction with the system was requested.

A noteworthy effect occurs when comparing the Total Glance Time to Task and Total Eyes-Off-Road Time variables. Given the experimental nature of the testing and the use of a closed-course test track, the main effect of using Total Eyes-Off-Road Time versus Total Duration of Glances to the System is an increase in the average value for the baseline conditions (where there is no participant interaction with the system and therefore more opportunity to glance at other non-forward-roadway locations). While the Total Eyes-Off-Road time during radio tuning is also slightly higher than its corresponding Total Duration of Glances to the System that increase is very minor compared to the increase observed during "just driving" conditions.

This Total Eyes-Off-Road Time effect is important in the context of whether to allow the use of this variable to replace Total Glance Time to Task. Total Eyes-Off-Road Time is usually an easier variable to obtain, especially when using machine vision protocols to extract glance information. In an experimental context such as this one, the increase in values appears to be relatively negligible, but that may be very different if the experiment is run in a real-world environment, where there are more events that require the driver's attention, or in a simulated environment with more than minimal visual content. Care should be taken to avoid those situations in this type of testing.

The kinematics variables evaluated (Lane Exceedances, Standard Deviation of Lane Position, Standard Deviation of Distance Headway, and Standard Deviation of Time Headway) generally did not exhibit significant differences from their associated baselines. For Phase I, while there were clear trends in the data toward more variability in both time and distance headway for task conditions as compared to baselines, these never approached the $p<0.05$ criteria for significance in Tukey-corrected paired comparisons. For Phase II, there did not appear to be a consistent trend for task conditions to be different from their baselines for any dependent measures, including headway variation. The exception was the headway measures for the most complex condition: the Impala button interface with a variable headway. This, combined with the headway trends from Phase I, suggests that differences from baseline driving may occur with combinations of more complex vehicular and interface control tasks.

These findings indicate that the eye glance measures are more sensitive to radio tuning task performance than are the kinematics variables evaluated.

WERE THERE DIFFERENCES AMONG SCENARIOS?

Duration

In Phase I, Button conditions tended to take longer to complete than Knob conditions in dynamic testing. This was not absolute, as there was no significant difference between the Impala Button condition and the Cadillac Knob condition, but both the Infiniti and Mercedes Button conditions took significantly longer than both Knob conditions. In addition, the Impala Knob condition took a shorter time to complete than any other condition, including both the same car's Button condition and the Cadillac Knob condition. The shortest time-to-completion was the Impala Knob, at 11.2 s., and the longest was the Infiniti Button, with 23.5 s.

The duration results for Phase II were consistent with Phase I, with the shortest duration in this case being the Impala Knob Constant Headway condition (11.1 s.), which was nearly identical to the equivalent condition in Phase I. The only Button condition tested in Phase II was the Impala Button, which had a duration of 19.2 s. in the Constant Headway condition (compared to 20.0 s. in the equivalent condition in Phase I). Interestingly, although there were significant differences between all three of the modality conditions in Phase II (Impala Knob had a shorter duration than the Prius Knob, which had a shorter duration than the Impala Button), there were no significant differences between headway conditions within modalities. This suggests that the variance in headway in the variable lead vehicle speed condition was not severe enough to draw drivers' resources away from the tuning task any more than does following a constant-speed vehicle.

Lane Exceedances

No conditions in Phase I or Phase II elicited any consistent lane exceedances; a few sporadic exceedances occurred, but these were rare and occurred across conditions. As instances were so rare, they were not analyzed further and were not considered a discriminator among input scenarios. It is likely that this was due to the relative straightness of the test track, and that curving roads may have resulted in more lane exceedances.

Standard Deviation of Lane Position

In Phase I, both the Impala Knob and Button conditions had lower standard deviations of lane position than the Cadillac Knob and Infiniti Button conditions, while the Mercedes Button condition did not differ significantly from any of the other conditions. It should also be noted that the differences in deviation were relatively small in magnitude, about 0.1 m between the lowest-deviation condition, Impala Knob (0.17 m.), and the largest, Infiniti Button (0.27 m.), and that the overall deviations were relatively low.

There was no overall main effect of scenario on standard deviation of lane position for Phase II, so no follow-up tests were conducted. The values for both Impala Constant conditions were very similar to their equivalent conditions in Phase I, while the Prius Knob condition had a lower standard deviation of lane position than the Cadillac Knob condition in Phase I. These mixed, low-magnitude results suggest that standard deviation of lane position may not be a particularly sensitive measure to discriminate between these relatively low demand scenarios.

Headway Measures

For standard deviations of both distance and time headway, the Impala Knob condition had significantly lower deviations than the Infiniti and Mercedes Knob conditions in Phase I; for time headway deviation, the Impala Knob condition was also significantly lower than the Cadillac Knob condition. No other conditions differed significantly from one another in either headway measure, although there was a marginal ($p = 0.06$) difference between the Impala and Mercedes Button conditions in time headway standard deviation.

The headway data in Phase II followed a similar pattern, although here the only condition to have significantly higher headway variability was the Impala Button Variable Speed condition, which had higher variability than both the Prius Constant Speed and Impala Knob (Constant and Variable Speeds) conditions for both time and distance standard deviation of headway measures. In addition, there was a marginally significant ($p = 0.05$) difference between the Impala Button Variable and Constant conditions for standard deviation of distance headway; the only case where a difference emerged between any variable's speed profile conditions. These headway data suggest that variable lead vehicle speed may be more discriminating when testing more complex tasks or interfaces.

Eye Glance Measures

The eye glance variables indicated marked differences between different radio systems, mostly related to the difference in duration that has already been discussed. For tuning with a knob, the first phase reliably showed that the Cadillac system had a larger visual demand than the Impala system. The Cadillac system had larger Total Glance Time to Task, Total Eyes-Off-Road Time, and a larger Rate of Glances to the System (observed only on the first repetition of the task, however). The system delays in the Cadillac are likely the source for most of these differences. The second phase tests showed larger Total Glance Time to Task and Total Eyes-Off-Road Time for the Prius system when compared to the Impala system. This observation tracked the results observed for task duration.

For tuning with the button, use of the Infiniti system resulted in significantly higher eye glance metrics than the Impala reference system for all variables except the Rate of Glances to the System. The Mercedes system was not significantly different from the Impala system with button tuning for any of the variables, although it was nominally higher for all of them. The additional visual load in the Infiniti system is likely due in part to an additional step that was required in transitioning between bands. This suggests that glance metrics have considerable sensitivity to visual demand of interface variations (even single step increases).

HOW DID THE RESULTS OF THE NHTSA SIMULATOR STUDY COMPARE TO THOSE OF THE VTTI TEST TRACK STUDY?

In general, the simulator study resulted in findings consistent with those of the equivalent condition (Toyota Prius, variable-headway) in the VTTI test track study. Task duration was somewhat longer in the simulator study than in the closed-road study, by roughly 6.0 s. with the

DFD metrics and 2.0 s. with the Alliance metrics. This increased duration could correlate with increases in other measures. The largest difference found between closed-road and simulator studies came with the number of lane exceedances, where the Alliance metric in particular had many more lane busts than the equivalent on-road condition. This could be due to either the simulator itself or the method in which exceedances were calculated; the second is somewhat more likely since there is such a discrepancy between Alliance and DFD metrics here. Interestingly, standard deviation of lane position metrics were very similar between the NHTSA and VTTI studies, which further suggests that the discrepancies found in lane exceedances may be a function of calculation method. Differences were also found in the standard deviation of time headway, where Alliance metrics were considerably lower (roughly 0.05 meter) than the on-road condition. The reason for this discrepancy is unclear, but could be linked to differences in the simulator and test track environments. Most eye glance metrics were similar for both studies, with the main differences observed in the glance rate and longest glance duration metrics. These differences, however, were relatively minor, and should not overshadow the similarities that were observed for many other important measures.

WHAT DOES THIS DATA FIND TO BE THE VISUAL DEMAND ACCEPTABILITY CRITERIA?

As pointed out above, similar results were found for the eye glance measures for testing performed using the VTTI test track and the NHTSA driving simulator. As a result, the VTTI test track data and the NHTSA driving simulator data were pooled together for analyses to determine visual demand acceptability criteria. Quite different results were found for the kinematics variable evaluated. Therefore, the VTTI and NHTSA kinematics variable data were not pooled.

The data indicate that visual demand acceptability criteria based upon driver 85th percentile (the same percentile as used in the Alliance Guidelines) radio tuning performance of the pooled data set would be: individual eye glances away from the forward road scene not exceed 1.3 s. and total eyes-off-road time to perform an entire task should not exceed 12.1 s.

NHTSA is interested in using both driving simulator testing and occlusion testing to determine the acceptability of tasks for performance while driving. Occlusion testing would be performed as specified in ISO 16673:2007, "Road Vehicles – Ergonomic Aspects of Transport Information and Control Systems – Occlusion Method to Assess Visual Demand due to the use of In-Vehicle Systems." This standard specifies a viewing interval (shutter open time) of 1.5 s. followed by an occlusion interval (shutter closed time) of 1.5 s. Each 1.5 s. unoccluded period corresponds to 2.0 s. of driving simulator eyes-off-road time. Therefore, specified acceptance criteria involving eyes-off-road time should be a multiple of 2.0 s.

For compatibility with occlusion testing, the above listed individual eye glances away from the forward road scene not to exceed time of 1.3 s. and total eyes-off-road time to perform an entire task not to exceed time of 12.1 s. are rounded off to the nearest multiple of 2.0 s. This gives that task eye glance acceptability criteria of individual eye glances away from the forward road scene should not exceed 2.0 s. and total eyes-off-road time to perform an entire task should not exceed 12.0 s. (This is referred to as the 2/12 rule.)

WERE THERE DIFFERENCES BETWEEN CONDITIONS WITH CONSTANT LEAD VEHICLE SPEED VERSUS A VARIABLE LEAD VEHICLE SPEED?

With the exception of the distance headway condition noted above, there were no significant or marginally significant differences between constant and variable lead vehicle speed conditions for any kinematics measures in any conditions. In terms of eye glance, there were also no statistical differences between conditions with a constant lead vehicle speed and those with a variable lead vehicle speed. The pattern of data presented in the headway conditions suggests that variable headway may present a slightly more challenging tracking task, but that this difference may not manifest itself in driving behavior unless combined with a particularly complex or time-consuming interface task. That was also the case for the eye glance measures, where the relatively short duration of these tasks (generally less than 20 s., and often less than 10 s.) did not appear to provide sufficient time for the eye glance measures to become sensitive to the increased demand that changes in lead vehicle speed should represent.

WERE THERE ANY DIFFERENCES BETWEEN TUNING MODALITIES?

Only the Impala system was considered for this question, as it was the only vehicle where both button and knob interface modalities were tested. Although the data trended toward poorer performance for the Button interface across the kinematic dependent measures, only the duration measures in both phases and the headway measures in Phase II (for the variable lead vehicle speed condition) show statistically degraded performance when the button interface is used.

Eye glance measures were much more discriminating between tuning modalities. Some eye glance variables showed sizeable differences between tuning with a knob and tuning with a button. Button tuning was typically more visually demanding than knob tuning. Interestingly, there was no statistically significant difference in tuning methods for the Average Duration of Single Glances to the System and the Duration of Longest Glance to the System. This finding suggests that these differences are based on the generally longer task durations required by button tuning. The characteristics of the glances to the system appear to not be altered between tuning methods, but rather by the overall effect of the longer task duration.

An interesting effect related to tuning method is illustrative of the large influence that system differences can have on these kinds of studies. From a visual demand perspective, the Cadillac system, in spite of being tuned with a knob, was not any better than button tuning in the Impala (in fact, it was often found to be more visually demanding than button tuning in the Impala). This showcases that, in the context of a relatively short task such as radio tuning, the influence of system properties such as delays and sensitivity can have sizeable effects on the overall outcomes of the evaluations.

WHAT CONCLUSIONS CAN BE DRAWN ABOUT THE TESTED INTERFACE MODALITIES?

The most “standard” interface to be tested, with reference to the Alliance guidelines, was in the Chevrolet Impala, and was controllable via either button or knob. This interface, particularly when controlled with the knob, proved to be the most conservative across measures. The more complex interfaces, particularly in the Infiniti, tended to be associated with longer task durations, larger values for total glance time to task and total eyes-off-road time, more deviation and lane position, and higher headway deviation than was the Impala; these differences were larger and more consistent when compared to the Impala Knob as opposed to the Impala Button.

DO MULTIPLE REPETITIONS RESULT IN DIFFERENT OUTCOMES?

Trial number showed several main effects and interactions across kinematics dependent measures. These were not large in magnitude. From an eye glance perspective, there were very few effects found between the two repetitions that were analyzed. In the first evaluation, the second task repetition required about 0.5 s. longer Total Duration of Glances to the System and 0.1 s. longer Average Glance Durations to the System. In the second evaluation, ~1.3 additional glances per minute were observed on the first repetition as compared to the second. These are not particularly sizeable effects, which, combined with their sporadic nature between the two phases in the study, suggests that once a minimum level of training has been achieved there are few differences between different repetitions of similar tuning tasks.

It is possible, however, that the relatively short duration of these tuning tasks may mask some effects of task repetition. From a statistical standpoint, more repetitions represent more reliable estimates. Therefore, caution should be used in interpreting these results to mean that repetitions of the same task should not be undertaken in this type of system testing.

WHAT EFFECTS WOULD A CHANGE IN VISUAL DEMAND THRESHOLDS HAVE ON THE "ACCEPTABILITY" OF THESE TASKS?

Table 9 lists the different systems that were tested and the "acceptability" of their radio tuning based on different potential visual demand thresholds. The acceptability is based on the measures from 85 percent or more of participants meeting the Alliance-specified threshold under Verification Alternative A of Principle 2.1 of the Alliance Guidelines. Since more than one observation was available for each participant, the results are shown based on the first repetition of each task.

Table 9. Acceptability of the Different Radio Tuning Tasks Based on Current and Hypothetical Visual Demand Thresholds

	Total Glance Time to Task			**Average Duration of Single Glances to the System**			**Duration of Longest Glance to the System****		
Scenario	**20 s.***	**15 s.**	**12 s.**	**2 s.***	**1.5 s.**	**1.3 s.**	**2.5 s.**	**2.25 s.**	**2.2 s.**
Cadillac - Knob Tuning - Constant Speed	Y	**N**	**N**	Y	**N**	**N**	**N**	**N**	**N**
Impala - Button Tuning - Constant Speed	Y	Y	Y	Y	Y	Y	Y	Y	Y
Impala - Knob Tuning - Constant Speed	Y	Y	Y	Y	Y	Y	Y	Y	Y
Infiniti - Button Tuning - Constant Speed	Y	Y	**N**	Y	Y	**N**	**N**	**N**	**N**
Mercedes - Button Tuning - Constant Speed	Y	Y	Y	Y	Y	Y	Y	**N**	**N**
Prius - Knob Tuning - Constant Speed	Y	Y	Y	Y	Y	**N**	Y	Y	Y
Total Meeting Criterion	6	5	4	6	5	3	4	3	3

* - Current Alliance Guidelines threshold for Verification Alternative A, Principle 2.1
** - Not currently used in Alliance Guidelines

It is important to note that all of these tuning tasks are exempt from testing under the Alliance Guidelines scope. Therefore, these comparisons are for academic purposes and not meant to represent an assessment of the acceptability of particular tuning tasks in the real world. With that caveat, it appears that the current Alliance Guidelines thresholds for Principle 2.1, Alternative A, would result in all the tuning tasks being considered "acceptable."

There is also a wide range of hypothetical scenarios that can be constructed using Table 8. For example, if a limit on maximum glance duration of 2.5 s. was added as a requirement, the Cadillac and Infiniti tuning tasks would no longer be considered acceptable. Recall that these tasks had system delays and/or extra steps embedded in them. If the 20 s. (total duration) threshold was reduced to 15 s., and the 2 s. (average single glance duration) threshold was reduced to 1.5 s., with no limit on maximum glance duration, the only tuning task considered "unacceptable" would be the Cadillac.

REFERENCES

Angell, L., Auflick, J., Austria, P. A., Kochhar, D. S., Tijerina, L., Biever, W. J., Diptiman, T., Hogsett, J., & Kiger, S. (2006, November). *Driver workload metrics: Task 2 final report* (Report No. DOT HS 810 635). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/Driver%20Distraction/Driver%20Workload%20Metrics%20Final%20Report.pdf

Antin, J. F., Lee, S., Hankey, J., & Dingus, T. A. (2011). Design of the In-Vehicle Driving Behavior and Crash Risk Study In Support of the SHRP 2 Naturalistic Driving Study. (Report No. SHRP 2 Report S2-S05-RR-1. Washington, DC: Transportation Research Board. Available at www.nap.edu/openbook.php?record_id=14494&page=1

Brookhuis, K. A., De Waard, D., & Mulder, B. (1994). Measuring driving performance by car-following in traffic. *Ergonomics , 37*, 427–434.

Driver Focus-Telematics Working Group. (2006). Statement of principles, criteria and verification procedures on driver interactions with advanced in-vehicle information and communication systems. Washington, DC: Alliance of Automobile Manufacturers.

Harms, L., & Patten, C. (2003). Peripheral detection as a measure of driver distraction. A study of memory-based versus system-based navigation in a built-up area. *Transportation Research Part F, 6* (1), 23-36.

Ranney, T., Mazzae, E. N., Baldwin, G. H. S., & Salaani, M, K. (2007, March). *Characteristics of voice-based interfaces for in-vehicle systems and their effects on driving performance.* (Report No. DOT HS 810 867). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2007/DOT-HS-810-867.pdf

Ranney, T., Baldwin, G. H. S., Parmer, E., Martin, J., & Mazzae, E. N. (2011). *Distraction effects of manual number and text entry while driving.* (Report No. DOT HS 811 510). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2011/811510.pdf

APPENDIX A. SURVEY RESULTS

2011 FORD EDGE WITH MYFORD TOUCH PREMIUM INFOTAINMENT SYSTEM

System	Description of Tuning Controls	Number of Soft Key Controls	Number of Hard Key Controls	Display Size	Size of Smallest Digit on the Display	Mounting Position	Radio Bands Available
2011 Ford Edge	Radio function selection: Soft key Toggle between bands: Soft key Frequency up and down: Hard keys (touch sensitive) Voice activation: Voice activates band and frequency Other tuning controls (describe):__________	27	22		5mm	Horizontal: __________ Vertical: __________	AM FM Sirius

Minimum Step between Station Frequencies	Method(s) of Control Available:	Description of Tuning Methods Described in Owner's Manual	Number of Steps for Owner's Manual Tuning Methods	Describe Additional Functions Embedded within the Infotainment System Containing the Radio	Time for Experimenter to Complete Standard Static Tuning Task (average of three trials)	Alliance Compliance Checklist:
AM: 10 kHz FM: 0.2 MHz Satellite Radio: 1 Other: ________	X Visual-Manual X Voice □ Other			X CD X MP3/iPod interface X Cell phone integration - Voice □ Cell phone integration - Voice & Text X Navigation X DVD Playback □ Internet features X Climate control X Vehicle settings	14.81 s	Controls X Radio function selection button available X Button to toggle between bands available X Frequency up button available X Frequency down button available X At least six additional controls not used for the task available Display X Size of digits on display is at least 5 mm Mounting Position □ Approximately 15° to the driver's right □ No more than 40° down Station Characteristics □ At least 20 stations available on each band (**location-dependent**) FM is OK, AM is not X White noise presented between stations □ AM 530 - 930 kHz with 10 kHz steps □ FM 89 - 108 MHz with 0.2 MHz steps

2011 INFINITI M37X

System	Description of Tuning Controls	Number of Soft Key Controls	Number of Hard Key Controls	Display Size	Size of Smallest Digit on the Display	Mounting Position	Radio Bands Available
2011 Infiniti M37x	Radio function selection: Left knob or voice Toggle between bands: Hard Key Frequency up and down: Knob Voice activation: Voice activates band, but not specific frequency Other tuning controls (describe):__________	16	14	7" X 4"	6 mm X 10 mm	Horizontal: __________ Vertical: __________	AM FM XM

Minimum Step between Station Frequencies	Method(s) of Control Available:	Description of Tuning Methods Described in Owner's Manual	Number of Steps for Owner's Manual Tuning Methods	Describe Additional Functions Embedded within the Infotainment System Containing the Radio	Time for Experimenter to Complete Standard Static Tuning Task (average of three trials)	Alliance Compliance Checklist:
AM: 10 kHz FM: 0.2 MHz Satellite Radio: 1 Other: _________	X Visual-Manual X Voice □ Other			X CD X MP3/iPod interface ?? X Cell phone integration - Voice □ Cell phone integration - Voice & Text X Navigation X DVD Playback □ Internet features X Climate control □ Vehicle settings		Controls X Radio function selection button available X Button to toggle between bands available □ Frequency up button available □ Frequency down button available □ At least six additional controls not used for the task available Display X Size of digits on display is at least 5 mm Mounting Position □ Approximately 15° to the driver's right □ No more than 40° down Station Characteristics □ At least 20 stations available on each band (**location-dependent**) FM is OK, AM is not X White noise presented between stations □ AM 530 - 930 kHz with 10 kHz steps □ FM 89 - 108 MHz with 0.2 MHz steps

2010 CHEVROLET IMPALA

System	Description of Tuning Controls	Number of Soft Key Controls	Number of Hard Key Controls	Size of Smallest Digit on the Display	Mounting Position	Radio Bands Available	Minimum Step between Station Frequencies
2010 Chevrolet Impala	Radio function selection: Large central button Toggle between bands: "Band" button Frequency up and down: Knob on right Other tuning controls (describe): REV/FWD buttons	4	18		Horizontal: __________ Vertical: __________	AM FM	AM: 10 kHz FM: 0.2 MHz Satellite Radio: ? Other: __________

Method(s) of Control Available:	Description of Tuning Methods Described in Owner's Manual	Number of Steps for Owner's Manual Tuning Methods	Describe Additional Functions Embedded within the Infotainment System Containing the Radio	Time for Experimenter to Complete Standard Static Tuning Task (average of three trials)	Alliance Compliance Checklist:
X Visual-Manual □ Voice □ Other	Knob: "Turn to select radio stations." Describes seek buttons, and scan functions. Does NOT describe REV/FWD method.	1) Power (Volume) 2) Band 3) Tune/Seek	X CD □ MP3/iPod interface □ Cell phone integration - Voice □ Cell phone integration - Voice & Text □ Navigation □ DVD Playback □ Internet features X Climate control □ Vehicle settings		Controls X Radio function selection button available X Button to toggle between bands available X Frequency up button available X Frequency down button available X At least six additional controls not used for the task available Display □ Size of digits on display is at least 5 mm Mounting Position □ Approximately 15° to the driver's right □ No more than 40° down Station Characteristics □ At least 20 stations available on each band (**location-dependent**) FM is OK, AM is not X White noise presented between stations □ AM 530 - 930 kHz with 10 kHz steps □ FM 89 - 108 MHz with 0.2 MHz steps

2010 TOYOTA PRIUS WITH PREMIUM INFOTAINMENT SYSTEM

System	Description of Tuning Controls	Number of Soft Key Controls	Number of Hard Key Controls	Display Size	Size of Smallest Digit on the Display	Mounting Position	Radio Bands Available
2010 Toyota Prius	Radio function selection: Hard key Toggle between bands: 3 hard keys, 3 soft keys Frequency up and down: Knob Voice activation: None (only for navigation) Other tuning controls (describe):__________	14 (at the radio screen)	21		<5mm	Horizontal: __________ Vertical: __________	AM FM "SAT"

Minimum Step between Station Frequencies	Method(s) of Control Available:	Description of Tuning Methods Described in Owner's Manual	Number of Steps for Owner's Manual Tuning Methods	Describe Additional Functions Embedded within the Infotainment System Containing the Radio	Time for Experimenter to Complete Standard Static Tuning Task (average of three trials)	Alliance Compliance Checklist:
AM: 10 kHz FM: 0.2 MHz Satellite Radio: 1 Other: ________	X Visual-Manual □ Voice □ Other			X CD X MP3/iPod interface X Cell phone integration - Voice □ Cell phone integration - Voice & Text X Navigation □ DVD Playback □ Internet features X Climate control X Vehicle settings	9.31 s	Controls X Radio function selection button available X Button to toggle between bands available □ Frequency up button available □ Frequency down button available X At least six additional controls not used for the task available Display □ Size of digits on display is at least 5 mm Mounting Position □ Approximately 15° to the driver's right □ No more than 40° down Station Characteristics □ At least 20 stations available on each band (**location-dependent**) FM is OK, AM is not X White noise presented between stations □ AM 530 - 930 kHz with 10 kHz steps □ FM 89 - 108 MHz with 0.2 MHz steps

2006 CADILLAC STS WITH PREMIUM INFOTAINMENT SYSTEM

System	Description of Tuning Controls	Number of Soft Key Controls	Number of Hard Key Controls	Size of Smallest Digit on the Display	Mounting Position	Radio Bands Available	Minimum Step between Station Frequencies
2006 Cadillac STS	Radio function selection: Left knob Toggle between bands: Band button or display Frequency up and down: Knob Voice activation: ??? Other tuning controls (describe):__________	18	15		Horizontal: __________ Vertical: __________	AM FM XM	AM: 10 kHz FM: 0.2 MHz Satellite Radio: 1 Other: __________

Method(s) of Control Available:	Description of Tuning Methods Described in Owner's Manual	Number of Steps for Owner's Manual Tuning Methods	Describe Additional Functions Embedded within the Infotainment System Containing the Radio	Time for Experimenter to Complete Standard Static Tuning Task (average of three trials)	Alliance Compliance Checklist:
X Visual-Manual □ Voice □ Other	Tuning knob: "Turn this knob to select radio stations" Seek: Press a button Scan: Press a button Local/Distant: Can set sensitivity for seek & scan functions	Power (Source) Band Find a station	X CD □ MP3/iPod interface □ Cell phone integration - Voice □ Cell phone integration - Voice & Text X Navigation X DVD Playback □ Internet features X Climate control □ Vehicle settings		Controls X Radio function selection button available X Button to toggle between bands available □ Frequency up button available □ Frequency down button available □ At least six additional controls not used for the task available Display □ Size of digits on display is at least 5 mm Mounting Position □ Approximately 15° to the driver's right □ No more than 40° down Station Characteristics X At least 20 stations available on each band (**location-dependent**) X White noise presented between stations □ AM 530 - 930 kHz with 10 kHz steps □ FM 89 - 108 MHz with 0.2 MHz steps

2006 INFINITI M35

System	Description of Tuning Controls	Number of Soft Key Controls	Number of Hard Key Controls	Size of Smallest Digit on the Display	Mounting Position	Radio Bands Available	Minimum Step between Station Frequencies
Infiniti M35	Radio function selection: Left knob Toggle between bands: Hard key Frequency up and down: Right knob Other tuning controls (describe): Seek buttons?	17	9		Horizontal: ________ Vertical: ________	AM FM XM	AM: 10 kHz FM: 0.2 MHz Satellite Radio: 1 Other: ________

Method(s) of Control Available:	Description of Tuning Methods Described in Owner's Manual	Number of Steps for Owner's Manual Tuning Methods	Describe Additional Functions Embedded within the Infotainment System Containing the Radio	Time for Experimenter to Complete Standard Static Tuning Task (average of three trials)	Alliance Compliance Checklist:
X Visual-Manual X Voice □ Other	Push "on" to call up the radio mode most recently used. Push "RADIO" to select band Use knob or seek/scan.	3	X CD □ MP3/iPod interface X Cell phone integration - Voice □ Cell phone integration - Voice & Text X Navigation X DVD Playback □ Internet features X Climate control X Vehicle settings		Controls X Radio function selection button available X Button to toggle between bands available ? Frequency up button available ? Frequency down button available X At least six additional controls not used for the task available Display □ Size of digits on display is at least 5 mm Mounting Position □ Approximately 15° to the driver's right □ No more than 40° down Station Characteristics □ At least 20 stations available on each band (**location-dependent**) FM is OK, AM is not X White noise presented between stations □ AM 530 - 930 kHz with 10 kHz steps □ FM 89 - 108 MHz with 0.2 MHz steps

2005 FORD ESCAPE LIMITED

System	Description of Tuning Controls	Number of Soft Key Controls	Number of Hard Key Controls	Size of Smallest Digit on the Display	Display Size	Mounting Position	Radio Bands Available
2005 Ford Escape	Radio function selection: Left knob Toggle between bands: Separate buttons for AM & FM Frequency up and down: Knob Voice activation: None Other tuning controls (describe):__________	11	8	0.75"		Horizontal: __________ Vertical: __________	AM FM

Minimum Step between Station Frequencies	Method(s) of Control Available:	Description of Tuning Methods Described in Owner's Manual	Number of Steps for Owner's Manual Tuning Methods	Describe Additional Functions Embedded within the Infotainment System Containing the Radio	Time for Experimenter to Complete Standard Static Tuning Task (average of three trials)	Alliance Compliance Checklist:
AM: 10 kHz FM: 0.2 MHz Satellite Radio: 1 Other: ________	X Visual-Manual □ Voice □ Other	Left knob: "Press to turn on/off." Separate AM & FM buttons: "Press to enter (AM or FM) mode (No explanation for tuning to different frequencies.)	2	X CD □ MP3/iPod interface □ Cell phone integration - Voice □ Cell phone integration - Voice & Text □ Navigation □ DVD Playback □ Internet features X Climate control □ Vehicle settings	6 sec	Controls X Radio function selection button available X Button to toggle between bands available □ Frequency up button available □ Frequency down button available X At least six additional controls not used for the task available Display X Size of digits on display is at least 5 mm Mounting Position □ Approximately 15° to the driver's right □ No more than 40° down Station Characteristics X At least 20 stations available on each band (**location-dependent**) X White noise presented between stations □ AM 530 - 930 kHz with 10 kHz steps □ FM 89 - 108 MHz with 0.2 MHz steps

2005 MERCEDES BENZ R350

System	Description of Tuning Controls	Number of Soft Key Controls	Number of Hard Key Controls	Size of Smallest Digit on the Display	Mounting Position	Radio Bands Available	Minimum Step between Station Frequencies
2005 Mercedes R350	Radio function selection: Left button Toggle between bands: Soft Key Frequency up and down: Toggle left & right Other tuning controls (describe):Toggle up & down to move among presets; seek +/-	15 (23 w/ number pad)	17 (27 w/ number pad		Horizontal: ___________ Vertical: ___________	AM FM "Sat radio"	AM: 10 kHz FM: 0.2 MHz Satellite Radio: ? Other: ___________

Method(s) of Control Available:	Description of Tuning Methods Described in Owner's Manual	Number of Steps for Owner's Manual Tuning Methods	Describe Additional Functions Embedded within the Infotainment System Containing the Radio	Time for Experimenter to Complete Standard Static Tuning Task (average of three trials)	Alliance Compliance Checklist:
X Visual-Manual □ Voice □ Other	"Turn on modular command system & select Radio." ("See separate MCS manual")		X CD □ MP3/iPod interface X Cell phone integration - Voice □ Cell phone integration - Voice & Text X Navigation X DVD Playback □ Internet features X Climate control □ Vehicle settings		Controls X Radio function selection button available X Button to toggle between bands available X Frequency up button available X Frequency down button available X At least six additional controls not used for the task available Display □ Size of digits on display is at least 5 mm Mounting Position □ Approximately 15° to the driver's right □ No more than 40° down Station Characteristics □ At least 20 stations available on each band (**location-dependent**) FM is OK, AM is not X White noise presented between stations □ AM 530 - 930 kHz with 10 kHz steps □ FM 89 - 108 MHz with 0.2 MHz steps

2003 BMW 530I

System	Description of Tuning Controls	Number of Soft Key Controls	Number of Hard Key Controls	Display Size	Size of Smallest Digit on the Display	Mounting Position	Radio Bands Available
2003 BMW 530i	Radio function selection: Press on knob OR select "Audio" Toggle between bands: AM/FM switch (soft key) Frequency up and down: Buttons (also has button for manual vs. seek tuning) Voice activation: None Other tuning controls (describe):__________	13	10		0.3"	Horizontal: __________ Vertical: __________	AM FM

Minimum Step between Station Frequencies	Method(s) of Control Available:	Description of Tuning Methods Described in Owner's Manual	Number of Steps for Owner's Manual Tuning Methods	Describe Additional Functions Embedded within the Infotainment System Containing the Radio	Time for Experimenter to Complete Standard Static Tuning Task (average of three trials)	Alliance Compliance Checklist:
AM: 10 kHz FM: 0.2 MHz Satellite Radio: 1 Other: ________	X Visual-Manual □ Voice □ Other	"Press the knob" "Select the band-Press left or right" "Select 'manual' (m)" "Set the frequency with (the arrow keys)"	4	X CD □ MP3/iPod interface □ Cell phone integration - Voice □ Cell phone integration - Voice & Text □ Navigation □ DVD Playback □ Internet features X Climate control X Vehicle settings	13.88s	Controls X Radio function selection button available X Button to toggle between bands available X Frequency up button available X Frequency down button available X At least six additional controls not used for the task available Display X Size of digits on display is at least 5 mm Mounting Position □ Approximately 15° to the driver's right □ No more than 40° down Station Characteristics X At least 20 stations available on each band (**location-dependent**) X White noise presented between stations □ AM 530 - 930 kHz with 10 kHz steps □ FM 89 - 108 MHz with 0.2 MHz steps

2001 BMW 330I

System	Description of Tuning Controls	Number of Soft Key Controls	Number of Hard Key Controls	Display Size	Size of Smallest Digit on the Display	Mounting Position	Radio Bands Available
2001 BMW 330i	Radio function selection: Left knob Toggle between bands: Separate buttons for AM & FM Frequency up and down: Buttons (also has button for manual vs. seek tuning) Voice activation: None Other tuning controls (describe):__________		23		0.5cm	Horizontal: __________ Vertical: __________	AM FM

Minimum Step between Station Frequencies	Method(s) of Control Available:	Description of Tuning Methods Described in Owner's Manual	Number of Steps for Owner's Manual Tuning Methods	Describe Additional Functions Embedded within the Infotainment System Containing the Radio	Time for Experimenter to Complete Standard Static Tuning Task (average of three trials)	Alliance Compliance Checklist:
AM: 10 kHz FM: 0.2 MHz Satellite Radio: 1 Other: ________	X Visual-Manual □ Voice □ Other	(Knob): "Press to turn unit off/on" "Change the frequency band: FM: With each touch actuation, you can change frequency…"	3	X CD □ MP3/iPod interface □ Cell phone integration - Voice □ Cell phone integration - Voice & Text □ Navigation □ DVD Playback □ Internet features X Climate control X Vehicle settings	17.67s	Controls X Radio function selection button available X Button to toggle between bands available X Frequency up button available X Frequency down button available X At least six additional controls not used for the task available Display X Size of digits on display is at least 5 mm Mounting Position □ Approximately 15° to the driver's right □ No more than 40° down Station Characteristics X At least 20 stations available on each band (**location-dependent**) X White noise presented between stations □ AM 530 - 930 kHz with 10 kHz steps □ FM 89 - 108 MHz with 0.2 MHz steps

1996 BUICK CENTURY

System	Description of Tuning Controls	Number of Soft Key Controls	Number of Hard Key Controls	Display Size	Size of Smallest Digit on the Display	Mounting Position	Radio Bands Available
1996 Buick Century	Radio function selection: Turn top knob Toggle between bands: Push on bottom knob Frequency up and down: Turn bottom knob Voice activation: None Other tuning controls (describe):__________		19		1.5cmx0.5cm	Horizontal: __________ Vertical: __________	AM FM

Minimum Step between Station Frequencies	Method(s) of Control Available:	Description of Tuning Methods Described in Owner's Manual	Number of Steps for Owner's Manual Tuning Methods	Describe Additional Functions Embedded within the Infotainment System Containing the Radio	Time for Experimenter to Complete Standard Static Tuning Task (average of three trials)	Alliance Compliance Checklist:
AM: 10 kHz FM: 0.2 MHz Satellite Radio: 1 Other: ________	X Visual-Manual □ Voice □ Other	"Turn the upper knob to turn the radio on & off, & to control the volume" "Press the lower knob to select AM or FM" "Turn the lower knob to choose radio stations"	3	□ CD □ MP3/iPod interface □ Cell phone integration - Voice □ Cell phone integration - Voice & Text □ Navigation □ DVD Playback □ Internet features X Climate control □ Vehicle settings	7.28s	Controls X Radio function selection button available X Button to toggle between bands available □ Frequency up button available □ Frequency down button available X At least six additional controls not used for the task available Display X Size of digits on display is at least 5 mm Mounting Position □ Approximately 15° to the driver's right □ No more than 40° down Station Characteristics X At least 20 stations available on each band (**location-dependent**) X White noise presented between stations □ AM 530 - 930 kHz with 10 kHz steps □ FM 89 - 108 MHz with 0.2 MHz steps

1995 MERCURY SABLE

System	Description of Tuning Controls	Number of Soft Key Controls	Number of Hard Key Controls	Display Size	Size of Smallest Digit on the Display	Mounting Position	Radio Bands Available
1995 Mercury Sable	Radio function selection: Button Toggle between bands: Single button Frequency up and down: Press 'AMS', then seek buttons (can hold down for quick tuning) Voice activation: None Other tuning controls (describe):__________	4	14		0.5"	Horizontal: __________ Vertical: __________	AM FM

Minimum Step between Station Frequencies	Method(s) of Control Available:	Description of Tuning Methods Described in Owner's Manual	Number of Steps for Owner's Manual Tuning Methods	Describe Additional Functions Embedded within the Infotainment System Containing the Radio	Time for Experimenter to Complete Standard Static Tuning Task (average of three trials)	Alliance Compliance Checklist:
AM: 10 kHz FM: 0.2 MHz Satellite Radio: 1 Other: _________	X Visual-Manual □ Voice □ Other	"Press the POWER button to turn the radio on. Press it again to turn it off." "Push the 'AM FM' button to select the desired frequency band." "You can change the frequency up or down one increment at a time by first pressing the 'AMS' button (display shows TUNE) then within approximately 5 sec pressing & releasing either the right or left side of the SEEK button. To change frequencies quickly, press & hold down either the right or left side of the SEEK button."	3	□ CD □ MP3/iPod interface □ Cell phone integration - Voice □ Cell phone integration - Voice & Text □ Navigation □ DVD Playback □ Internet features X Climate control □ Vehicle settings	7.67s	Controls X Radio function selection button available X Button to toggle between bands available X Frequency up button available X Frequency down button available X At least six additional controls not used for the task available Display X Size of digits on display is at least 5 mm Mounting Position □ Approximately 15° to the driver's right □ No more than 40° down Station Characteristics X At least 20 stations available on each band (**location-dependent**) X White noise presented between stations □ AM 530 - 930 kHz with 10 kHz steps □ FM 89 - 108 MHz with 0.2 MHz steps

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