Multidimensional Warnings: Evaluating Curve Warning Stimuli in an On-Road Environment

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ABSTRACT

Horizontal curves on roadways are the site of numerous crashes and motorist deaths each year. Traditional methods to warn drivers of curve hazards, including static roadside signs, are sometimes ineffective at influencing driver behavior for reasons such as driver acclimation to inconsistency in posted advisory speeds. In-vehicle curve warning devices (CWDs) may be an effective alternative for reducing the number of collisions at curves. Multi-modality displays have elicited positive driver results and should be further explored. The objective of this study was to determine the most effective curve warning system using on-road performance and subjective evaluation. Two top-performing warning stimulus presentations, as determined by a recent simulator study, were tested at the Virginia Smart Road closed test highway. Both warnings exhibited auditory (speech) and visual (Heads Down Display) stimuli, however one included a throttle pushback haptic stimulus and the other did not. No on-road studies of this type of haptic stimulus, nor of CWDs, have been published to date. Forty-eight individuals, 24 age 18-25 years and 24 age >60 years, participated in the study. A 2 (Age) x 3 (Stimulus Presentation) between-subjects design was used to examine participant performance and ratings for the first "surprise" experience with the stimulus while driving on the Smart Road, and a 2x3 mixed factors design examined stimulus as a repeated measure. Participant braking reaction times, speed, and subjective evaluations were compared between stimulus presentations as well as driver age. Throttle reaction times and brake reaction times were significantly quicker, and curve entry speed significantly closer to an advisory speed for participants receiving a warning presentation than those without a warning presentation at α=0.05. No statistical differences between objective measures were found between the stimulus presentation with the haptic and the stimulus presentation without the haptic stimulus. Age was a significant main effect as older drivers reached more appropriate curve entry speeds than younger drivers. Driver risk-taking style was significantly related to age and to curve entry speed. During an interview, participants demonstrated higher comprehension when presented with the stimulus lacking the haptic component, and ranked this presentation higher, though ratings gathered from questionnaires were not significantly different between the two stimulus presentations. Driver comments were examined using a content analysis technique organized by design guideline topics. Discussion was presented in terms of four main research questions and recommendations toward CWD design guidelines were developed based on the objective and subjective results of this study. In addition, this research developed a foundation for further on-road testing of CWDs and other multi-modal in-vehicle warning systems.

DEDICATION

I did this research for my Aunt Barb. Barb was killed in the Fall of 2001 when her car ran off the road on a dangerous curve in rural New York State. For all of our beloved family members and friends lost in crashes, I hope this research provides even just a little fuel for the drive toward safer transportation.

ACKNOWLEDGEMENTS

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ACRONYM LIST

AASHTO – American Association of State Highway and Transportation Officials
ATIS – Advanced Traveler Information System
A-V – Audio-Visual Stimulus Presentation
BRT – Brake Reaction Time
C-HIP – Communications Human Information Processing model
CMS – Changeable Message Sign
CWD – Curve Warning Device
H – Hypothesis
H-A-V – Haptic-Audio-Visual Stimulus Presentation
HDD – Heads Down Display
HUD – Heads Up Display
IRB – Institutional Review Board
ISO – International Organization for Standardization
ITS – Intelligent Transportation Systems
IVCAWS – In-Vehicle Collision Avoidance Warning System
JND – Just Noticeable Difference
LCD – Liquid Crystal Display

MUTCD – Manual on Uniform Traffic Control Devices

PRspeed – Public Road Curve Entrance Speed

SAE – Society of Automotive Engineers

SRspeed – Smart Road Curve Entrance Speed

RQ – Research Question

TRT – Throttle Reaction Time

VTTI – Virginia Tech Transportation Institute

CHAPTER 1: INTRODUCTION

Motivation

In 2003, more than 42,000 people were killed in fatal crashes on United States highways. Of these fatal crashes, approximately 25% occurred on horizontal curves (National Highway Traffic Safety Administration, 2004a). In addition to these fatality statistics, it has been found that the accident rate for horizontal curves is about three times the average accident rate for straight highway segments (Torbic, Harwood, Gilmore, Pfefer, Neuman, Slack, & Hardy, 2004). These considerable figures have prompted federal organizations, research institutes, and vehicle manufacturers to explore ways to mitigate the accidents that occur on curved roadways.

Crashes on curves are sometimes attributed to poor weather, roadway design or condition, or some other external circumstance. The majority of crashes, however, are attributed to driver behavior (Persaud, Retting, & Lyon, 2000). Causation for crashes is a complicated mixture of many different agents. The human factors in curve accident causation may include driving at an unsafe speed, driver distraction, overconfidence, and/or under-experience. Though it is important for engineers and researchers to address the physical infrastructure factors in roadway safety, these factors may not address the whole problem. Improvements focusing on the human component of the equation need to be explored.

One method of driver support currently under evaluation is an in-vehicle curve warning device (CWD). The number of Intelligent Transportation Systems (ITS) has been growing rapidly over the past decade. With this rapid development comes a great need for empirical testing to determine the safety and success of new technologies. Simulator studies have examined the performance of CWD (Comte & Jamson, 2000; Neurauter, 2004), however additional research, especially occurring in an on-road setting, is necessary to determine the capabilities of this technology. If designed properly, ITS, specifically curve warnings, have the potential to save thousands of lives each year.

Review of Literature

The Problem: Curve Hazards

Excessive speed and miscalculated maneuvers can create a very dangerous situation on curved roadways. Outcomes include run-off-road accidents, collision with fixed objects, head-on crashes, and rollovers. Run-off-road and hit fixed object crashes are more numerous at curves and turns than along other sections of roadway (Fleming, 2004; Hood, 2001). Approximately 76% of curve-related fatal crashes were single-vehicle crashes in which the vehicle left the roadway and either hit a fixed object or rolled over and 11% of the curve-related fatal crashes were head-on crashes (Torbic et al., 2004). The ratio for rollover odds among single-vehicle fatal crashes was 2.15 for curved verses straight roadways from 1995 to 1998 (Farmer & Lund, 2002). Rollover risk was highest on rural curves, but rollover risk was also high for young drivers of smaller light trucks on urban curves. The geometry of a curved roadway creates an implicit hazard.

Not only are crashes on curves numerous, but they are also more likely to be fatal. Crashes in which the vehicle failed to negotiate a curve were 4.7% of total crashes, but about three times that (14%) of fatal crashes (O'Connor, 2004). Other counts have also indicated that motor-vehicle crashes on curved roadway sections are more frequent and severe than crashes on straight sections. A study of statistics from the Fatality Analysis Reporting System (FARS) and the National Automotive Sampling System (NASS) found that more than twice as many people were in crashes per mile of curved road compared with straight sections, and crashes on curves resulted in three times as many fatalities per mile as crashes on straight sections (Persaud et al., 2000).

One Solution: Curve Warnings

Safety professionals have developed a hierarchy of methods of hazard control: 1)Design out, 2)Guard, 3)Warn (Laughery & Hammond, 1999). Designing a hazard out of a system is the most desirable solution; however this is not always possible. In the case of roadway design, curves are often unavoidable and thus cannot be designed out. Certain guards do exist in driving such as barriers, guard rails, airbags, and seatbelts, however these are reactive measures rather than proactive in preventing crashes.

Warnings are third in the hierarchy because it is often difficult to influence behavior. In the case of curve dangers, however, the prevalence of roadway curves and the cost of installing and maintaining guards at each may prove warnings to be a viable approach in improving curve safety.

Another hierarchy of engineering responses, directed toward collision mitigation, can be designed on three levels (O'Connor, 2004). The first, and least invasive, is the warning or advisory based on sensors inside or outside the vehicle. The second and more severe responses are those that take over partial control of the vehicle by actions such as tightening seatbelts and/or decreasing vehicle speed without driver action. The most invasive response is to assume total control of the vehicle. Curve and other collision warning systems exist on the principle that enabling drivers to accurately recognize their environment will enhance their safety. If these technologies work, they could not only save lives and money, but may also help to correct some unsafe driver behaviors.

Traditional curve warning signs. Warning signs and advisory speed plates have been used to inform unfamiliar drivers of possible hazardous situations at curves for many years. Hood (2001) explains guidelines for these signs including arrow symbol shapes, advisory speeds, and placement. Several sources indicate that warning signs reduce the occurrence of accidents at curves (Bhullar, Moore, & Cutler, 1993; Donald, 1997); however, few recent studies have examined the effectiveness of this method in detail.

A study by Chowdhury, Warren, Bissell, and Taori (1998) identified several shortcomings of the traditional hazard warning system. Methods for setting advisory speeds have remained relatively unchanged since the 1930's and were hypothesized to be too conservative for today's vehicles. In the study, 28 sites on two-lane highways in three different states were selected to assess the advisory speeds as well as monitor the compliance of traffic to the posted speeds. Researchers found that at most curves, prevailing traffic speed was well above advisory speeds posted on the signs. They also found that many posted advisory speeds were below the recommended values as determined by either of the two standard advisory speed calculation methods used in the United States; the ball bank method and the advisory speed formula (see descriptions of these methods in Neurauter, 2004 and in the American Association of State Highway

Transportation Officials, 2001). Though signs advised drivers to slow down an average of 15 miles per hour, most only slowed an average of 6 miles per hour. The combination of already conservative methods with additionally conservative signage created a large mismatch between suggestion and practice.

Because there is some subjectivity in the suggested methods of advisory speed posting, there is a lack of uniformity between speeds posted in different states. Chowdhury et al. (1998) found notable differences in advisory speeds posted in Maryland, Virginia, and West Virginia. This poses a problem as motorists may become accustomed to speed signs that are much more conservative than necessary for their driving comfort. The motorist may then encounter less conservative speed postings and choose an unsafe speed based on past experience.

Even if the driver is in compliance with the advised speed, the speed may not be appropriate for the vehicle in question. Advisory speed guidelines were originally designed for passenger vehicles in daylight with clear weather (Donald, 1997). Trucks and sport utility vehicles exhibit different performance dynamics than cars; therefore, roadside advisory speeds may not be correct for such vehicles to safely maneuver curves. One option suggested in response to this discrepancy is to install separate truck advisory speed signs (Donald, 1997). Rather than adding more visual clutter to the roadside environment, in-vehicle warnings designed to support individual vehicle capabilities may be a more appropriate solution.

Non-traditional curve warning signs. Because several studies have indicated that traditional curve warning signs can be ineffective in influencing motorists' speeds, a number of institutions are examining the effectiveness of new warning sign designs. Researchers in New Zealand measured drivers' speed selection after they were presented with roadside curve speed warnings in a driving simulator (Charlton, 2004). Three warning types were tested: (a) a diamond warning sign with curved arrow plus a curve advisory speed, similar to traditional signage, (b) chevron warning with advisory speed, and (c) road marking warning with advisory and transverse lines painted on the pavement approaching the curve (Table 1.1).

Table 1.1: Images of three curve warning types tested (Charlton, 2004, p. 879).

a) Diamond warning sign with curved arrow plus curve advisory speed	b) Chevron warning with advisory speed	c) Road marking warning with advisory and transverse lines painted on pavement approaching curve
		

There were also three types of curves in the study from smallest radii (most "severe"), to be driven at 28 mph (45 km/h), middle at 40 mph (65 km/h), and largest at 53 mph (85 km/h). Seventeen female and 13 male participants, age 17 to 68 years (mean 28.43 years), performed multiple tasks including driving the simulated curved road, detecting signals in the form of road signs, road markings, and vehicle dash lights, and performing secondary cell phone tasks of varying levels of difficulty. Results indicated that drivers' speed decreased in the presence of each of the warnings as compared to a no warning condition for the most severe curves (45 km/h), regardless of the presence of a cell phone task. In the pavement marking conditions, participants failed to slow on the 53 mph curves, and the diamond signs were ineffective at slowing participants at both the 40 and 53 mph curves in the presence of secondary tasks. The author suggests that the chevron signs result in the slower speeds because they are more visible to drivers at greater distances than the pavement markings, and because the signs highlight the shape of the upcoming curves, suggesting that they contain additional perceptual cues. Charlton concludes that curve warnings that emphasize the physical features of the roadway curvature work best.

Several studies have evaluated the effectiveness of roadside dynamic signs; devices that measure motorists' speed and display personalized speed information. The Minnesota Department of Transportation conducted a study of a dynamic warning device (Preston & Schoenecker, 1999). In this study, the dynamic device consisted of a radar system to detect vehicle speed. For all vehicles traveling at a speed higher than 53 mph, video and speed data were recorded, and the system randomly chose half of the vehicles to display the message "CURVE AHEAD – REDUCE SPEED" for 10 seconds. A total of three sign categories were examined:

1. Static Curve Ahead Warning Sign + LED "CURVE AHEAD" Message
2. Static Curve Ahead Warning Sign + Alternating LED "CURVE AHEAD" / "REDUCE SPEED" Message
3. Static Curve Ahead Warning Sign

Two main questions were addressed in this research: 1) Is there a relationship between a vehicle's speed during the approach to a curve and the ability to successfully navigate the curve? and 2) Is there a difference between static and dynamic signing in the ability to reduce the speed of high-speed vehicles? Field data including speed and video of lane behavior were collected for 2,600 vehicles over four days. Results indicated that the speed of a vehicle prior to entering a curve is significantly related to the probability of successfully navigating the curve. Overall, the effect of the dynamic sign on vehicle speed was relatively small; however the dynamic system had a greater effect on high-speed vehicles than the static curve warning sign.

In California, the Advanced Curve Warning Project also examined the success of interactive curve warning signs (Wenham, 2000). Results of a seven-month test period indicated a reduction of truck collision rate from 6.4 to 1.4 per year. The advanced curve warning systems combined speed-measuring radar and 7 x 10 foot changeable message signs (CMS). The LEDs displayed warning messages that included "YOUR SPEED XX MPH," "XX MPH CURVES," a graphic of a truck tipping over, and a graphic of a curve warning sign. Since the implementation of the CMS, the average number of annual tractor-trailer collisions has dropped to less than two. The researchers attributed much of this drop to the presence of the warning system. One drawback of the system as identified by the authors was limitations of radar: improper aim causes the system to detect traffic on the opposite side of the freeway creating inaccurate displays to drivers.

In-Vehicle Curve Warning Potential. In response to the shortcomings of roadside signs, researchers are exploring the option of an in-vehicle curve warning system. These devices may be able to help drivers anticipate hazards without degradation by weather conditions, physical obstruction or wear of the sign, or driver inattention. Hypothetically, in-vehicle curve warning devices could alert a driver if he or she is approaching a curve at an unsafe speed.

Comte and Jamson (2000) compared both external and in-vehicle curve warning devices using a driving simulator. These devices included transverse bars (pavement marking with decreasing spacing), a variable message sign (dynamic display including advisory speed and driver's license plate), an in-vehicle Liquid Crystal Display (LCD) (to left of instrument panel displaying advisory speed), and a speed limiter (automatically reduces vehicle speed to advisory speed). Performance measures included percentage of speed reduction completed before curve entry, steering performance, and curve negotiation speed in relation to advisory speed. As expected, the automatic speed limiter affected drivers' speeds the most, as it directly controlled vehicle speed at curves. This device, however, was rated unacceptable by drivers because it was more obtrusive and took control from the drivers. Contrary to initial speculation, driver performance indicated no disruption caused by the presence of an in-vehicle visual stimulus. Results indicated that each of the devices was effective in significantly reducing speeds when activated.

Various types of technology exist which could support the development of an in-vehicle curve warning system. In the August 2002 edition of ITS View, Dr. Ralf G. Herrtwich, head of Telematics and E-business, Research and Technology for DaimlerChrysler AG commented on the emerging applicability of digital roadmaps. The curve warning device under development by DaimlerChrysler utilizes safety-relevant information stored in digital maps. Herrtwich explains the device as follows:

> It uses the road map data to calculate the topography of the highways. The radius of curvature gives an indication of the speed at which this curve can be safely negotiated. If the navigation system determines that the vehicle is approaching a curve at excessive speed, it first issues a visual warning in the display, e.g. in the form of an illuminated miniature curve warning sign. If the driver then fails to brake, he or she additionally receives an acoustical warning.

For this technology to be successful, curves need to be registered with sufficient precision. The system is to not only retrieve information from the outside conditions, but also recognize and register the driver's style, adapting threshold values to the individual driver (Herrtwich, 2002). Other research is being conducted at Ohio State University to also determine the performance of a curve warning system that utilizes digital mapping technology (Ohio State Center for Mapping, n.d.).

Technology for Advanced Traveler Information Systems (ATIS) is in rapid development, from digital entertainment and communications technology to navigation systems and vehicle warning displays. In relation to in-vehicle warning display design, a simulator study conducted by Neurauter (2004) examined the effectiveness of twenty-four combinations of stimuli in presenting curve warnings. Modalities and presentation formats included the following:

- Visual
    - Heads Down Display (HDD)
    - Heads Up Display (HUD)
- Auditory
    - Icon (tire screech)
    - Tone
    - Speech
- Haptic (throttle push-back)

Objective measures included speed, lane position, and braking, and subjective measures included ratings of acceptability gathered from younger (18-25 years old) and older (>60 years old) participants. Results suggested that the speech stimulus was the most appropriate of the auditory modality for both objective and subjective measurements. Objectively, the HDD and HUD were comparable with respect to performance, although the participants tended to favor the HDD with their subjective ratings. The throttle push-back was not successful when presented alone, however the speech, HDD, and throttle push-back combination warning elicited the second best subjective and objective results overall. Ranking slightly above this multi-modality display was the top-performing combination of the speech and HDD (no haptic stimulus included).

Human Information Processing

Some of the human responses to warnings can be explained by fundamental principles of human information processing. The Communication Human Information Processing (C-HIP) Model is one framework that describes how people process warnings and other forms of communication (Wogalter, DeJoy, & Laughery, 1999). The model is a flow chart that combines the communication model (source, channel, and receiver) with the human information processing framework (stages associated with the receiver). Human information processing has been simplified in this model to create a serial process that can generalize to any form of communication, though the authors acknowledge that the chain of events is not always linear.

Using elements similar to the ones in the C-HIP Model, but tailoring the model specifically to warnings, Rogers, Lamson, and Rousseau (2000) describe the less serial nature of warning processing. It should be noted that Rogers et al. used only visual warning literature to fill in variables in the model, though it can still translate to the processing of other warnings. The main warning process components are *notice*, *encode*, *comprehend*, and *comply* (Figure 1.1). These broad components were defined as follows:

- Notice the warning – attention is directed to the warning
- Encode the warning – external information is translated into some internal representation through reading words, processing symbols, and so on
- Comprehend the warning – the meaning of the warning is understood
- Comply with the warning – behavior is in accordance with the warning

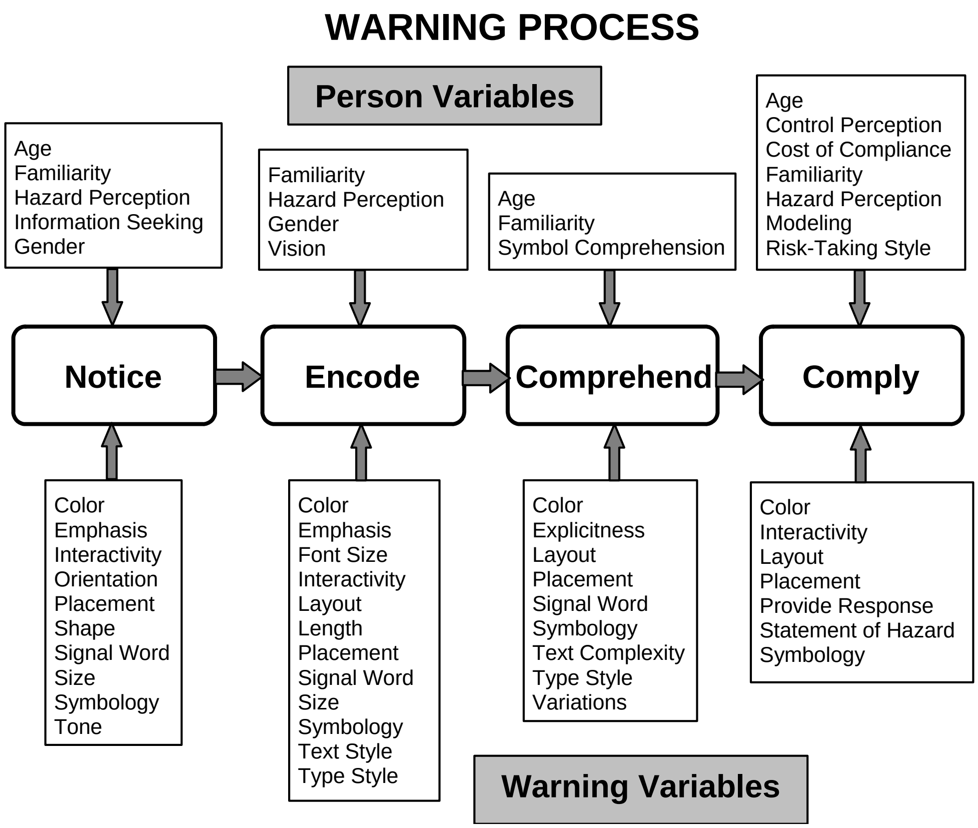


Figure 1.1: Warning Process Model (Rogers et al., 2000, p. 105).

Illustrated above and below the four model components are lists of person variables and warning variables that have been shown through research to influence each component. The model is less linear than the C-HIP Model, as shown by the repetition of variables that can affect each component. This better illustrates the non-serial way people may process warnings. For example, hazard perception is listed by Rogers et al. as an influence of both the encode stage and comply stage of the process. A driver's hazard perception can influence his or her willingness to comply with safety measures which in turn can influence how he / she encodes the information, or applies the warning information to her mental model of the hazard.

The success of warnings cannot be accurately measured by looking at just one component of this process. Different tests can measure various components in the model. Simple reaction tests can examine how variables influence the notice component. A large body of literature has already been established providing human factors design guidelines which can direct the design of warning displays to improve noticeability (Campbell, Carney, & Kantowitz, 1998; Green, Levison, Paelke, & Serafin, 1995; Sanders & McCormick, 1993). Encoding and comprehension of the information can be examined using subjective measurement tools such as questionnaires and interviews. Compliance with the warning is sometimes considered the ultimate test of warnings, and it is often the most difficult to measure. Behavioral responses to warnings are evaluated using true experiments involving participants exposed to simulated hazards and warnings. Results of studies strictly examining compliance may not be generalizable to real-life instances of hazards. In some cases it is beneficial to measure the users' intent to comply, as projected to a real-world situation (Silver & Braun, 1999). However, compliance, or even intent to comply, does not examine the full range of factors that determine the successfulness of warnings. By testing a number of person and warning variables and their effects on various components of the Warning Process model, it is possible to have a more complete view of the system and identify where problems exist to improve warning design.

Hazard Perception

One of the person variables affecting warning compliance identified in the Warning Process model is hazard perception (Rogers et al., 2000). Hazard perception is an individual's judgment of the degree of danger associated with a product, activity, or situation. In a study measuring hazard perception, users of two different liquid chemical products were more likely to comply with a warning to the degree that they perceived the products as dangerous (Friedmann, 1988). In another study of hazard perception, Vredenbugh and Cohen (1995) examined the perceptions and activities of scuba divers and skiers. The researchers found that people who thought that the activity was more dangerous were more likely to read and comply with safety precautions.

Specific to curve warning signs, studies have indicated a mismatch between the hazard information presented to drivers, and driver compliance (Chowdhury et al., 1998). Methods for determining curve advisory speeds have remained the same since their creation in the 1930's. Their development, therefore, was based on the capabilities of vehicles in the 1930's and may be too conservative for vehicle capabilities today. As noted earlier, several studies have found low driver compliance with curve speed advisories (Charlton, 2004; Chowdhury et al., 1998; Preston & Schoenecker, 1999). It seems that drivers perceive curves to be less hazardous than advisory speed signs indicate those curves to be, and are thus less likely to comply with curve warning advisory speeds.

Risk-Taking Style

As described in Rogers et al. (2000), risk-taking style has been found to influence warning compliance. Willingness to engage in risk varies between individuals. The amount of influence that warnings have on individuals' risk-taking behavior may also vary from person to person. In a study by Purswell, Schlegel, and Kejriwal (1986), participants considered risk-takers based on a risk-taking attitude questionnaire were less likely to comply with warnings indicating the safe use of tools. Similarly, a strong correlation between risk-taking attitudes gathered using questionnaires and future risky driving behavior was found in a study by Iversen (2004). Results in this study indicate the usefulness of subjective measures of risk-taking style in predicting driver behavior.

Hazard perception and risk-taking style are interrelated concepts. Several studies have examined participants' perceptions of driving hazards and the participants' corresponding risk-taking style. In a study by Lerner and Rabinovich (1997), seventeen younger participants (age 16 and 17 years) and 17 older participants (25-47 years) viewed 20 video clips of driving scenarios from the driver's view, 16 of which were potentially hazardous situations. The participants then rated the scene on risk acceptance, degree of risk, collision likelihood, and vehicle control ability. The ratings were examined between the two Age groups, Genders, and interactions of the two. The effects of Gender and Age were additive, as young males were the most "risk-prone" and older females the least "risk prone," without significant interaction effects. Specifically, younger male drivers rated the scenes as less risky, collisions less likely, considered themselves to be better able to handle the vehicle to avoid the hazard, and found the risks more acceptable than any of the other groups. It has been found that the younger (16-20 years old) male demographic group has substantially higher accident involvement rates than any other group of drivers (NHTSA, 2003). Drivers age 16-20 have an accident rate per-mile traveled that is about four times the crash rate of adults in other age groups. Thus this group of drivers has been found to perceive driving scenarios to be less hazardous, report riskier driving decisions, and exhibit higher real-world accident rates than other drivers.

Age and Driving Behavior

In addition to risk-taking style and hazard perception, age is a person variable that affects the warning process. Age is also an important factor to examine when considering transportation safety. The aging population is growing rapidly. In the past 10 years, the number of people age 70 and older increased twice as fast as the total population. This age group makes up approximately 9% of the total U.S. population, but accounts for close to 14% of all traffic fatalities and around 18% of all pedestrian deaths annually (NHTSA, 2004b). Seniors drive markedly fewer miles per year than younger drivers. According to a report by NHTSA, the vehicle miles traveled per year for the previously mentioned older driver group (age 70+ years) is only 4% of the total vehicle miles traveled (NHTSA, 1993). Since older drivers' exposure to driving is much lower than younger drivers' exposure, the older group's fatality statistics are even more staggering.

Aging individuals experience some deterioration of psychophysiological functions. A review of literature conducted by Owens and Lehman (2001) describes some of these functions such as greater difficulty in simultaneously performing multiple tasks, reduced functional field of view, and slower reaction time. In terms of reaction times, Warshawsky-Livne and Shinar (2002) tested the capabilities of participants in three age groups defined as young (18-25 years, mean of 23), middle (26-49 years, mean of 30), and older (>50 years, mean of 62). Only the youngest and oldest groups were significantly different from each other ($p = 0.03$).

Various studies specific to the transportation domain have found that older drivers have delayed reaction times to the appearance of brake lights of a lead vehicle, difficulty judging the distance to oncoming vehicles, and deterioration of steering tracking performance with a slowing of steering angle input (Uno & Hiramatsu, 2001). One study of driving performance and age found older drivers (>60 years) to have significantly lower sign detection and recognition, peripheral reaction times, and driving time than younger drivers (<30 years) (Wood, 1998). Participants drove on a closed circuit course and identified traffic signs placed along the road. Of the 62 participants, 15 were normal-vision younger drivers, 26 were normal-vision older drivers, and 21 were older drivers with a range of early visual impairments. Older drivers with normal vision missed twice as many signs than the younger group with normal vision, and visually impaired older drivers missed three times as many signs than the young normal group. Only 11% of the variance could be attributed to differences in visual acuity. The author suggested that the difference in performance could also be attributed to the possibility that older individuals were less adept at dividing attention between concurrent tasks, in this case driving, reacting to vehicle-mounted lights, and identifying signs. Wood concluded that driving performance differences exist based on age irregardless of visual acuity. In general, aging drivers can experience deterioration of perception, information processing, and motor skills, thus increasing risk when encountering dangerous driving situations.

A simulator study examined the capabilities of older drivers (>65 years versus <60 years) when encountering a surprise emergent traffic situation in a simulator (Uno & Hiramatsu, 2001). Findings indicated, as expected, that older drivers needed anywhere from 1.35 to 2.7 seconds more than the younger drivers in order to successfully avoid the oncoming hazard. Other results indicated that the older drivers had a much more restricted steering velocity (250 deg/s) versus younger drivers (450 deg/s). Encouragingly, older drivers' avoidance performance improved greatly when presented with an advanced auditory warning 3.0 seconds prior to their arrival at the simulated intersection. If ITS design and development centers on the needs of older drivers, there is potential to augment the older driver's on-road experience to improve safety.

In summary, three different person variables are described in the previous sections: risk-taking style, hazard perception, and age. Some research links these variables with the way that people process warnings. The next few sections examine the influence of specific warning variables on receiver performance. These variables include modality, urgency, and false alarms.

Warning Modalities

Warning stimuli are traditionally presented to drivers in two forms: Auditory and visual stimuli. Many studies have been performed to determine the most appropriate form of these for different in-vehicle displays. Results from a wide range studies indicate both strengths and weaknesses for both the auditory and visual modalities depending on display characteristics, environment, operator characteristics, and driving situation urgency. In addition to this huge body of results, researchers are investigating a new form of warning stimuli: haptic displays which use movement or tactile means to transmit information to the receiver. The major findings pertaining to modality and warning design are highlighted in Table 1.2, Table 1.3, and Table 1.4.

Table 1.2: Summary of visual warning attributes.

Warning Type	Positive Attributes	Negative Attributes
Visual (Pictorial) Warnings in General	Lee, Gore, & Campbell (1999) • Traditional means for portraying driving information • The potential for higher information rate • Less likely to startle Wogalter, Conzola, & Smith-Jackson (2002) • Can enhance comprehension	Sprenger (1993) • Compete with other visual driving information • Less attention-grabbing Wogalter, DeJoy, & Laughery (1999) • Discriminability affected by light conditions
Heads Down Display (HDD)	Hanowski, Dingus, Gallagher, Kieliszewski, & Neale (1999) • Traditional location for in-vehicle warnings and alerts; more easily recognized by older population • May have increased discriminability due to better figure/ground contrast as compared to HUDs	Sprenger (1993) • May not be in line of sight – result in eyes-off-road time
Heads Up Display (HUD)	Sprenger (1993) • May be more apt to notice; in the line of sight • Shorter glance time necessary	Sprenger (1993) • Discriminability of HUD may be compromised in bright conditions • Visibility of road objects blocked by HUD

Table 1.3: Summary of auditory warning attributes.

Warning Type	Positive Attributes	Negative Attributes
Auditory Warnings in General	Lee et al. (1999) • Do not add to visual demand of driving task Edworthy (1994) • Omnidirectional	Sanders & McCormick (1993) • Can be masked by radio or other in-vehicle sounds Lee et al. (1999) • Can startle receiver
Tone	Lee et al. (1999) • Quickly attract attention; alert Edworthy (1994) • Short, simple • Discreet if situation alerting to is embarrassing • Can be designed to portray levels of urgency	Edworthy (1994) • Do not provide hazard details • Do not inform receiver of specific correct response • Depending on design could startle receiver
Speech	Wogalter, DeJoy, & Laughery (1999) • Can portray level of urgency Wogalter, Kalsher, & Racicot (1993) • May increase compliance	Edworthy (1994) • Can embarrass if not discreet • May take too long to convey necessary info (if imminent situation)
Auditory Icon	Belz, Robinson, & Casali (1999) • Can convey recognizable meaning if match mental model Graham (1999) • Shorter driver-reaction times than tones and speech	Graham (1999) • More false positives – inappropriate response (accelerate when should apply brake) • Can result in larger and more abrupt reactions

Table 1.4: Summary of haptic warning attributes.

Warning Type	Positive Attributes	Negative Attributes
Haptic Warnings in General	Suzuki & Jansson (2003) • Do not add to visual demand of driving task • If match mental model, can elicit quick response	Suzuki & Jansson (2003) • Unfamiliar to receivers • May not be salient as an alert • Can startle • Can cause inappropriate response or even opposite of desired response Lloyd, Wilson, Nowak, & Bittner (1999) • Intrusive to receiver as cannot be "shut out"
Throttle Push-Back	Janssen & Nilsson (1993) • Show positive results in vehicle studies (reduction in collisions, increase in safe headway, fewer lane deviations) Tijerina (2001) • Could stop more abruptly when presented with a high brake pedal jerk rate Manser, Ward, Kuge, & Boer (2004) • Decreased driver response time and improved response appropriateness when alerting to lead vehicle braking in a simulator	Neurauter (2004) • May go unnoticed by driver if foot is not positioned on pedal Manser et al. (2004) • Increase in driver decision time when alerting to lead vehicle braking in a simulator
Steering Wheel Feedback	Suzuki & Jansson (2003) • Can improve reaction time to run-off-road hazards • Can assist in monitoring vehicle lateral position (steering wheel vibration)	Suzuki & Jansson (2003) • More false positives – inappropriate response (accelerate when should apply brake)
Seat Vibrations	Gray, Tan, & Young (2002) • Potential for improving response times by cuing to changes in a scene Hoffman, Lee, & Hayes (2003) • Rated to be trustworthy and beneficial by drivers in a simulator study	Tijerina, Johnston, Parmer, Pham, & Winterbottom (2000) • Limited information can be conveyed • Mostly used to alert to lane violations (Virtual Rumble Strips)

Mutli-Modal Warnings. Several studies indicate that displays combining several modalities lead to better performance (Belz et al., 1999; Labiale, 1990). In driving tasks, vision is always engaged, therefore visual warning devices may be more effective when an additional stimulus is presented (Liu, 2001). When a visual icon in the dash cluster was accompanied by an auditory tone, reaction times in collision-avoidance scenarios were almost one-third of the reaction times recorded when no warning was presented (Hanowski et al., 1999). Warning developers need to be cautious about presenting too many stimuli to the driver, as senses may become overloaded with the proliferation of in-vehicle information systems, however multi-modal displays demonstrate advantages that should be further explored.

Warning Urgency

The urgency of warnings varies depending on the driving situation, for example some in-vehicle warnings inform the driver of low fuel level while others alert the driver of a potential forward collision. The International Organization for Standardization (ISO) issued a technical specification outlining a method to determine in-vehicle message priority (International Organization for Standardization, 2003b). Table 1.5 and Table 1.6 describe the prioritization criteria, criticality and urgency, and levels of each. Using these criteria, a curve warning may be rated a 2 for criticality, or "Injury or possible injury," and also rated 2 for urgency, or "Respond within a few seconds." The combined rating for a CWD would then be 4, whereas the highest priority messages are rated 6. This categorization illustrates that the CWD is neither the most critical nor the most urgent type of message system. It is important, then, that the level of criticality and urgency of the curve hazard is accurately portrayed by the modalities and design of the curve warning display.

Table 1.5: Criticality Rating Scale (ISO, 2003, p. 6).

Rating	Risk to vehicle, occupants and / or pedestrians	Examples
3	**Severe or fatal injury**	Ignoring speed warning when driving significantly above the speed limit. Collision as a result of loss of braking due to ignoring the brake failure warning. Departing roadway due to ignoring lane departure warning. Collision at high speed. Leaving the roadway, head-on collision and collision with structures at intermediate speed. Following vehicle ahead too closely at high speed.
2	**Injury or possible injury**	Risk of collision due to following a vehicle ahead too closely at intermediate speed. Vehicle(side)-to-vehicle(side) collision due to ignoring collision warning at intermediate or low speed, vehicle leaving the road, head on collision and collision with structures at intermediate or low speed.
1	**No injury** **(vehicle damaged)**	Vehicle-to-vehicle collision except head-on collision at low speed. Following vehicle ahead too closely at low speed. Collision with structures at low speed.
0	**No injury** **(no vehicle damage)**	Vehicle-to-vehicle contact at very low speed. Collision with structures at very low speed.

Table 1.6: Urgency Rating Scale (ISO, 2003, pp. 6-7).

Rating	Description	Examples
3	**Respond immediately** Take immediate action or decision (within zero to three seconds) according to the displayed information.	Obstacle immediately in the vehicle path. Brake immediately. Steer to avoid dangerous situations. ACC malfunctioning.
2	**Respond within a few seconds** Take action or decision according to the information within 3 to 10 seconds.	Obstacle within a few seconds in the vehicle path. Brake in a few seconds. Steer away from danger as required.
1	**Response preparation** Prepare to take action or decision according to the information within 10 seconds to 2 minutes.	Onset of detection of an obstacle.
0	**Information only** No direct action or decision required by the driver	System on.

Effects of Warning False Alarms

Even if the physical characteristics of a warning are salient and understandable, the warning can be unsuccessful if the underlying technology of the system is faulty. Warnings must convey an appropriate level of sensitivity and reliability in alerting the driver to a hazard. In terms of the signal detection theory, a well designed curve warning device is one that is activated when a curve hazard is present (Hit) and is not activated when no hazard exists (Correct Rejection). Systems are imperfect, though, and at times the curve warning device does not activate when there is a curve (Miss), or it is activated when no curve hazard is present (False Alarm) (Wickens & Hollands, 2000). These components of the signal detection theory are summarized in Table 1.7.

Table 1.7 Signal Detection Theory as applied to curve warnings.

<table>
<tr><th></th><th></th><th>Curve Hazard Present (Signal)</th><th>Curve Hazard Absent (Noise)</th></tr>
<tr><td rowspan="2">System Response</td><td>Warning is Presented</td><td>HIT</td><td>FALSE ALARM</td></tr>
<tr><td>Warning is NOT Presented</td><td>MISS</td><td>CORRECT REJECTION</td></tr>
</table>

The reliability of signal detection of the warning has been found to affect driver responses. A two-part study by Bliss and Acton (2002) examined responses to collision warnings that were 50%, 75%, and 100% reliable. In the first experiment, participants were to determine whether an auditory alarm actually signaled an approaching car (hit) or not (false alarm). If the alarm was true, drivers were told to swerve to avoid being struck from behind by an approaching car. The second experiment utilized the same design, however warnings were presented spatially to possibly provide more information to the drivers about the imminent hazard. As expected, driver swerving reactions were better with systems demonstrating higher reliability. The authors' suggestions were to design warnings to maximize alarm reliability while minimizing alarm invasiveness.

Negative consequences of false alarms were also demonstrated in a study by Dingus, McGehee, Jahns, Carney, and Hankey (1997) examining driver safe headway maintenance when using a forward collision warning system. The study indicated that overall, younger drivers (18 – 25 years old) tended to follow a lead vehicle more closely than older drivers (>65 years old). Drivers were presented with different forward collision warning displays while driving in a simulator. As warning false alarms increased, younger drivers increased their following distance more than older drivers. This continued until warning presentation was 60% false alarms, at which point younger drivers decreased headways indicating possible loss of trust in the system.

Unlike the previous results, two other studies found little negative effect of false alarms (Maltz & Shinar, 2004; Mitta & Folds, 1997). In the research by Mitta and Folds, participants were asked to monitor twenty-four cameras for reports of incidents. After receiving a report of an incident they were required to either locate the incident or to reject it (false alarm). Operator performance indicated no significant effect of false alarm rate. In Maltz and Shinar, the in-vehicle collision avoidance warning system (IVCAWS) led to safer (longer) headway maintenance overall. The reliability of the IVCAWS was not a significant factor in the responses to true alerts. Drivers were able to assess the situation independently of the warning systems. Overall, the drivers with IVCAWS drove more cautiously than without them even when there was a higher false alarm rate.

Credibility can be lost when a false warning sends a message to a motorist traveling at a safe speed that they should reduce their speed to navigate a curve (Torbic et al., 2004). Design tradeoffs must consider the consequences of either missing the hazard or 'crying wolf'. It has also been suggested that warning signs should not be used for conditions that are readily apparent to motorists as excessive use results in disrespect for warnings in general (Hood, 2001).

Alarm Annoyance

Alarm annoyance is sometimes related to false alarms (Maltz & Shinar, 2004). If drivers are annoyed with the performance of the system and have the option to disable the system, no benefits from warnings will result. Lerner, Dekker, Steinberg, and Huey (1996) examined how many false alarms are too many according to drivers. Results indicated that 4 false alarms per hour and 1 false alarm per hour were significantly more annoying and less acceptable than 1 false alarm per 4 hours and 1 false alarm per 8 hours. The two less-frequent rates appeared potentially reasonable for systems.

When encountering two warning messages in close temporal proximity, it was predicted that drivers would be more annoyed if auditory warnings were not correctly mapped to urgency (Wiese & Lee, 2004). Annoyance with highly urgent sounds (such as a tire skid sound) increased workload. In Wiese and Lee (2004), ratings of annoyance and subjective workload were found to be strongly associated.

Summary

Literature reviewed in this section illustrates the need to address the transportation safety issue of curve crashes and fatalities. The danger of curves is a complicated issue made up of many contributing factors such as roadway design, poor weather, and driver behavior. One possible way to mitigate the dangers associated with driving on curves is to provide an in-vehicle curve warning to the driver. The research cited sheds some light on the warning process and what factors may contribute to a successful warning. Researchers have found that both person-related and warning-related variables affect the way that a receiver processes and responds to a warning. The following sections will describe a means of further examining these person and warning variables to then provide recommendations toward the design of a curve warning device.

CHAPTER 2: RESEARCH OBJECTIVES

Rationale for the Study

According to the Fatality Accident Reporting System (FARS), 10,709 people, or about 25% of all recorded crash-related fatalities, were killed on curved roadways in 2003 (NHTSA, 2004a). The precision of any fatality count categorized by road curvature is questionable, though, as highway agencies operating accident record-keeping often do not have inventory files that identify the locations or geometrics of horizontal curves to link to accident data (Persaud, 2000). The crash and fatality count may be higher than what is on record. It has been estimated that there are more than 10 million horizontal curves in the U.S. on two-lane highways alone (Torbic et al., 2004). That is a large number of curves to monitor, especially since many exist on rural roadways, sometimes outside of Department of Transportation jurisdiction.

Not only is it difficult to keep track of all of the potentially dangerous curves on US roadways, it is also difficult to maintain these roads and institute measures at each hazard to improve safety. Efforts are being made, however, and AASHTO has created a Strategic Highway Safety Plan with the goal to reduce annual highway fatalities by 5,000 to 7,000 (Torbic et al., 2004). The seventh volume of this plan provides strategies to reduce the number of collisions that occur on horizontal curves. The two main objectives for improving the safety on horizontal curves are to

1) Reduce the likelihood of a vehicle leaving its lane and either crossing the roadway centerline or leaving the roadway at a horizontal curve
2) Minimize the adverse consequences of leaving the roadway at a horizontal curve.

The majority of AASHTO's potential strategies to address Objective 1 and all for Objective 2 relate to physical aspects of the curved road. These include providing adequate sight distance, installing rumble strips, widening the roadway, improving lighting, preventing edge drop-offs, installing automated anti-icing systems, and removing objects in hazardous locations. These solutions may prove to be very difficult to institute on rural roadways, the setting for 72% of curve-related accidents (NHTSA, 2004a).

AASHTO also proposed two strategies to reduce the likelihood of the vehicle leaving its lane or the road in the first place. The first is to provide advance warning of unexpected changes in horizontal alignment, and the second is to provide dynamic curve warning systems. These more proactive approaches refer to advance warnings in the form of roadside signage. Traditional signage is one of the least costly and most timely strategies suggested. As noted in the literature, however, traditional signage may not be the most effective solution. Nontraditional signs such as pavement arrows, transverse striping treatments, and roadside dynamic warning signs with more individualized displays show promise in reducing speeds and accidents, at least in the short-term (Charlton, 2004; Preston & Schoenecker, 1999; Wenham, 2000), however few studies of these types of warnings have been performed.

As shown by the efforts of AASHTO and a number of research institutions, improving curve-related safety is a priority. An effective solution needs to overcome the challenges posed by hazards in rural areas, construction costs, and driver inattention to traditional warning efforts. These criteria point to the potential success of an in-vehicle warning system.

Background

Technology for the creation of in-vehicle curve warning systems already exists. For example, means to communicate hazardous curve information to an in-vehicle device include digital roadmaps (Herrtwich, 2002). Some guidelines for curve warning systems also exist (Pomerleau et al., 1999), however there is little current research establishing the most-effective presentation format for curve warnings.

The research study by Neurauter (2004) set out to contribute empirical evidence toward the design of curve warnings. This simulator study examined driver performance and reactions to a number of curve warning presentation modalities and determined combinations of stimuli that were most successful based on objective and subjective measurements. The top performing stimulus presentation was the speech and HDD, and the second-rated presentation was the speech and HDD once again, with the throttle push-back. The Neurauter (2004) results in addition to several other studies (Janssen & Nilsson, 1993; Manser, Ward, Kuge, & Boer, 2004) have found haptic displays to be an effective driver warning presentation mode. Additional testing is important in determining the added value of the haptic component for both manufacturing costs and reaction time improvement in a real world setting.

No on-road studies of in-vehicle curve warning systems have been published to date. In order to increase the external validity of curve-warning studies, performance in a setting as close to the actual driving setting should be used. Results from an on-road study may be more generalizable to real-life driving situations.

Experimental Goal

The goal of this research is to determine an effective configuration of stimuli to be used in curve warning design. The top two warning modality combinations from Neurauter (2004), along with a no-warning condition, will be compared by performing an empirical test with an instrumented vehicle on a closed test highway. The aim of this study is to determine which condition outperforms the other two conditions in improving curve driving safety. More specifically, does one condition elicit the most appropriate and desirable responses from younger and older drivers? Also, are there differences in performance between drivers with different levels of hazard perception or different risk-taking style? This study will utilize on-road performance in conjunction with subjective evaluation to make recommendations toward curve warning design guidelines.

Research Questions and Hypotheses

This study addresses several questions regarding in-vehicle presentation formats for a curve warning device. Research questions (RQ) and hypotheses (H) based on previous literature are presented next.

Research Question 1: Stimulus Presentation and Performance

RQ 1.1. *How does driving performance compare between stimulus presentation groups based on the presentation (including the condition with no stimulus presentation) received first in the "surprise" stimulus presentation?*

H 1.1. Based on previous research cited in the Review of Literature section, participants presented with a curve warning stimulus are expected to have quicker throttle and brake reaction times as well as greater speed compliance once reaching the curve entrance than those not receiving a curve warning stimulus (Comte & Jamson, 2000; Dingus et al., 1997; Neurauter, 2004; Uno & Hiramatsu, 2001). Participant performance in the first surprise stimulus presentation could mirror overall results for the stimulus presentation types. When examining the performance of drivers receiving a stimulus including the haptic mode, though, a difference may emerge as a result of participant annoyance and/or confusion associated with the haptic stimulus shown in the Neurauter (2004) study. These ratings of annoyance may be related to the intrusiveness associated with this modality – there is no way for those experiencing haptic feedback to shut the stimulus out (Lloyd et al., 1999). According to the findings from Suzuki & Jansson (2003), driver responses to haptic feedback are sometimes "false positives," or opposite to the desired response, possibly due to driver unfamiliarity or confusion. It is predicted that participants receiving a warning containing the haptic stimulus in the first stimulus presentation will not perform as well as those receiving warnings without the haptic stimulus first due to confusion or annoyance. A warning presentation that does not perform well in the first "naïve" presentation may indicate a weakness in the warning design. Warnings are to be effective even without training, and should elicit appropriate responses even in surprise situations.

RQ 1.2. *Overall, what changes in driving performance occur when different stimulus presentations are presented to the driver?*

H 1.2. As predicted for the first "surprise" stimulus presentation, participants presented with a curve warning stimulus are expected to have quicker throttle and brake reaction times as well as greater speed compliance once reaching the curve entrance than those not receiving a curve warning stimulus (Comte & Jamson, 2000; Dingus et al., 1997; Neurauter, 2004; Uno & Hiramatsu, 2001).

Based on simulator study objective results, a stimulus presentation including the HDD, and Speech stimuli is expected to elicit quicker reaction times and lower curve entrance speeds than the same presentation with the throttle push-back haptic stimulus (Neurauter, 2004), though the degree of this difference is uncertain. Also, the haptic throttle push-back may have some added value as found in the Manser (2004) study, and results may change in the on-road setting as compared to the simulator setting.

RQ 1.3. *How does driving performance compare between the surprise and subsequent stimulus presentations?*

H 1.3. Participants are likely to show improved performance over time due to a training or experience effect. Brake and throttle reaction times are likely to be quicker in subsequent stimulus presentations as participants become aware of what to expect in terms of the roadway and the warning presentation. Driver curve entry speed may also improve, or better match the advisory speed, once participants gain experience with a warning system.

Research Question 2: Age and Performance

RQ 2.1. *How does driving performance differ between age groups?*

H 2.1. Older drivers are likely to have slower reaction times, including brake and throttle reaction times, in response to the stimuli (Hanowski et al., 1999; Neurauter, 2004; Warshawsky-Livne& Shinar, 2002). Participants may, however, may reach a more appropriate curve entry speed (closer to the advisory speed). Older participants have exhibited greater warning compliance while driving in several studies (Neurauter, 2004; Uno & Hiramatsu, 2001).

RQ 2.2. *In what ways do stimulus presentations affect driving performance of participants in different age groups?*

H 2.2. It is expected that reaction times between age groups will differ, however the overall performance results indicating the greater effect of one warning over the other is likely to stay constant between the age groups. Throttle reaction times may be quicker for both younger and older participants in the stimulus presentation including a haptic push-back. Brake reaction times are likely to be similar between warning stimulus presentations for each age group. For curve entry speed, the stimulus presentation including throttle push-back may be accompanied by better performance by younger participants while a stimulus presentation without the throttle may lead to better performance by older participants (Neurauter, 2004). Owens and Lehman (2001) described general findings that aging leads to deterioration of perception and information processing and such deterioration may impair older participants' experience of the haptic stimulus.

Research Question 3: Subjective Evaluation

RQ 3. *How will subjective ratings differ between the stimulus presentations and driver age groups?*

H 3. A HDD and Speech stimulus presentation is expected to be rated more favorably than a HDD, Speech, and Throttle Push-back presentation based on the results of the simulator study. Ratings gathered by Neurauter (2004) indicated that the presentation including the haptic stimulus may be rated as more annoying than a presentation without this stimulus. Lloyd et al.(1999) also cites the potential for the misinterpretation of the haptic component as a mechanical failure, and thus this may result in unfavorable reactions. Despite low subjective reactions, the presence of haptic stimuli in driving studies has been found to improve driving performance in several studies and its contribution should be evaluated (Janssen & Nilsson, 1993; Manser et al., 2004; Neurauter, 2004)

Research Question 4: Hazard Perception and Risk-Taking Style

RQ 4. *Is there a relationship between drivers' hazard perception and/or risk-taking style with curve warning compliance?*

H 4. Individuals with higher hazard perception scores are likely to comply with curve advisory speeds more than individuals with low hazard perceptions (Friedmann, 1988; Vredenburgh & Cohen, 1995). A tendency toward risky behavior may influence compliance with curve warnings (Purswell et al., 1986). The risk-taking style measurement described in Iversen (2004) may be more appropriate in predicting long-term or future compliance with warnings than predicting short-term performance.

CHAPTER 3: METHODS

Experimental Design

The experimental design for this study was a 2 (Age) X 3 (Surprise Stimulus Presentation) between-subjects design. The Age variable included two levels, Younger, 18-25 years old, and Older, >60 years old. The three levels of Surprise Stimulus Presentation included the two top-performing warning presentation configurations as determined by Neurauter (2004): 1) Speech with Heads Down Display (HDD) (Audio-Visual), 2) Throttle push-back, Speech, and HDD (Haptic-Audio-Visual), 3) Baseline condition. In this design, Stimulus Presentation was treated as a nested factor balanced between participants, as each participant received one of the stimulus presentations during their first "surprise" stimulus presentation (See Table 3.1.) In other words, though participants encountered each of the three stimulus presentations, the first stimulus presentation occurred without any prior knowledge of the stimuli or the curvature of the road. Performance and reactions to this first stimulus encounter were examined. Presentation orders were determined using a Balanced Latin Square included in Appendix A.

The study data were also analyzed as a 2 (Age) X 3 (Stimulus Presentation) mixed factors design. The between-subjects variable was Age and the within-subject variable was Stimulus Presentation. Table 3.2 shows the structure for the mixed-factors design.

Table 3.1: Experimental design - between-subjects for first "Surprise" Stimulus Presentation.

	Stimulus Presented First in "Surprise" Stimulus Presentation											
Age	Audio-Visual				Haptic-Audio-Visual				Baseline			
Younger	S1	S5	S7	S11	S2	S6	S8	S12	S3	S4	S9	S10
	S13	S17	S19	S23	S14	S18	S20	S24	S15	S16	S21	S22
Older	S25	S29	S31	S35	S26	S30	S32	S36	S27	S28	S33	S34
	S37	S41	S43	S47	S38	S42	S44	S48	S39	S40	S45	S46

Table 3.2: Experimental design – mixed factors.

	Stimulus Presentation		
Age	Audio-Visual	Haptic-Audio-Visual	Baseline Driving
Younger	S1 - S24	S1 - S24	S1 - S24
Older	S25-S48	S25-S48	S25-S48

Participants

Eight participants ran as pilots and 48 additional participants performed the study. Pilot data were not used in data analysis. The participants were recruited by word of mouth in addition to posted flyers (Appendix B). The study lasted no more than one and a half hours and participants were paid $20.00 per hour for their time. No participants chose to withdraw from the study before its completion. More details pertaining to participants are in the following sections, and are included in the Institutional Review Board (IRB) document in Appendix C.

Independent Variables

Participants from two age groups participated in the study. Each participant was presented with three stimulus presentations: Audio-Visual; Haptic-Audio-Visual; and a Baseline condition (as seen earlier in Table 3.1 and Table 3.2). In the Baseline condition, no stimulus was presented.

Age

Participants were recruited from two age groups: 24 Younger (18-25 years old) and 24 Older (>60 years old). The mean age for the younger group was 22 years (*SD* =

1.7) and mean age for the older group was 69 years (*SD* = 3.5). Significant differences in reaction times have been found between these age groups (Warshawsky-Livne & Shinar, 2002; Wood, 1998). Each age group was balanced for gender (i.e., 12 male and 12 female per group). Running an equal number of male and female participants upheld equal opportunity in the hiring of those eligible. Balancing for gender also controlled the variable to allow for further exploratory analyses based on gender.

Stimulus Presentations

Stimulus Presentations.

1. Audio-Visual: Speech and HDD
2. Haptic-Audio-Visual: Throttle Push-Back, Speech, and HDD
3. Baseline - No stimulus is presented

First "Surprise" Stimulus Presentation. The components of this independent variable were the same as Stimulus Presentation; however they were analyzed as a between-subjects variable. This independent variable (IV) was defined as the first stimulus presentation that the participant received.

Visual Stimulus. The HDD was an orange-yellow and black flashing icon created using the drawing in Figure 3.1. This symbol was derived from the combination Horizontal Curve / Advisory Speed Sign following specifications in the Manual on Uniform Traffic Control Devices (MUTCD) (Federal Highway Administration, 2003) and was adapted for use in the Neurauter study (2004). The image was 222 x 160 pixels, equaling 1.81 inches wide by 1.12 inches high. The icon flashed at a blinking cycle of 0.2 seconds until the participant reached 15 mph. Figure 3.2 shows the location of the HDD, though the color quality in the photograph is skewed due to the flash-rate of the display. This position on the dash display was chosen for several reasons: 1) Viewing angle (within proper limits as defined by Sanders and McCormick (1993)) 2) Availability of space to accommodate the HDD without interfering with other displays 3) Proximity to relevant information (speedometer) on the display. A close-up of the HDD is included in Figure 3.3. Only a left-handed turn arrow was used in this study as Neurauter (2004) and Comte & Jamson (2000) did not find any significant differences in driver performance between right and left turns.

Figure 3.1 Visual icon for left-handed turn with 15mph advisory speed.

Figure 3.2: HDD location on dash.

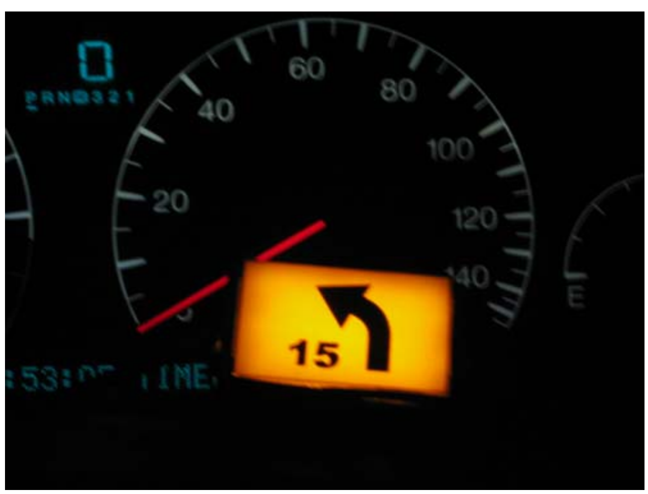


Figure 3.3: HDD

Auditory Stimulus. For the speech display, a digitized female voice said, "Curve ahead. Reduce speed to 15 miles per hour." The reason a curve advisory speed of 15 mph and a maximum study speed of 55 mph were chosen is included in a later section pertaining to curve design. The digitized format has been shown to be more favorable than synthesized speech (Tan & Lerner, 1995). Display design, as described here, followed that used in Neurauter (2004). The phrase "Curve ahead. Reduce speed to 15 miles per hour" was presented at 156 words per minute (NHTSA, 1996). All auditory output was presented 13 dBA over the masked threshold in all of the 1/3 octave bands, respectively, based on interior noise (Berger, Royster, Royster, Driscoll, & Layne, 2000). Sound measurements of interior noise were gathered at the maximum study speed of 55 mph, and were used to determine the appropriate warning levels for the auditory warning. Graphs of cab interior sound level as well as audio warning sound level are included in Appendix D.

Haptic Stimulus. The throttle push-back was applied at a force of approximately 12 lbf (~53N) and was presented for three seconds (Neurauter, 2004). The push-back force needed to be detectable and was designed to exceed the just noticeable difference (JND). With respect to force, a JND is the degree of augmentation that a person can experience before he or she detects the augmentation (Allin, Matsuoka, & Klatzky, 2002). Such a force was the minimum requirement for the display. Pilot tests indicated that the initial proposed force of 6 lbf (~25N) (Janssen & Nilsson, 1993; Neurauter, 2004) did not meet this specification while driving the test vehicle on a real roadway. Five initial participant pilots experienced the 6 lbf feedback but did not mention feeling the haptic force, and when the force was described to them they confirmed that they did not feel it. The haptic pedal was then isolated from the visual and auditory stimuli and tested with additional participants at a higher force. Three naïve participants piloted the pedal at a force of 7 lbf while driving 30 mph and each of the participants mentioned the stimulus without prompting. An additional three naïve participants received 8 lbf while driving on a real road 55 mph to simulate study conditions, and again all three mentioned the stimulus without prompting.

Little testing of this type of force has been published in the literature, and thus specifications for stimulus design were formed based on available information. Possible factors causing the pedal to go unnoticed in the pilot testing included participant age and degraded sensory (Sanders & McCormick, 1993); surprise, distraction, or confusion that occurred during the surprise situation; or overloading processing capabilities by using three stimuli at once. For this study, it was important that participants experienced all three stimuli to evaluate the influence of adding a haptic stimulus, and thus a very noticeable stimulus was desired. In working with the hardware technology crew at VTTI, a maximum mechanical safe force of the device was calculated to be 12 lbf, and this level was tested with three participants to confirm that the force was not too startling and in no way painful. The force of the throttle push-back was measured using an analog force meter pictured in Figure 3.4. The protocol for measuring the force is included in Appendix E.

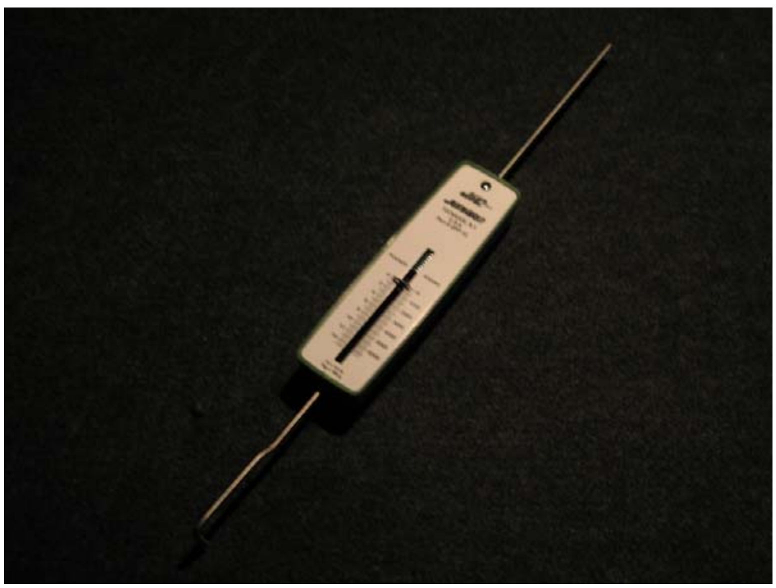


Figure 3.4: Analog force meter used to measure throttle push-back force.

Dependent Variables

Objective Data Collection

Objective dependent variables were based on relevant measures collected in the Neurauter (2004) simulator study and are measures that point to warning success at various stages of the warning process. Response times and speed are also main measures taken in a number of other driver warning studies, including Charlton (2004), Dingus et al. (1997), and Manser et al. (2004).

1. Throttle Reaction Time (TRT) – the time it took for a participant to remove his/her foot from the throttle pedal if his/her foot was in this location at stimulus onset.
2. Brake Reaction Time (BRT) – the time it took for a participant to begin braking, starting from stimulus onset.
3. Vehicle Speed at Entrance of Curve – vehicle speed calculated for the entrance of the curve.

Subjective Data Collection

Stimulus Comprehension. Once participants completed a stimulus presentation, they parked the vehicle and verbally answered questions pertaining to stimulus comprehension. Retrospective probing consisting of a short interview was used to elicit the driver's knowledge about the stimulus. Initial interview questions were very general to avoid biasing the participants, and then more specific questions gathered driver thoughts and understanding of the curve warnings. Example questions are in Appendix F and include, "Did you notice anything just now?", "Can you describe what you noticed?", and "What did it mean to you?" The stimulus comprehension interview was administered after the Baseline condition in addition to the two warning stimulus presentations.

Post-Condition Questionnaire. After each curve warning presentation, participants completed the Post-Condition Questionnaire. This questionnaire consisted of 5 items rated on a five-point Likert-type scale and are the same items used in Neurauter (2004). The items gathered drivers' reactions to the warning in categories such as its urgency, annoyance, and appropriateness. Responses were written and on a scale from 1, Strongly Agree to 5, Strongly Disagree. One written open-ended question was also included in the questionnaire which asked whether participants would change something about the warning, and if yes, what it would be. The Post-Condition Questionnaire is included in Appendix G.

Curve Warning Acceptance. After all three curve warning presentations, participants completed the Curve Warning Acceptance Questionnaire. This questionnaire was based on a tool developed by Van Der Laan, Heino, and De Waard (1997) and consisted of 9 items rated on a five-point Likert-type scale. Items asked the participants to rate whether the warnings were useful, pleasant, annoying, effective, irritating, and desirable, to name a few. The full questionnaire is included in Appendix H. Just after completing this questionnaire the participants were asked to choose which warning stimulus presentation they liked most, and which they liked least. These questions were asked and answered verbally.

Hazard Perception. Participants' perceptions of driving hazards, specifically those on curves, were collected once at the end of the night using a Hazard Perception Questionnaire (Appendix I). The Hazard Perception Questionnaire consisted of 5 items rated on a five-point Likert-type scale. Participants indicated at what point on their first trial they became aware of a curve ahead on the Smart Road (SR) (prior to the warning, during the warning, or after the warning). They also indicated whether they perceived the SR curve to be a potential hazard. In addition, they rated the level of danger associated with driving on curves in general.

Risk-Taking Style. Participants' risk-taking style were measured by written questionnaires based on those used by Iversen (2004). The Risk-Taking Style Questionnaire (Appendix J) was administered to each participant once, at the end of the night. Items pertaining to attitude towards rule violations and speeding, and attitude towards drinking and driving were measured using a scale from (1), strongly agree to (5) strongly disagree. On another scale, from (1), very often to (5) never, drivers indicated their behaviors such as traffic rule violations/speeding, reckless driving, and seat belt use.

Overview of Variables: Warning Process Conceptual Model

Figure 3.5 includes a conceptual model illustrating all variables in the study as they relate to the warning process, adapted from Rogers et al. (2000). This diagram includes the warning process components: notice, encode, comprehend, and comply, described earlier in the Review of Literature section. The difference between this figure and the process model set forth by Rogers is the inclusion of only the independent variables to be tested in the current study, as well as dependent measures to be collected, indicating driver experience and performance at the different phases of the model. Specific independent and dependent variables are labeled in the diagram, with indication of subjective or objective measurements of these variables.

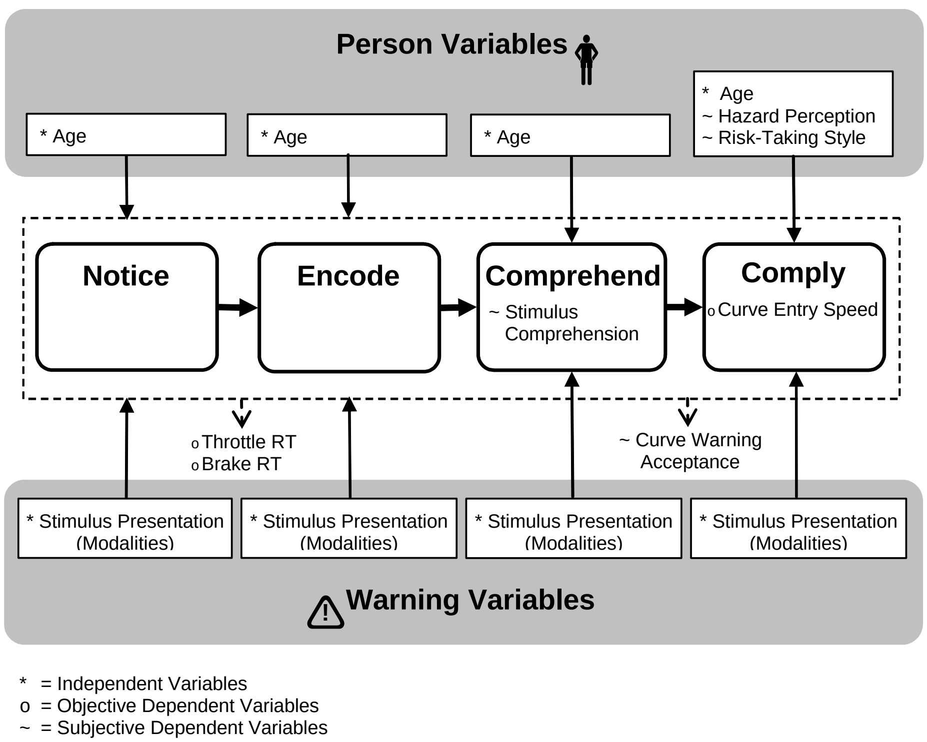


Figure 3.5: Conceptual model detailing variables for the study as they relate to the warning process (Adapted from the model in Rogers et al., (2000), p. 105).

As indicated in the upper portion of the diagram, person variables examined were Age, Hazard Perception, and Risk-Taking Style. A single warning variable was examined: Stimulus Presentation which varied by modalities presented in the warning. The subjective measurement of the *Comprehend* stage was the Stimulus Comprehension interview. The subjective measurement of acceptance was expected to shed light on the receiver's ability and decision to comply, but may have also indicated other processes such as decision making. Thus the pictorial representation indicated that acceptance was a variable affected by various stages of the model. One objective measurement for *Comply* was Curve Entry Speed. The other objective measurements, Throttle Reaction Time (TRT) and Brake Reaction Time (BRT), were listed as possibly occurring at any point along the warning process. It was difficult to determine one warning processing stage at which these occur for all individuals– the measures may have indicated a simple reaction once the stimulus was noticed, or may have occurred after decision to comply. Nonetheless, these response times were included in the study to help evaluate successful warning performance.

Apparatus

Smart Road

The research facility used for this research was the Virginia Department of Transportation and Virginia Tech Smart Road (SR). The SR is used for evaluating ITS as well as infrastructure concepts, technologies, and products (Figure 3.6). It is currently a 2.2-mile two-lane roadway with a high speed banked turnaround at one end (Top Turn), and a low-speed flat turnaround on the opposing end (Bottom Turn) (Figure 3.7). Based on the grade and curvature of the road, it was designed to handle a speed of up to 100 km/h, or approximately 62 mph. For the current research, participants drove the length of the road from the top turnaround to the bottom turnaround at a speed of 55mph and encountered the first surprise stimulus presentation at the Bottom Turn. No other vehicles were present on the road when the participant vehicle was present. For all stimulus presentations following the surprise event, participants used only the stretch of road between Turn 3 and Bottom Turn to decrease overall time required for each participant. Access to the SR is controlled by a dispatcher and electronic gates creating a safe location to conduct research. This allows researchers to complete experiments that would not be possible on an open roadway.

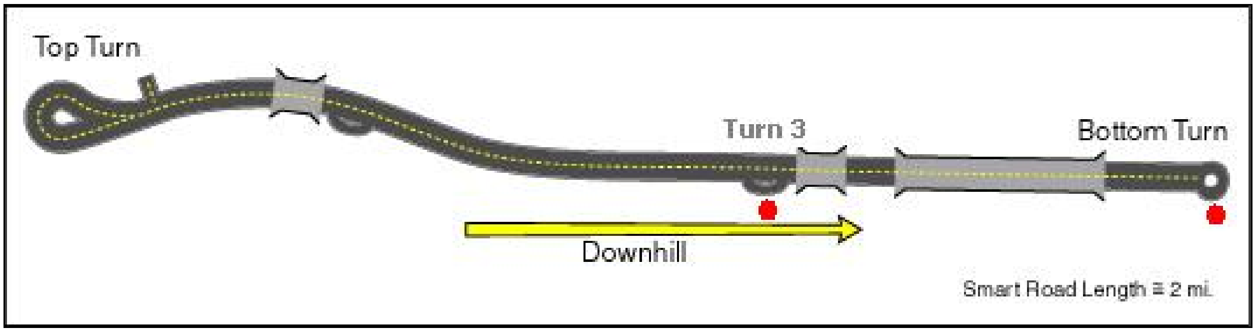


Figure 3.6: Diagram of the Smart Road.

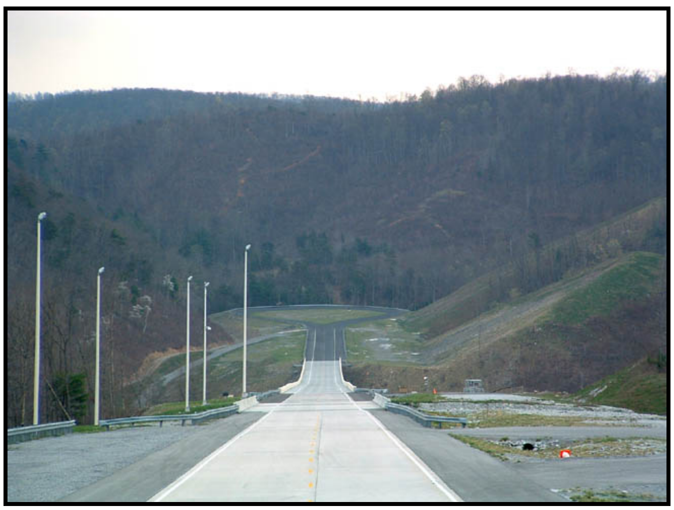


Figure 3.7: Photograph of the Bottom Turnaround at the end of the Smart Road.

Research Vehicle and Data Collection Equipment

A 2000 Cadillac Deville DTS was used as the test vehicle for the study (Figure 3.8). The vehicle's safety features included anti-lock brakes, dual front and side airbags, traction control, StabiliTrak antiskid system, and Continuously Variable Road Sensing Suspension. An additional safety feature was a custom-built hand-operated braking system located in reach for the experimenter seated in the rear passenger-side seat (Figure 3.9). Force for this system, as well as for the throttle push-back system, was generated using a nitrogen tank located in the trunk (Figure 3.10). For the throttle push-back system, the tank was a 20 cubic foot compressed nitrogen cylinder with heavy duty rotary air actuator and 6.75" throttle to generate force at the assumed point on the pedal. The braking system utilized the same nitrogen cylinder along with a pneumatic air cylinder which applied axial force to the brake pedal arm.

Figure 3.8: Research vehicle, Cadillac Deville DTS.

Figure 3.9: Custom-built hand brake accessible to backseat passenger.

Figure 3.10: Nitrogen tank located in trunk used to power throttle push-back as well as emergency brake.

The data acquisition system contained within the vehicle was custom-built by VTTI and located out of view of the participant. This equipment included a hard drive and hard drive housing unit contained in the trunk (Figure 3.11) with an interface located in the rear passenger-side seat (Figure 3.12). The interface consisted of a mounted computer monitor, video monitor, and keyboard. The experimenter used custom-written software which allowed user-defined settings, including entering participant information and setting the stimulus presentation type. The system was linked to a laser trigger mounted on the SR. When the laser was broken by the passing vehicle, it would trigger the stimulus presentation at a set distance.

Figure 3.11: Data collection hardware located in trunk.

Figure 3.12: Experimenter data collection interface.

Small video cameras (1” square by ¼” deep, seeing through a 1/32” aperture) (Figure 3.13) were mounted inconspicuously within the vehicle. Views of the cameras included the driver’s face, throttle and brake pedals, an over-the-shoulder view of the steering wheel and dash, and a forward road view (Figure 3.14). Cameras also used infra-red light sources as light conditions were too low to discern video images. Video was used to confirm warning onset as well as participant foot location for data reduction.

Figure 3.13: Mounted camera in experimental vehicle.

Figure 3.14: Four camera views (Image taken while driving the orientation route on public roads).

Curve Design

Advisory Speed

Safe speeds for curves on U.S. roadways are usually determined by one of two methods: 1) the ball-bank method and 2) the standard curve formula. A detailed description of these methods can be found in Neurauter (2004). The curve formula was used for this study, and calculations are detailed in the following sections.

The SR curve used for this project had a radius of 92ft and average superelevation of 6%. The following formula set forth by Pomerleau et al. (1999) was used to calculate the curve advisory speed:

$$V = \sqrt{Rg\frac{e+f}{1-ef}}$$

For the equation, *V* is the calculated advisory speed, *R* is the radius of the curve (ft), *g* is the gravitational constant (32.2. ft/s^2), *e* is the superelevation (%), and *f* is the side friction factor. Based on criteria from the ball-bank advisory speed method, the side friction factor was 0.21 (AASHTO, 2001). Also, curve warnings should indicate a speed that is 90% of the maximum safe speed (Pomerleau et al., 1999) as well as a rounded number to include on the advisory sign. Based on these criteria and the formula stated above, the warning indicated an advisory speed of 15 mph (see calculations in Appendix K).

As in the simulator study by Neurauter (2004), SR participants were instructed to maintain 55 mph. The speed limit of 55 mph was based on the fact that nearly 40% of all fatalities involving a curve from 2000 to 2003 were on roads with a speed limit of 55mph (NHTSA, 2004a). Also, a speed of 55 mph paired with a turn advisory speed of 15 mph required a large amount of deceleration in order to maneuver the curve safely.

Warning Onset

Once the curve radius and safe advisory speeds were calculated, the location for warning onset was determined. The guidelines set forth by Pomerleau et al. (1999) recommend a longitudinal deceleration threshold of 4.92 ft/s (or no more than 50% of what the vehicle is capable of). To determine the point at which the warning should be presented based on speed, the following equation was used:

$$a = \frac{V^2 - V_c^2}{2(d - t_r V)}$$

where a is the deceleration (4.92 ft/s), V is the current speed (55 mph or 80.67 ft/s), V_c is the maximum safe speed for the curve (24.47 ft/s), d is the distance to the apex of the curve, and t_r is the reaction time of the driver (at least 1.5s). Based on current design practices, the reaction time was set at 2.5 seconds (AASHTO, 2001). According to these calculations (Appendix L), the warning began 802 ft from the apex of the curve assuming the participant was traveling at the set speed of 55 mph (Hood, 2001).

A diagram of the points used on the SR is included in Figure 3.15. These points will be discussed in following sections pertaining to data collection.

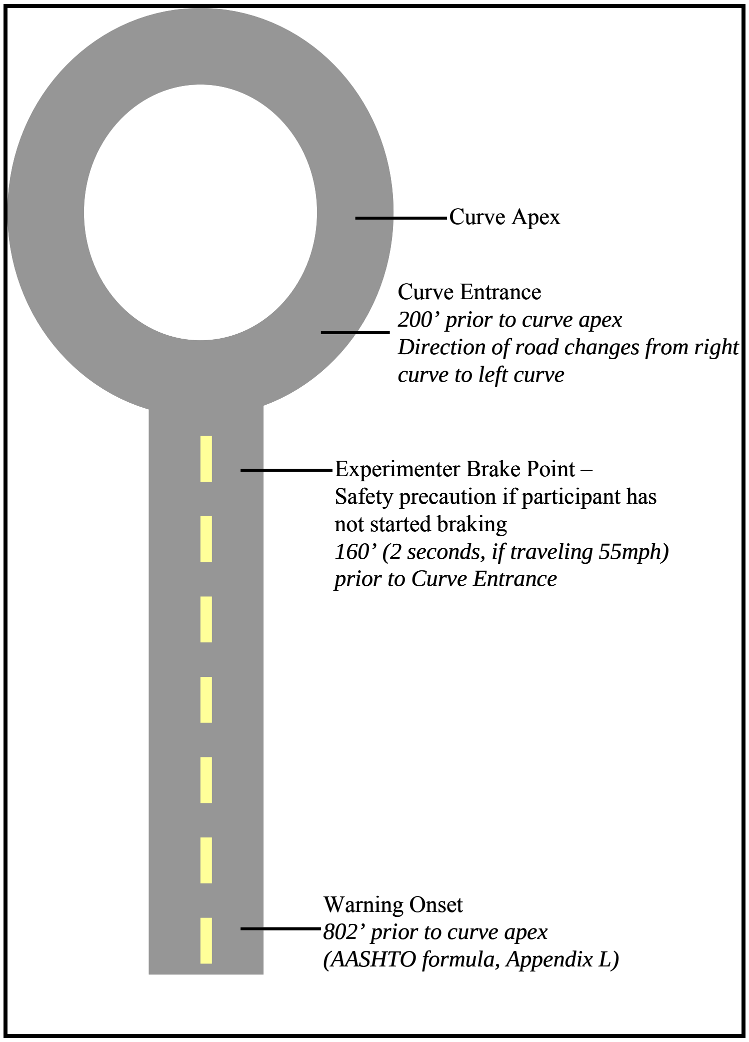


Figure 3.15: Diagram of points of interest on the Smart Road curve.

Experimental Procedure

Participant Screening

Participants were screened over the telephone using a health status and eligibility questionnaire (Appendix M). Participants were ineligible if they exhibited certain health conditions, poor driving record, had participated in a study that used the full length of the SR within the past year, or had ever participated in a SR study with surprise events. Upon arrival, the participants presented a valid driver's license and were given an Informed Consent Form (ICF). The ICF informed them of any risks associated with the study and their option to withdraw freely from the study at anytime with no penalty. If they withdrew, the participants would be compensated for their time up to that point (See ICF in Appendix N). The participants also completed a Virginia Tech W-9 Tax Form in the event that the accumulation of their earnings required the documentation (Appendix O). They completed the Snellen test to assess visual acuity and to see if their vision met the Virginia acuity criteria for driving of 20/40 (Department of Motor Vehicles, 2004). The Ishihara Color Vision test was also administered as well as an informal hearing test (Appendix P).

For the hearing test, a series of four tones of 1, 2, 3, and 4KHz were played from a laptop. The participant sat 4 feet away with his or her back to the laptop, speakers at the sides of the laptop with the back of the laptop pointing toward the participant. Original levels for these tones were determined so that they exceeded 13dB above the masked threshold at the frequency of that tone (Sanders & McCormick, 1993). At this level, though, three out of the first five older participants (>60 years old) did not pass the test. Because the measure was not meant to be a stringent test to exclude participants, this level was adjusted so that the sound level at the tone frequency exceeded the highest masked threshold for any frequency. This was done based on research indicating that an upward spread of masking may have been occurring, where there is threshold elevation in octave bands higher than the masking sound itself (Berger et al., 2000). This means that the lower frequency room noises (in this case, fan and HVAC noise) were masking the higher frequency test tones. The fan and HVAC sounds could not be eliminated, thus the tones were played above the masked thresholds of lower frequencies as well as of the frequencies of the tone. Graphs indicating the sound level for each of the tones in comparison with room noise are included in Appendix Q. The protocol detailing all vision and hearing testing is included in Appendix R.

Study Conditions

The study took place in nighttime hours during clear weather conditions and dry pavement conditions to maintain safety. By conducting data collection in darkness there was a reduction in visual cues which indicate curve location and characteristics to drivers. Drivers' curve detection performance is improved by road view, lighting, guardrails, and signs (Hagiwara, Suzuki, Tokunaga, Yorozu, & Asano, 2001). In order to better isolate the effectiveness of the curve warning device in alerting the driver to an upcoming curve from the effects of these other cues, a nighttime setting with low ambient light levels was used.

Participant Orientation

Just as visual foresight was to be limited by nighttime conditions, cognitive expectancies were lessened by waiting to inform participants of the curve warnings being tested until the end of each participant's driving session. Following the initial vision and hearing tests, the experimenter oriented the participant to the study and to the research vehicle. Description of the study indicated that participants would be examining the effects of cellular phone usage while driving. This deception was necessary to gain information on how people react to warnings without prompting.

After receiving instructions and asking any questions they had, the participant was asked to drive a short highway route. The experimenter was in the vehicle with the participant at all times (See full experimenter protocol in Appendix S). The highway route was chosen to help familiarize the participants to the vehicle features and handling, and to help them become comfortable driving at 55 mph without revealing the curvature of the SR. The route was 7.3 miles long, round trip, and consisted of a 4-lane highway stretch at 55 mph to familiarize the participants with driving the vehicle at 55mph. The public road route also included more rural roads with speeds ranging from 25 – 45 mph. On one 25 mph stretch there was a curve requiring a reduction in speed from 25 mph to a 10 mph advisory speed (Table 3.3).

Table 3.3: Photographs of curve signage on the orientation route.

a) Diamond warning sign with curved arrow plus curve advisory speed located prior to the curve	b) View of curve to the left with signs at the apex denoting sharp turn	c) Close-up at signs located at curve apex
		

Data Collection

Participant data collection began on the orientation route. The driver's speed was recorded at the entrance of a curve requiring reduction of speed from 25 mph to 10 mph. Upon completion of the orientation highway loop, the participant entered the SR and drove the length at 55 mph. At the first encounter of the Bottom Turn, one stimulus presentation (either Audio-Visual, Haptic-Audio-Visual, or Baseline) was presented to the driver at the determined distance from the curve apex. A Balanced Latin Square was used to determine participant presentation orders and is included in Appendix A. After the surprise stimulus presentation, the experimenter asked the participant to park the vehicle at the end of the Bottom Turn. The experimenter conducted the Stimulus Comprehension Interview (Appendix F) followed by the Post-Condition Questionnaire (Appendix G) if a warning was experienced. Next, the experimenter read a debriefing statement explaining the true purpose of the study (Appendix T). The participant then read and signed an additional informed consent form included in Appendix U. Following debriefing, the participant indicated whether the data from their first curve encounter could be kept. Once ready, the participant drove the loop from Turn 3 to the Bottom turn for a total of two more times to experience the other stimulus presentations. After each stimulus presentation the participant parked and completed the interview and questionnaire. After all three trips to the curve, the participant completed the Curve Warning Acceptance Questionnaire (Appendix H) based on opinions related to the curve warnings in general. The Risk-Taking Style Questionnaire (Appendix J) was only administered once, at the end of the night. Before participants left they received the Debriefing and Payment Form (Appendix V) with compensation for the time they spent participating in the study.

Data Analysis

Methods for reducing and analyzing all objective and subjective data collected from each participant are detailed in the following sections.

Data Reduction

Video and performance data files from each participant were downloaded from the hard drive located in the trunk to a portable flash drive. These files were viewed using a custom-written program that could display variables individually and in sync with the video, and could import numerical data into Excel spreadsheets. Using the spreadsheets in conjunction with the video, values for each participant's dependent variables were gathered. For consistency, only one person performed the data reduction. TRT was the time from the warning onset (confirmed using video) to the point when the participant lifted his or her foot off of the throttle (identified using both video and pedal force measures). BRT was the time from warning onset to the point that the foot began to depress the brake. Curve entry speed was the participant's speed at a point 730 feet after the warning onset which demarcated the point where the orientation of the road began to turn to the left. Similarly, the Public Road curve entry speed was calculated using a sign landmark in the video which was a measured distance from the point where the road began to veer to the left. Speed from each of these points was recorded for each participant.

Objective Data Analysis

Objective data collected during the study include throttle reaction time (TRT), brake reaction times (BRT), and speed at the entrance of curve (SRspeed). The mean and standard error for the dependent measures was calculated for each of the stimulus presentations, for the first surprise stimulus presentation, as well as by age group. An analysis of variance (ANOVA) was performed to evaluate the Stimulus Presentation and Age differences with respect to the dependent measures. The analytical degrees of freedom for each ANOVA are in the following tables (Table 3.4 and Table 3.5).

Table 3.4 ANOVA degrees of freedom for between-subjects design.

Source	***df***
Between	
AGE	1
SURPRISE STIMULUS PRESENTATION	2
AGE X SURPRISE STIMULUS PRESENTATION	2
PARTICIPANT(AGE SURPRISE STIMULUS PRESENTATION)	42
TOTAL	47

Table 3.5 ANOVA degrees of freedom for mixed factors design.

Source	***df***
Between	
AGE	1
PARTICIPANT(AGE)	46
Within	
STIMULUS PRESENTATION	2
AGE X STIMULUS PRESENTATION	2
STIMULUS PRESENTATION X *PARTICIPANT(AGE)*	92
TOTAL	143

Using α set at 0.05, the objective data analysis identified any significant main effects of Stimulus Presentation or Age. Significant interactions between Age and Stimulus Presentation were also identified. Significant interactions were examined graphically to determine relationships between variables, and any instances where Stimulus Presentation had a significant effect were examined using the Bonferonni *t* post hoc test to adjust for the error rate of multiple tests. This test is often used by researchers as a more conservative method which helps to prevent inflation of α error when making multiple comparisons (Cohen, 2001). This test is also recommended when n's are unequal, as was true for this study. A Bonferonni correction of $\alpha = 0.0167$ was used to determine where differences occurred between the three levels of the Stimulus Presentation main effect (α of 0.05 adjusted for a total of 3 comparisons: $0.05 / 3 = 0.0167$).

In addition to TRT, BRT, and SRspeed, a comparison of driver speed on the public road curve (PRspeed) with driver speed on the SR curve (SRspeed) was performed. A Pearson correlation was used to determine whether a relationship existed between the drivers' PRspeed and their SRspeed. PRspeed was also used as an indicator of more "naturalistic" driving and compared with participant hazard perception and risk-taking scores, a measure discussed in the following section.

Subjective Data Analysis

The subjective data analysis consisted of evaluating the responses from the Stimulus Comprehension Interview (Appendix F), Post-Condition Questionnaire (Appendix G), Hazard Perception Questionnaire (Appendix I), Curve Warning Acceptance Questionnaire (Appendix H), and Risk-Taking Style Questionnaire (Appendix J). Content analysis was performed on the open-ended responses to code and summarized ideas that emerged from participant statements to determine how these ideas related to the different warning stimuli. For acceptance ratings, ANOVAs were performed to determine any significant differences between the stimulus presentations, as well as between age groups, in addition to determining the mean and standard deviation for each stimulus presentation. Regression analysis was performed for the risk-taking and hazard perception questionnaires to examine any significant relationships between these measures and driver warning compliance. Warning compliance was approximated using the surrogate measure SR curve entry speed (SRspeed) as well as Public Road curve entry speed (PRspeed).

CHAPTER 4: RESULTS

Data Reduction

During the data reduction phase, some data needed to be removed from the data set based on certain parameters. If the participant passed a safety threshold point on the way to the SR curve without beginning to brake the vehicle, the experimenter would either instruct him or her to "brake", or the experimenter would apply the emergency brake. If either of these actions occurred, the TRT, BRT, and SRspeed would be dropped for that participant. Five participants required the verbal "brake" while one required the application of emergency brake (Table 4.1). These participants required this intervention for one run each; 4 occurring on their surprise stimulus presentation, 2 on the last stimulus presentation. Five of these were Baseline, one was Audio-Visual.

Another situation necessitating the removal of data points was the participants' foot location at warning onset. Using video in conjunction with pedal force readings, foot locations were determined to be either 1) on the throttle, 2) on the brake, 3) neither on the throttle or the brake. For a list of participants in the "foot on the brake" or "foot on neither" categories, please refer to Table 4.1. Of the 144 trials (48 participants each with 3 stimulus presentations), only 6 trials were categorized as foot on the brake (4%), and 1 had foot on neither (1%). This means that 95% of the trials were not affected by foot position. TRT and BRT were not examined for participants with their foot on the brake, and TRT was not included for the participant with her foot off of both pedals, and neither TRT nor BRT was included for one participant who applied the brake with his left foot. Adjusted cell counts after data point removal are included in Table 4.2.

Table 4.1: Descriptions of removed data points.

	Participant	Age	Gender	Order	Stimulus Presentation	Data Lost	Reason Data Lost
1	7	Younger	Female	3rd	B	TRT, BRT, Srspeed	Verbal "Brake"
2	8	Younger	Female	3rd	A-V	TRT	Foot on neither pedal
3	9	Younger	Female	2nd	A-V	TRT, BRT	Foot on brake
4	29	Older	Female	3rd	H-A-V	TRT, BRT	Foot on brake
5	33	Older	Female	2nd	A-V	TRT, BRT	Foot on brake
6	34	Older	Female	1st	B	TRT, BRT, Srspeed	Verbal "Brake"
7	37	Older	Male	1st	A-V	TRT, BRT, Srspeed	Experimenter Brake
8	41	Older	Male	1st	A-V	TRT, BRT	Left foot braking
9	41	Older	Male	2nd	B	TRT, BRT	Left foot braking
10	41	Older	Male	3rd	H-A-V	TRT, BRT	Left foot braking
11	45	Older	Male	1st	B	TRT, BRT, Srspeed	Verbal "Brake"
12	46	Older	Male	1st	B	TRT, BRT, Srspeed	Verbal "Brake"
13	48	Older	Male	3rd	B	TRT, BRT, Srspeed	Verbal "Brake"

Table 4.2: Adjusted participant counts for each stimulus presentation and objective dependent variable.

Throttle Reaction Time

	Stimulus Presented First in "Surprise" Scenario		
Age	Audio-Visual	Haptic-Audio-Visual	Baseline
Younger	8	8	8
Older	6	8	5

Throttle Reaction Time

	Overall Stimulus Presentation		
Age	Audio-Visual	Haptic-Audio-Visual	Baseline
Younger	22	24	23
Older	21	22	19

Brake Reaction Time

	Stimulus Presented First in "Surprise" Scenario		
Age	Audio-Visual	Haptic-Audio-Visual	Baseline
Younger	8	8	8
Older	6	8	5

Brake Reaction Time

	Overall Stimulus Presentation		
Age	Audio-Visual	Haptic-Audio-Visual	Baseline
Younger	23	24	23
Older	21	22	19

SR Curve Entry Speed

	Stimulus Presented First in "Surprise" Scenario		
Age	Audio-Visual	Haptic-Audio-Visual	Baseline
Younger	8	8	8
Older	7	8	5

SR Curve Entry Speed

	Overall Stimulus Presentation		
Age	Audio-Visual	Haptic-Audio-Visual	Baseline
Younger	24	24	23
Older	23	24	20

Research Question 1: Stimulus Presentation and Performance

Stimulus Presentation and Performance for the Surprise Stimulus Presentation

RQ 1.1. *How does driving performance compare between stimulus presentation groups based on the stimulus presentation received first in the "surprise" stimulus presentation?*

Several objective performance measures were gathered from participants for each of three stimulus presentations. Stimulus Presentation included three levels: 1) Audio-Visual, 2) Haptic-Audio-Visual, and 3) Baseline condition (no stimulus presentation). Three performance dependent variables were examined: 1) throttle reaction time (TRT), 2) brake reaction time (BRT), 3) Smart Road curve entry speed (SRspeed). Analyses of variance (ANOVAs) were conducted to determine differences in performance due to Stimulus Presentation.

The first set of analyses examined the data collected from each participant's first encounter with the SR curve. A between-subjects design was used to determine differences in performance due to stimulus presentation experienced in the first "surprise" stimulus presentation. In these analyses, Surprise Stimulus Presentation is treated as a between-subjects variable, whereas the next section will take into account participants' encounters with each of the three stimulus presentations.

Significant differences between Surprise Stimulus Presentations were found for TRT, BRT, and SRspeed (See full ANOVA tables in Appendix W.1). Means and standard errors calculated for each performance measure for the Surprise Stimulus Presentation are included in Table 4.3. The Bonferonni post-hoc test showed that the Baseline condition was significantly slower than the two presentations that included warning stimuli for TRT ($F[2, 37]=20.65$, $p<.0001$), for BRT ($F[2, 37]=9.85$, $p=.0004$), and for SRspeed ($F[2, 38]=12.08$, $p<.0001$). A summary of all significant findings for this between-subjects objective data analysis is included in Table 4.6. Means, standard errors, and post-hoc results for the reaction time dependent variables are displayed in

Figure 4.1. Figure 4.2 shows the results for the SRspeed measure, highlighting the difference between the mean speeds and the advisory speed of 15mph.

Table 4.3: Mean (M), n, and Standard Error (SE) for Surprise Stimulus Presentation performance measures (n is the number of measurements included out of 16 possible).

	Audio-Visual			Haptic-Audio-Visual			Baseline		
	M	n	SE	**M**	n	SE	**M**	n	SE
TRT (s)	**1.7**	14	0.3	**1.1**	16	0.3	**3.8**	13	0.4
BRT (s)	**2.9**	14	0.2	**2.8**	16	0.2	**4.4**	13	0.3
SRspeed (mph)	**19.6**	15	1.3	**19.6**	16	1.0	**27.0**	13	1.4

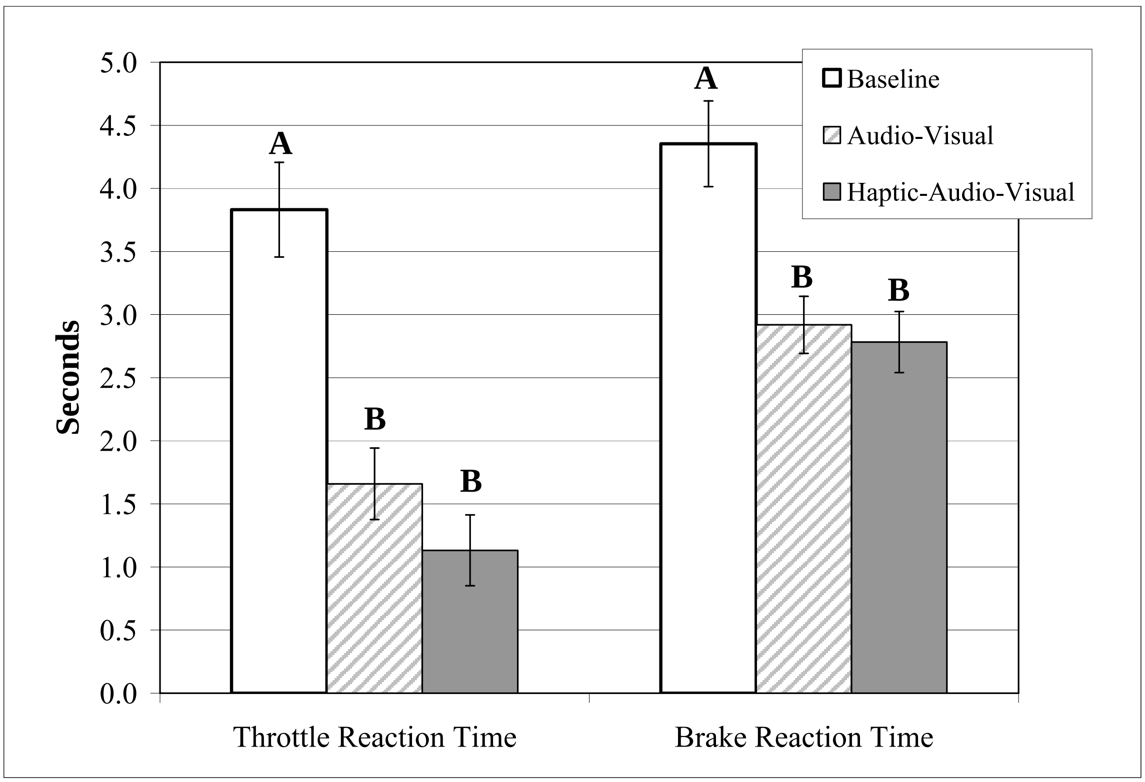


Figure 4.1: Bonferonni post-hoc results for Reaction Times by Surprise Stimulus Presentation (Means with the same letter are not significantly different).

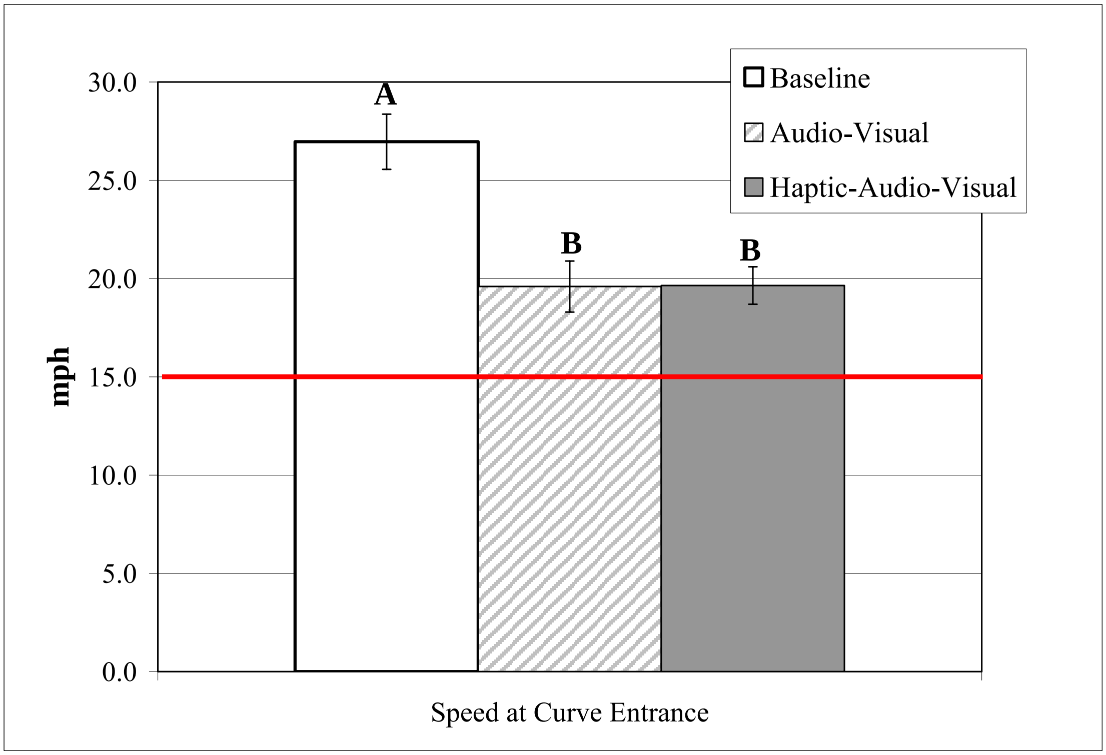


Figure 4.2: Bonferonni post-hoc results for Smart Road Curve Entry Speed by Surprise Stimulus Presentation (Means with the same letter are not significantly different).

Driver reactions to their first "surprise" encounter with the curve were examined using the video recordings. Views of the drivers' faces, hands, feet, and over the shoulder were used to see if there were any physical or verbal reactions to the surprise situation. Five main categories of reactions emerged from the videos:

1. No Reaction: Participant does not display a reaction, other than maneuvering the vehicle as one normally would, at the warning onset.
2. Delayed Reaction: Participant reacts, usually by smiling or saying something, several seconds after the warning onset.
3. Facial: Participant's facial expression changes (e.g., eyes widen, smiles, mouth open).
4. Body: Participant's body "jumps."
5. Verbal: Participant states or exclaims something at the warning onset.

Reactions were tallied for each surprise encounter. Participants may have demonstrated multiple responses. Therefore, results presented are not mutually exclusive (e.g. Facial and Verbal response simultaneously). Table 4.4 includes the frequencies for each type of reaction grouped by Stimulus Presentation. This table shows that the Haptic-Audio-Visual stimulus presentation received more Facial, Body, and Verbal reactions than the other two Stimulus Presentation conditions.

Table 4.4: Participant reactions to the "surprise" grouped by Stimulus Presentation.

	No Reaction	**Delayed Reaction**	**Facial**	**Body**	**Verbal**
Baseline	13	0	2	1	0
A-V	6	3	2	5	2
H-A-V	3	1	5	7	4

Overall Stimulus Presentation and Performance

RQ 1.2. *Overall, what changes in driving performance occur when the driver receives different stimulus presentations?*

As mentioned, a mixed-factors design was also utilized to evaluate data from participant encounters with all three stimulus presentations. An ANOVA showed significant differences between stimulus presentations for all three performance measures (Appendix W.2). A summary of significant results is included at the end of all sections discussing objective results (Table 4.7). Means, total cell counts, and standard errors of the dependent variables are calculated for each stimulus presentation and included in Table 4.5. Similar to the results of the between-subjects analysis, the Bonferonni post-hoc test showed that the Baseline condition was significantly slower than the two warning stimulus presentations for TRT ($F[2, 80]=160.32$, $p<.0001$). The Baseline condition was also significantly slower than the two warning stimulus presentations for BRT ($F[2, 81]=104.10$, $p<.0001$) (Figure 4.3). Finally, participants in the Baseline condition drove significantly faster than the two warning stimulus presentations (SRspeed $F[2, 86]=54.48$, $p<.0001$). The graph of the means for SRspeed also highlights the advisory speed of 15 mph with the bolded line (Figure 4.4).

Table 4.5: Mean (M), n, and Standard Error (SE) for each stimulus presentation overall.

	Audio-Visual			Haptic-Audio-Visual			Baseline		
	M	n	SE	**M**	n	SE	**M**	n	SE
TRT (s)	**1.0**	43	0.1	**0.7**	46	0.1	**3.8**	42	0.2
BRT (s)	**1.9**	44	0.2	**1.8**	46	0.2	**4.5**	42	0.1
SRspeed (mph)	**19.3**	47	0.6	**18.5**	48	0.5	**25.8**	43	0.7

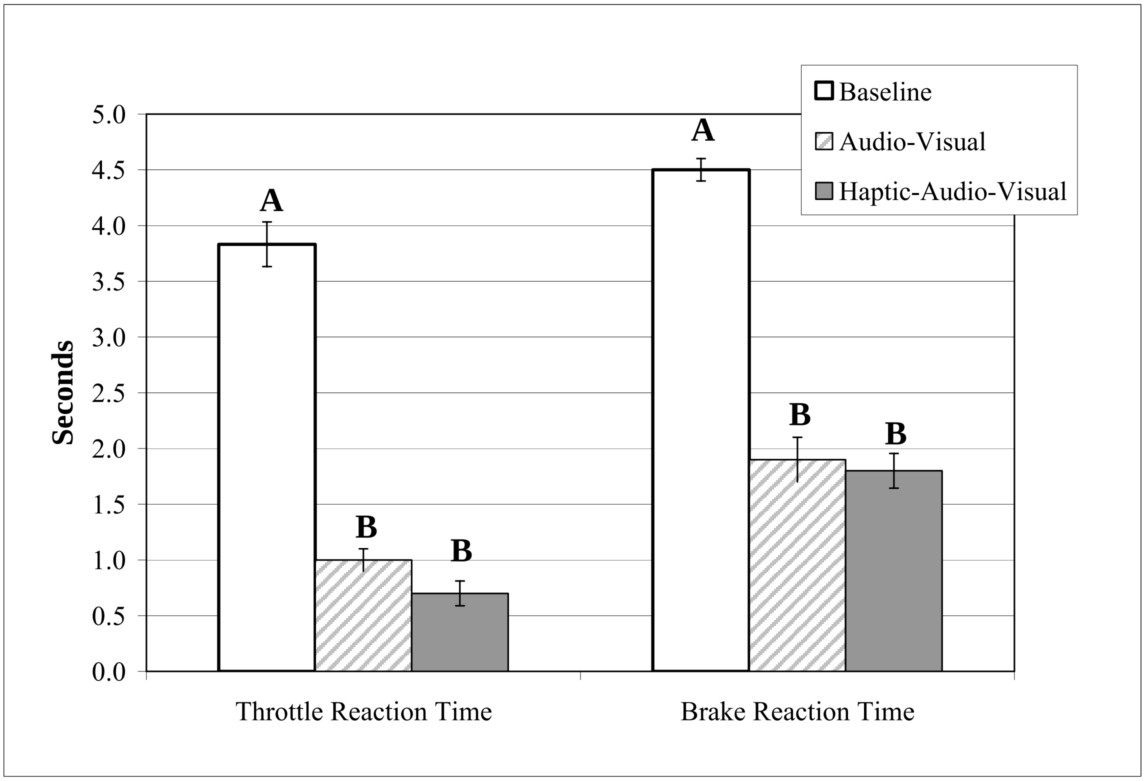


Figure 4.3: Bonferonni post-hoc results for Reaction Times by Stimulus Presentation (Means with the same letter are not significantly different).

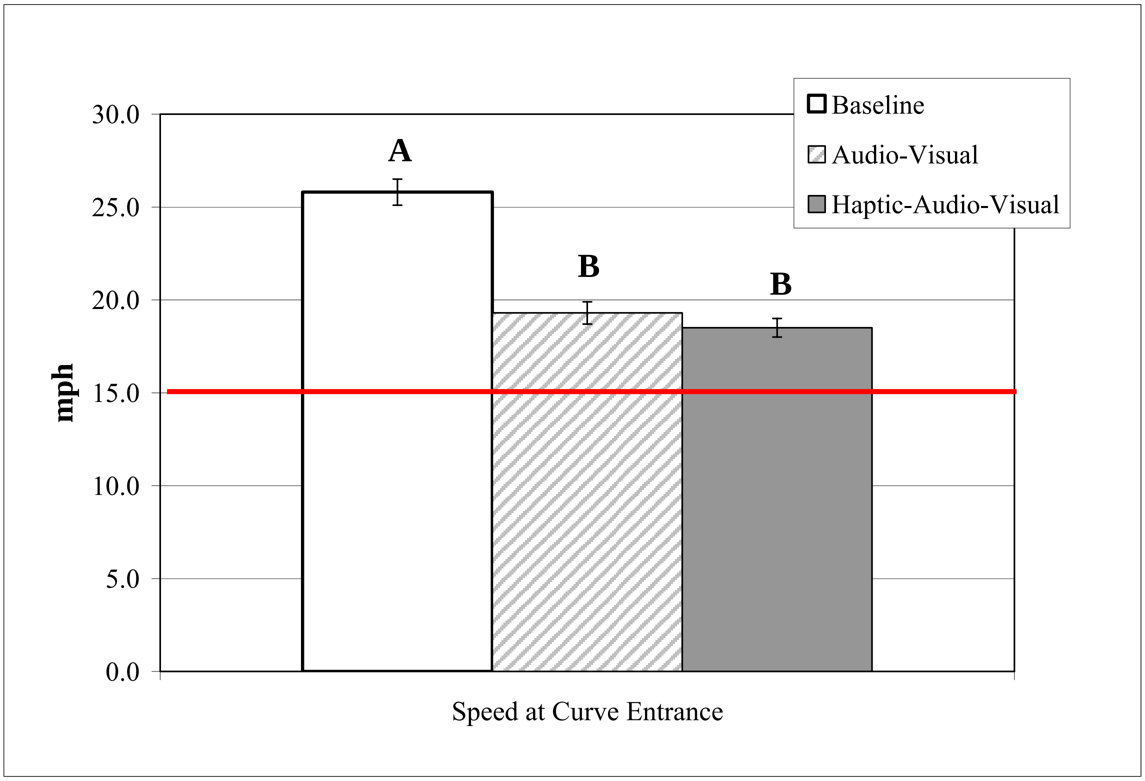


Figure 4.4: Bonferonni post-hoc results for Curve Speed Entry by Stimulus Presentation (Means with the same letter are not significantly different).

Performance for Each Run

RQ 1.3. *How does driving performance compare between the surprise and subsequent stimulus presentations within subject?*

Each participant experienced the SR curve three times. As noted, the first time they encountered the curve it was a "surprise." It was predicted that participants would demonstrate quicker TRT and BRT and SRspeed closer to the advisory speed on their second and third runs as compared to the first run. Means and standard errors for the different performance measures are graphed by run number in Figure 4.5 and Figure 4.6. An ANOVA was performed to examine Run, and the resulting Tables are included in Appendix W.3. Run was a significant main effect for BRT at $\alpha = 0.05$ ($F[2, 83]=3.97$, $p=.0225$). A Bonferonni post-hoc test on BRT found that Run 1 was significantly slower than Run 3. None of the other differences for the performance measures for each Run were significantly different.

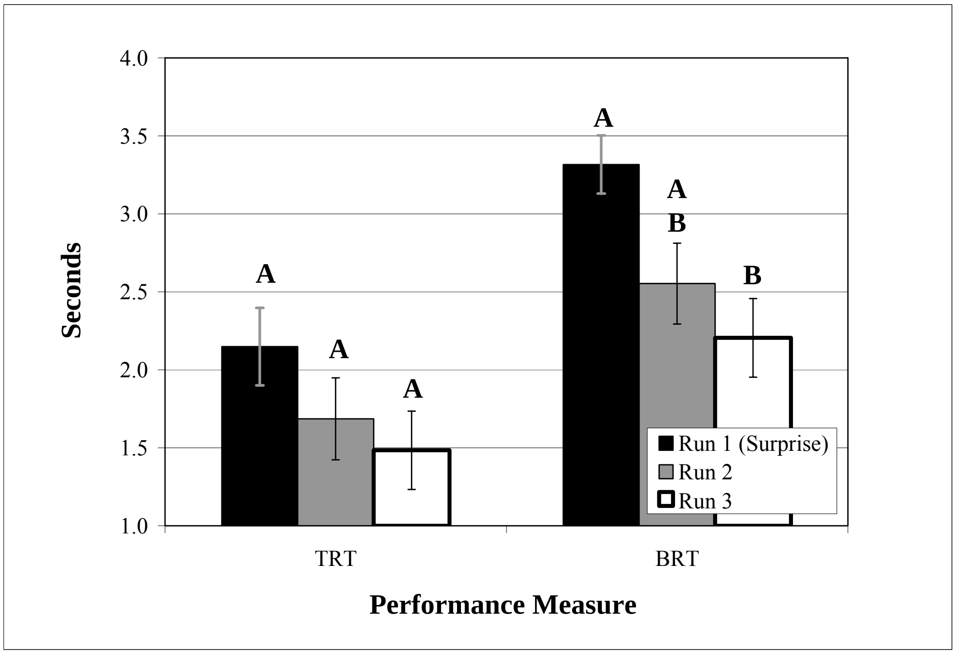


Figure 4.5: Bonferonni post-hoc results for Reaction Times by Run (Means with the same letter are not significantly different).

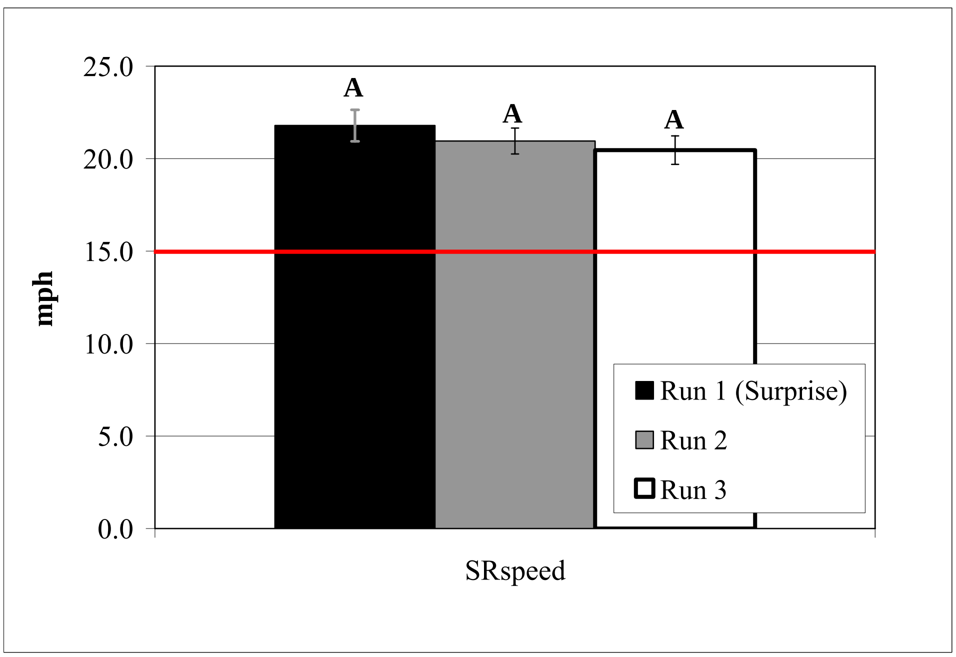


Figure 4.6: Bonferonni post-hoc results for Curve Entry Speed by Run (Means with the same letter are not significantly different).

Research Question 2: Age and Performance

Age and Performance

RQ 2.1. *How does driving performance differ between age groups?*

The participant variable Age was examined using an ANOVA to determine differences in performance between younger drivers (18-25 years old) and older drivers (>60 years old). SRspeed was significantly different based on Age for the between-subjects design, looking at only the stimulus presentation for each participants' surprise stimulus presentation ($F[1, 38]=9.05$, $p=.0046$) (Younger: M=23.9 mph, SE=0.96, Older: M=19.3 mph, SE=1.18) (See Appendix W.1 for full ANOVA tables).

Similarly, a significant main effect of Age was found for SRspeed using the mixed factors design including all three stimulus presentations for each participant (not just the surprise stimulus presentation), $F[1, 46]=7.42$, $p=.0091$ (Younger: M = 22.2 mph, SE=0.6, Older: M=19.8 mph, SE=0.6). Figure 4.7 includes means for SRspeed based on Age for the surprise stimulus presentation and for all stimulus presentations combined.

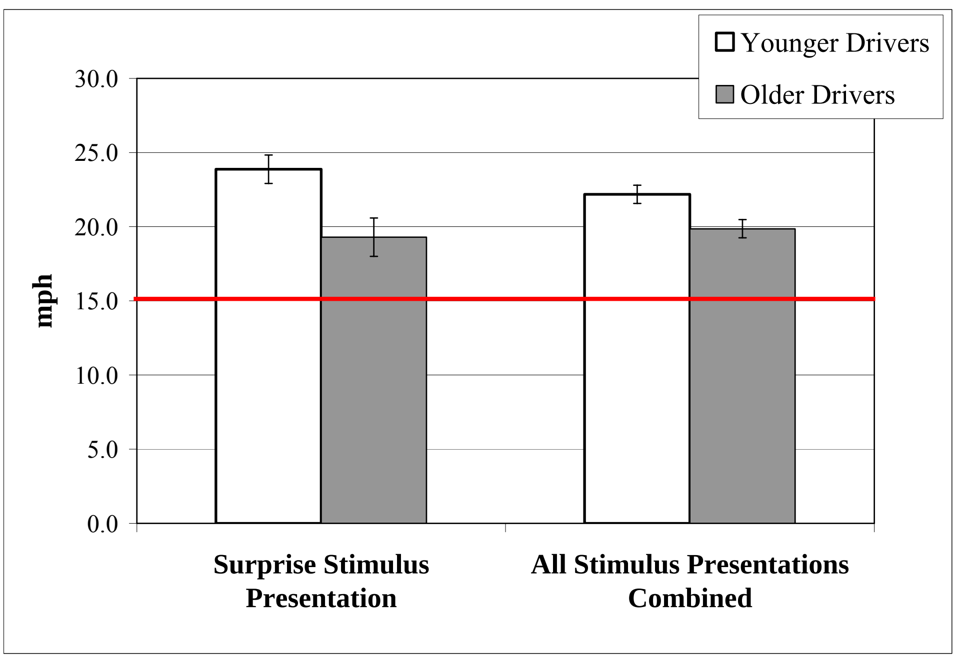


Figure 4.7: Means and standard errors for SRspeed by Age for the Surprise Stimulus Presentation and for All Stimulus Presentations Combined.

Age, Stimulus Presentation, and Performance

RQ 2.2. *In what ways do stimulus presentations affect driving performance of participants in different age groups?*

The interaction of Age and Stimulus Presentation was evaluated using an ANOVA. When looking at Surprise Stimulus Presentation as a nested variable, no significant interactions between Age and Surprise Stimulus Presentation were found (Appendix W.1). When analyzing Stimulus Presentation as a repeated measure, the Age x Stimulus Presentation interaction was only found to be significant for the TRT performance variable (F[2, 80]=3.90, p=.0242) (See full ANOVA tables in Appendix W.2). The significant interaction of Age and Stimulus Presentation for TRT is included in Figure 4.8.

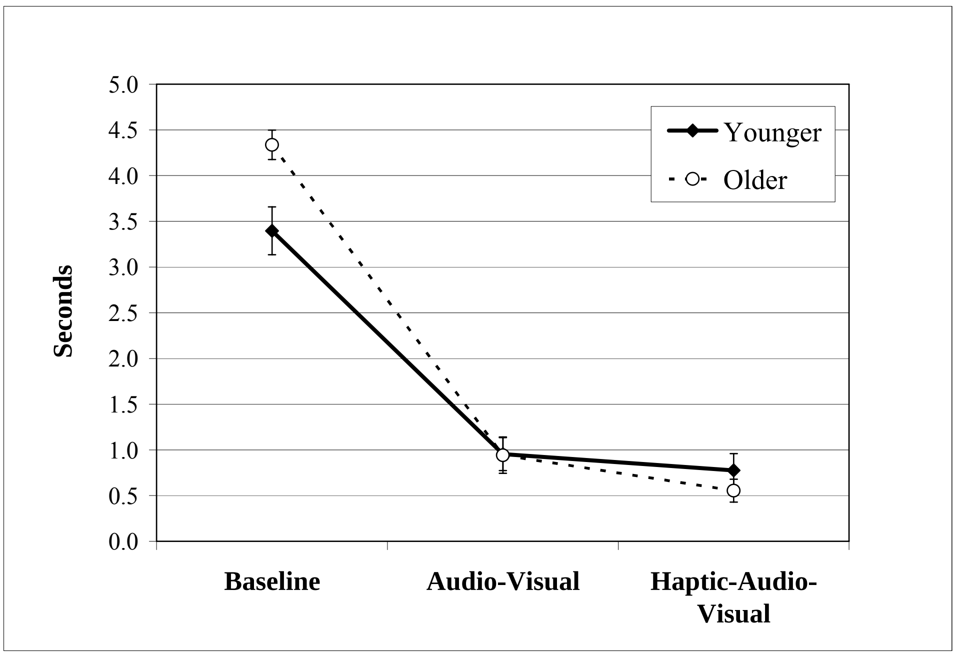


Figure 4.8: Interaction of Stimulus Presentation and Age for TRT.

Summary of Objective Measures Results

Two different ANOVAs, one between-subjects and one mixed factors, were performed to determine significant differences between the objective measures TRT, BRT, and SRspeed. Both ANOVAs addressed Research Questions 1 and 2 pertaining to Stimulus Presentation and Age. The following tables summarize all of the objective results, first from the between-subjects design (Table 4.6), and second from the mixed factors design (Table 4.7).

Table 4.6: Summary of significant main effects and interactions for the between-subjects objective measures ANOVA.

	Significance Summary per Objective Measure		
Source	**TRT**	**BRT**	**Srspeed**
Between			
Age			x
Surprise Stimulus Presentation	x	x	x
Age * Surprise Stimulus Presentation			
Participant (Age Surprise Stimulus Presentation)			

x = p < 0.05 (significant)

Table 4.7: Summary of significant main effects and interactions for the mixed factors objective measures ANOVA.

	Significance Summary per Objective Measure		
	TRT	**BRT**	**Srspeed**
Between			
Age			x
Participant (Age)			
Within			
Stimulus Presentation	x	x	x
Age * Stimulus Presentation	x		
*Stimulus Presentation * Participant(Age)*			

x = p < 0.05 (significant)

Power Analysis for Between-Subjects Objective Measures

Because sample sizes changed due to the inability to collect several objective dependent variables from participants, a power analysis was run using the PROC GLMPOWER procedure in the SAS statistical program. The between-subjects cell counts were tallied and 5 data points were lost; 3 in the Older Baseline condition cell and 2 in the Older Audio-Visual cell. Standard deviation of the mean squared error terms was used in the SAS GLMPOWER procedure to calculate the power of the analyses to detect a meaningful effect. For behavioral research, power of 0.8 is considered adequate

(Cohen, 2001). Table 4.8 includes computed power and computed N (entire sample) necessary to get a significant result with adequate probability (power = 0.8). The actual N for the study was 43 and for the non-significant findings the proposed numbers of participants to add to achieve power were too high to be feasible. Levels of power for Surprise Stimulus Presentation as an individual source were all adequate, ranging from 0.904 to 0.999. For Age and Age x Surprise Stimulus Presentation, however, the TRT and BRT analyses showed very low power of <0.3. Very large samples, some >1000 participants, would need to be added to detect a meaningful effect of Age or Age x Surprise Presentation for the reaction time and curve entry speed measures.

Table 4.8: Power analysis results for the between-subjects design categorized by each source (N Total is the whole sample size, not the n for each cell).

TRT			
Source	**Test DF**	**Actual Power**	**N Total Necessary to Achieve 0.8**
AGE	1	0.074	1548
SURPRISE STIMULUS PRESENTATION	2	0.999	43
AGE X SURPRISE STIMULUS PRESENTATION	2	0.304	172

BRT			
Source	**Test DF**	**Actual Power**	**N Total Necessary to Achieve 0.8**
AGE	1	0.192	301
SURPRISE STIMULUS PRESENTATION	2	0.974	43
AGE X SURPRISE STIMULUS PRESENTATION	2	0.161	301

Srspeed			
Source	**Test DF**	**Actual Power**	**N Total Necessary to Achieve 0.8**
AGE	1	0.831	44
SURPRISE STIMULUS PRESENTATION	2	0.992	44
AGE X SURPRISE STIMULUS PRESENTATION	2	0.076	1188

Research Question 3: Subjective Evaluation

RQ 3. *How will subjective ratings differ between the stimulus presentations and driver age groups?*

Stimulus Comprehension Interview

This Stimulus Comprehension Interview was a series of general probing questions administered after each encounter with the SR curve. Participant responses varied in content and level of detail. One participant interview, for the haptic-audio-video stimulus presentation, was lost due to interview recording equipment failure. To analyze the data, a rating system of High, Medium, and Low Comprehension was developed to categorize participants' level of understanding and feedback based on their interview. These three categories were assigned based on points tallied for responses based on three criteria: 1) Noticed stimulus, 2) Identified all components of stimulus correctly, 3) Identified proper response action. Participants meeting all three criteria received a score of High Comprehension, those meeting two were assigned Medium Comprehension, and those with one were categorized as Low Comprehension. A complete list of participant comments and criteria tallies is included in Appendix X.

Table 4.9 shows the total number of participants receiving each comprehension rating categorized by Stimulus Presentation. Following the Audio-Visual presentation, 26 participants (over half) received a High Comprehension score. The majority of interviews following the Haptic-Audio-Visual presentation, 28, received a Medium Comprehension score. Of the 28 participants who received a Medium rather than High rating for Haptic-Audio-Visual, 16 were due to not identifying all components of the stimulus correctly. Specifically, these participants did not mention the haptic component.

Table 4.9: Total number of participants receiving each stimulus comprehension rating (Low, Medium, or High) for the two stimulus presentations.

	Audio-Visual n=48	**Haptic-Audio-Visual n=47**
Low Comprehension	4	11
Medium Comprehension	18	28
High Comprehension	26	8

Post-Condition Questionnaire

The Post-Condition Questionnaire (Appendix G) asked participants to what degree they agreed with statements pertaining to five aspects of the warnings. An analysis of variance of the Likert-type ratings gathered in the Post-Condition Questionnaire determined whether there were significant differences between Stimulus Presentations and Age at $\alpha=0.05$ (Appendix W.4). There was a significant difference in ratings between age groups for the item, "If my car was equipped with a curve warning device, I would want this type of warning to be presented" ($F[1, 46]=4.65$, $p=.0364$). That same item had a significant interaction of Age by Stimulus Presentation ($F[1, 46]=6.16$, $p=.0.0168$). A summary table displaying the ANOVA sources and significance is included in Table 4.10. Mean ratings grouped by Age are included in Figure 4.9. Mean ratings grouped by Age and Stimulus Presentation are graphed in Figure 4.10. The means for the significant interaction of Age and Stimulus Presentation for the "want this type of warning" item are shown on this graph. An ANOVA of ratings for just the first Surprise Stimulus Presentation was not possible due to lacking degrees of freedom, however the means are graphed in Figure 4.11. Like the overall Stimulus Presentation means, the item with the largest difference in ratings was also "If my car was equipped with a curve warning device, I would want this type of warning to be presented." The direction for a few of the ratings changes between the mixed and between designs. For some items, Older participants rate the stimulus higher than Younger participants rated it for the surprise presentation, and then rate it lower than the Younger participants do for the overall stimulus presentation, and vice verse.

Table 4.10: Summary of significant main effects and interactions for the Post-Condition Questionnaire mixed factors ANOVA.

	Significance Summary per Statement				
Source	**1**	**2**	**3**	**4**	**5**
Between					
Age					x
Participant(Age)					
Within					
Stimulus Presentation					
Age*Stimulus Presentation					x
*Stimulus Presentation*Participant(Age)*					

x = p < 0.05 (significant)

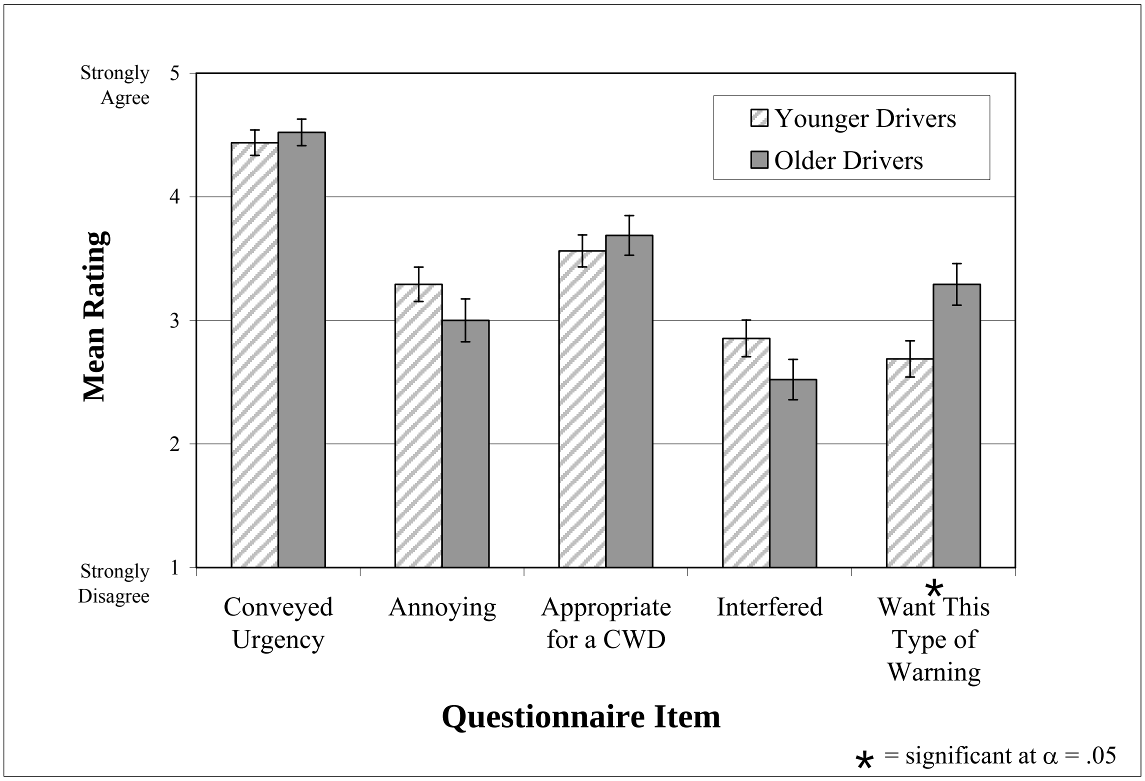


Figure 4.9: Mean ratings and standard errors for Post-Condition Questionnaire Items by Driver Age

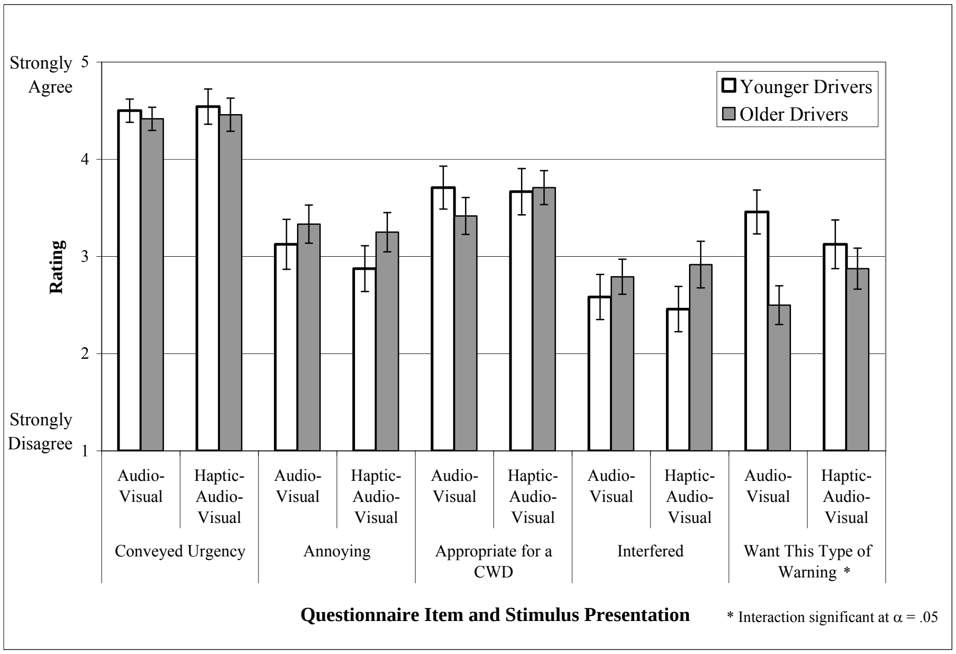


Figure 4.10: Mean ratings and standard errors for Post-Condition Questionnaire items (Age by Stimulus Presentation).

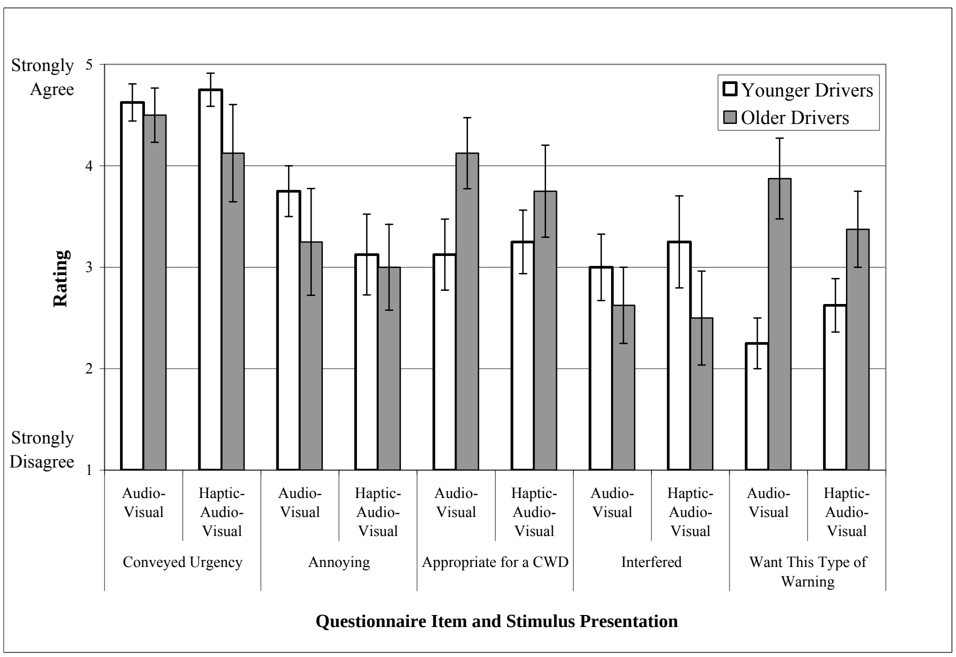


Figure 4.11: Mean ratings and standard errors for Post-Condition Questionnaire items (Age by Surprise Stimulus Presentation).

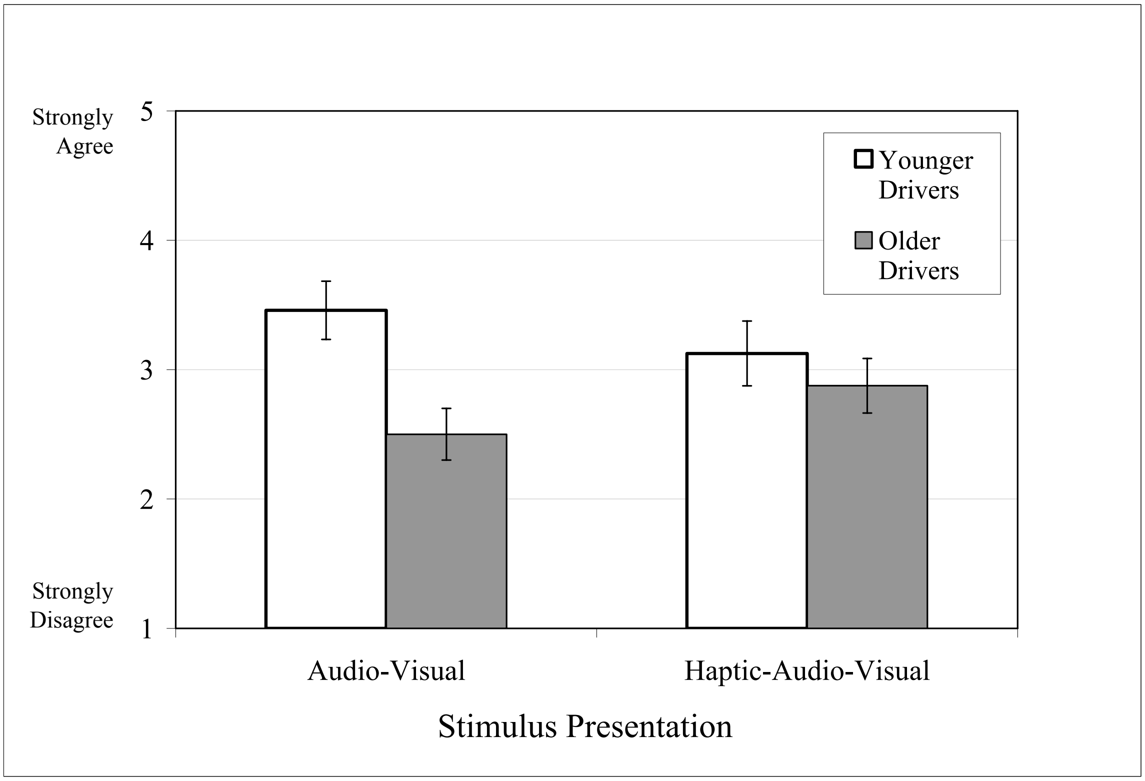


Figure 4.12: Mean ratings for the significant interaction of Age and Stimulus Presentation for the item, "If my car was equipped with a curve warning device, I would want this type of warning to be presented."

Participants wrote responses to the open-ended Post-Condition Questionnaire item, “Would you change something about the warning? If yes, what would it be?” A content analysis of all written responses was performed to analyze the frequency with which comments pertaining to a similar theme occurred. Because this question encouraged critique and not praises for the system, the codes for the content analysis were created based on design guideline categories. These categories were gathered from previous curve warning and human factors design guidelines created by Pomerleau (1999) and NHTSA (1996). Table 4.11 lists each code, the source for that code as well as its operational definition. Table 4.12 shows the frequency of occurrences for each code by Stimulus Presentation. All participant responses to this question are included in Appendix Y.

Table 4.11: Codes and code definitions developed for the Post-Condition Questionnaire content analysis based on human factors design guidelines.

Code Name	Definition	Source
Time Correctly	The curve warning device activates early enough to allow the driver to respond properly.	Pomerleau [C-2]
Avoid Startling	The CWD should be designed so that it is not so intense that it overloads the driver's sensing capabilities or that it evokes a startle response from the driver.	Pomerleau [C-36]
Be Detectible/ Discriminable	The CWD should be designed so that it is not masked by other stimuli present while driving. The CWD should also be distinct from other in-vehicle warnings.	Pomerleau [C-34, C-35]
Be Understandable/ Indicate Proper Action	The CWD should be interpretable and indicate the appropriate driver response without causing driver confusion.	Pomerleau [C-38]
Avoid Distracting Driver	The CWD should be presented in a way that does not overload the driver's processing capabilities while engaging in the driving task.	Pomerleau [C-32]
Convey Urgency Appropriately	The modality and characteristics of the stimuli should convey the urgency of the danger.	Pomerleau [C-33]
Be Adjustable	The CWD should be adjustable in a range that does not compromise system effectiveness.	Pomerleau [C-41]
Train Properly	Users should receive orientation to the system through documentation, video, or hands-on training.	Pomerleau [C-51]
Design Auditory Stimulus Properly	Audio level, quality, duration, and integration with other stimuli (for example, tone prior to speech) should follow human facators guidelines.	NHTSA (1996)
Design Visual Stimulus Properly	Visual stimulus size, color, intensity, symbols, and location should follow human factors guidelines	NHTSA (1996)
Remove Auditory Stimulus	User desires the removal of the auditory stimulus.	
Remove Visual Stimulus	User desires the removal of the visual stimulus.	
Remove Haptic Stimulus	User desires the removal of the haptic stimulus.	
Include Haptic Stimulus	User desires the addition of the haptic stimulus.	

Table 4.12: Frequency for each code in responses to the Post-Condition Questionnaire open-ended item, ""Would you change something about the warning? If yes, what would it be?"

Audio-Visual		Haptic-Audio-Visual	
Code	**Freq.**	**Code**	**Freq.**
Design Auditory Stimulus Properly	18	Design Auditory Stimulus Properly	12
Avoid Startling	8	Design Visual Stimulus Properly	9
Time Correctly	6	Time Correctly	7
Remove Auditory Stimulus	6	Be Understandable / Indicate Proper Action	6
Be Understandable / Indicate Proper Action	4	Avoid Startling	5
Design Visual Stimulus Properly	4	Remove Auditory Stimulus	5
Convey Urgency Appropriately	3	Be Adjustable	3
Be Adjustable	3	Avoid Distracting the Driver	3
Be Detectible/ Discriminable	2	Be Detectible/ Discriminable	2
Avoid Distracting the Driver	2	Convey Urgency Appropriately	1
Train Properly	2	Train Properly	1
Remove Visual Stimulus	2	Remove Visual Stimulus	1
Include Haptic Stimulus	1	Remove Haptic Stimulus	1
Remove Haptic Stimulus	0	Include Haptic Stimulus	0

One more specific topic fell under the most frequently occurring code, "Design Auditory Stimulus Properly." Nineteen out of the 30 of these comments were that the volume was too high or should be lowered.

Curve Warning Acceptance Questionnaire

The Curve Warning Acceptance Questionnaire (Appendix H) gathered user ratings of the curve warnings in general, not about each stimulus presentation separately. An ANOVA for this measure indicated a significant difference between younger and older ratings for three of the nine questionnaire items (Appendix W.5). Figure 4.13

displays the means and standard errors for each item as well as which of these items were rated significantly different between age groups. Older participants rated curve warnings more favorably than younger participants did on 8 of the 9 questionnaire items.

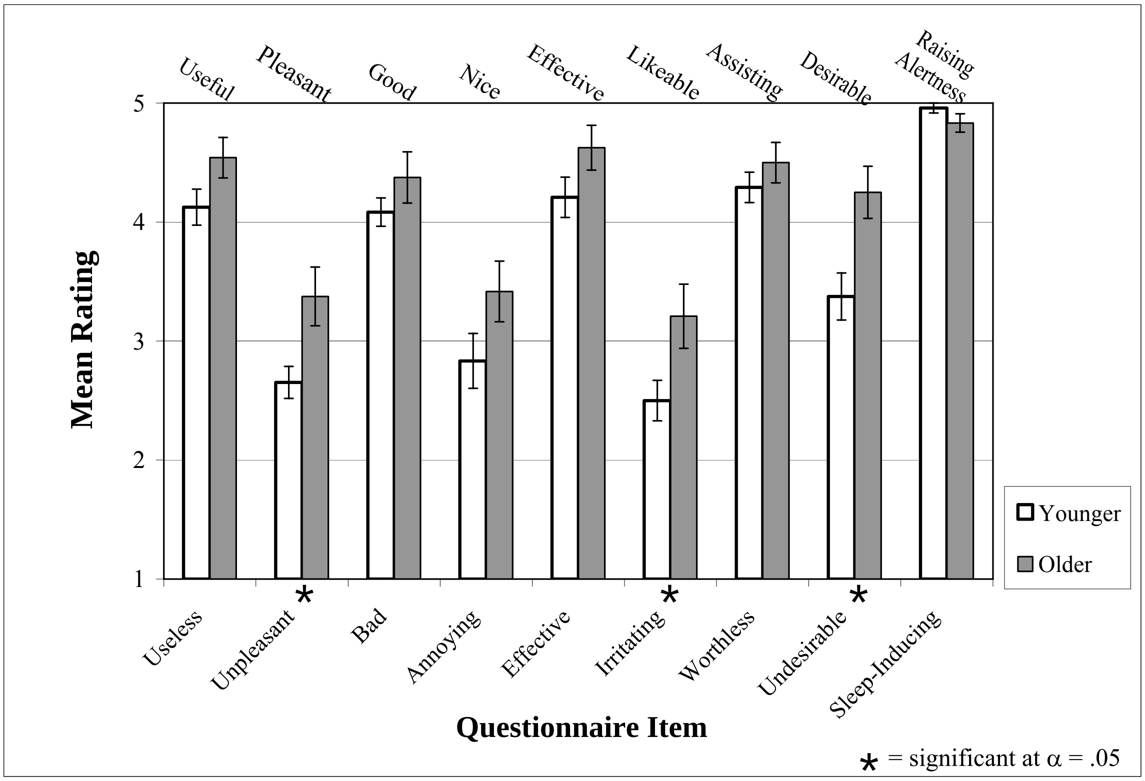


Figure 4.13: Mean ratings and standard errors for Curve Warning Acceptance Questionnaire items by Age.

After completing the Curve Warning Acceptance Questionnaire, participants were asked to rank the three stimulus presentations. They verbally stated which stimulus presentation they liked best, and which they liked least. Tallies of votes for each of the stimulus presentations are displayed in Figure 4.14. Fifty-seven percent of Haptic-Audio-Visual rankings were in the "Most Liked" category, as liking most and 30% of Audio-Visual rankings were "Most Liked." Fifty-six percent of Baseline rankings were in the "Liked least" category, but many indicated that they liked whatever they received in the first surprise stimulus presentation least because it was a surprise. Nearly 60% of participants specified the stimulus presentation they received first in the surprise stimulus presentation as the presentation they liked least (Figure 4.15).

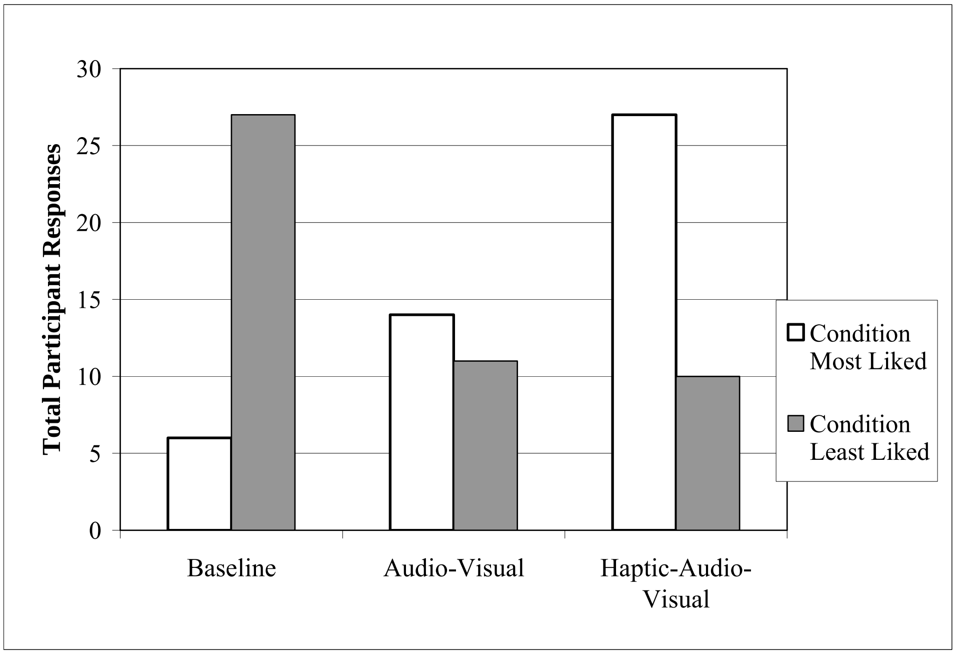


Figure 4.14: Total participant responses categorizing stimulus presentations as "most liked" and "least liked."

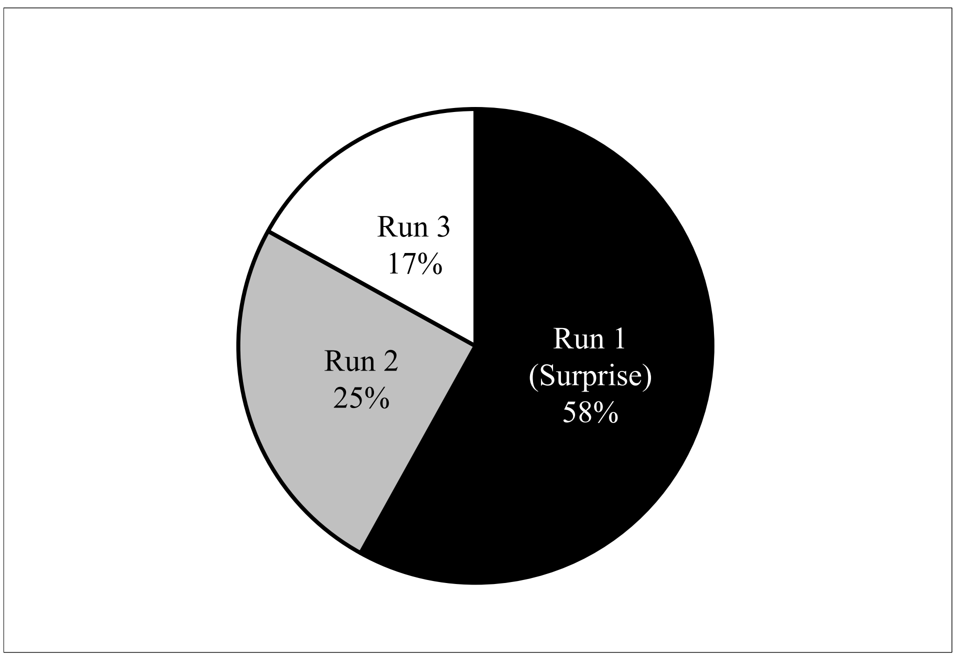


Figure 4.15: Percentages in which the stimulus presentation chosen as least liked was presented in each Run.

Research Question 4: Hazard Perception and Risk-Taking Style

Hazard Perception

The Hazard Perception Questionnaire (Appendix I), which included five items pertaining to driver perceptions of hazards ranked on a Likert-type scale, was completed by each participant. Participants reported to what degree they agreed with statements on a scale from 1 (Strongly Disagree) to 5 (Strongly Agree). Mean ratings for each item by age group are displayed in Figure 4.16. ANOVAs were performed to see whether differences in mean ratings were significant based on Age and all ANOVA tables are presented in Appendix W.6. None of the items of the questionnaire had mean ratings that were significantly different based on Age.

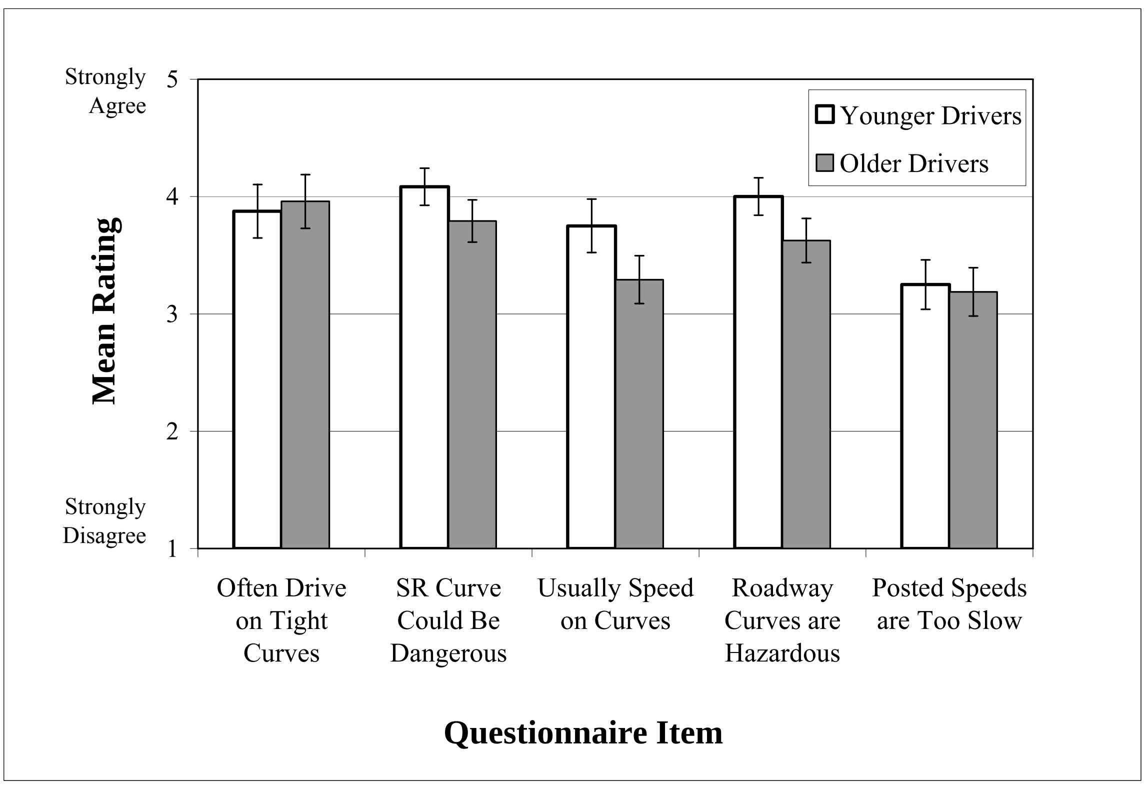


Figure 4.16: Mean ratings and standard error bars for Hazard Perception Questionnaire items by Age.

Also as part of the Hazard Perception Questionnaire, drivers who experienced a stimulus presentation in their first run down the road verbally asked, “Would you say that you first became aware of the sharp curve (turnaround loop) at the end of the SR *prior* to the warning, *during* the warning, or *after* the warning?” The majority of participants said that they noticed the curve during the warning Figure 4.17.

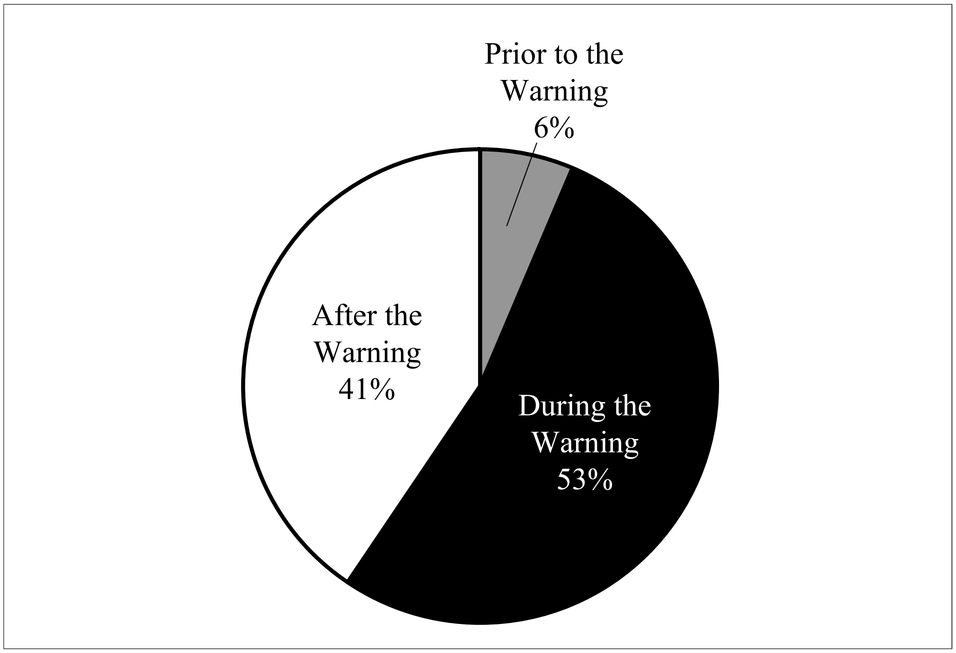


Figure 4.17: Response percentages for the Hazard Perception Questionnaire Item, "When did you first become aware of the sharp curve (turnaround loop) at the end of the Smart Road?"

Driver performance was compared between participants’ responses to when they first noticed the curve on the SR. The two participants reporting that they saw the curve prior to the warning did reach lower curve entrance speeds, though their speed was not significantly different than participants who noticed the curve during and after the warning. Means and standard errors are graphed in Figure 4.18.

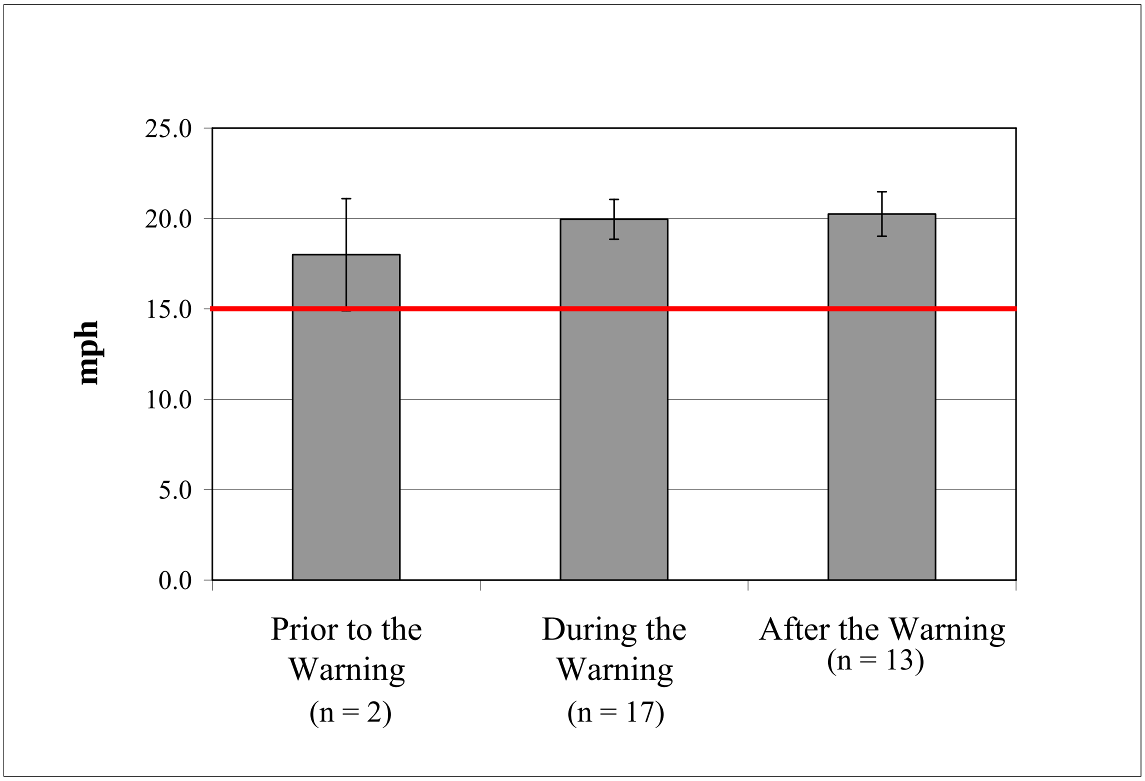


Figure 4.18: Mean SRspeed and standard errors for participants reporting that they "First noticed the curve: Prior to the warning," "During the warning," and "After the warning."

Hazard perception was also compared with SRspeed and PRspeed to see if there was a relationship between this measure and advisory speed compliance. A Pearson correlation found that the sum of participants' Hazard Perception Questionnaire rankings (HP Score) did not have a significant relationship with PRspeed or with SRspeed. Also, individual questionnaire items were not correlated with curve entry speeds. A full Pearson correlation matrix for the Hazard Perception questionnaire is included in Table 4.13.

The Pearson correlation matrix in Table 4.13 also includes the correlation between PRspeed and SRspeed. The two curve entrance speed measures were significantly related at $\alpha = 0.05$, though the correlation coefficient was still quite low at .43. This indicates that a driver's curve driving performance on the SR is related to his or her curve driving performance on a "real road."

Table 4.13: Pearson Correlation for Hazard Perception Questionnaire Ratings and overall Score with Public and Smart Road Curve Entry Speeds (Significant cells are highlighted).

		PRspeed	SRspeed
Hazard Perception Questionnaire Items	**Drive**	0.02	0.01
	p-value	0.9173	0.9535
	N	48	44
	Dangerous	0.04	0.26
	p-value	0.7998	0.0900
	N	48	44
	Speed	-0.24	-0.13
	p-value	0.1007	0.4161
	N	48	44
	Hazardous	0.11	0.10
	p-value	0.4450	0.5236
	N	48	44
	Signs	-0.09	-0.01
	p-value	0.5589	0.9389
	N	48	44
	Hazard Score	-0.09	0.07
	p-value	0.5535	0.6537
	N	48	44
	SRspeed	0.43	1.00
	p-value	0.0037	
	N	44	

: significant at α = 0.05 (shaded cells)

Risk-Taking Style

Like the Hazard Perception Questionnaire, the Risk-Taking Style Questionnaire (Appendix J) was completed once by each participant. Mean ratings for each item by age group are displayed in Figure 4.19 and in Figure 4.20. ANOVAs were performed to see whether differences in mean ratings were significant based on Age (Appendix W.7). Eight of the 12 items had significantly different means based on Age.

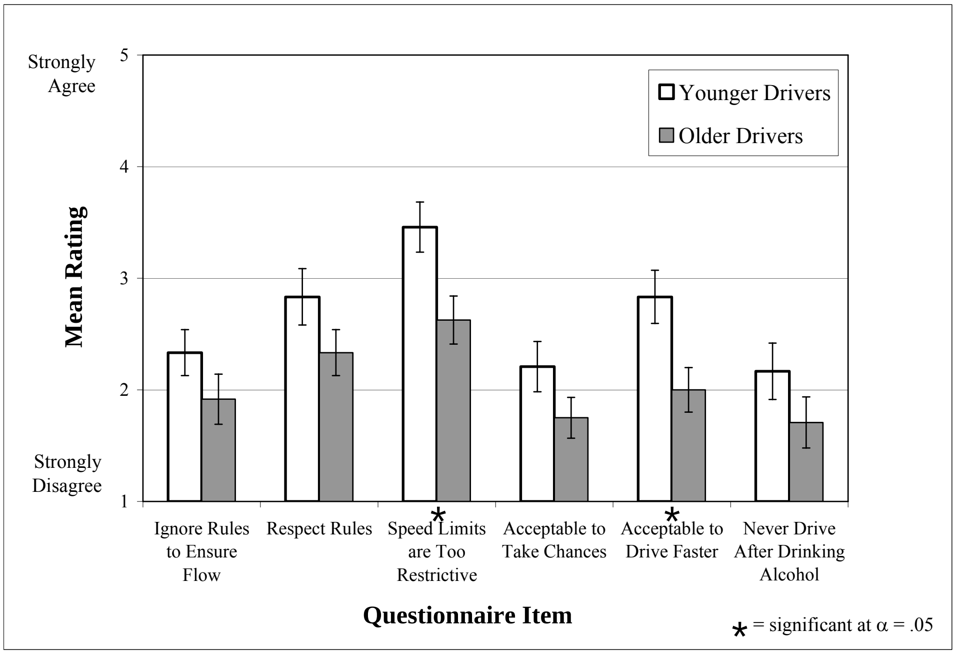


Figure 4.19: Mean ratings and standard errors for Risk-Taking Style Questionnaire items by Age (Questions 1-6).

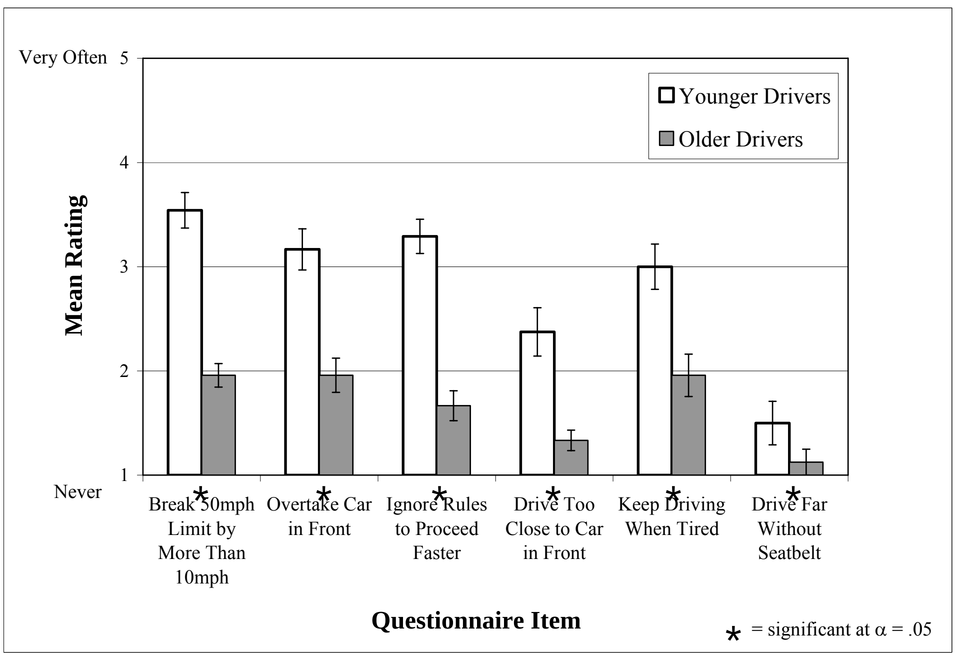


Figure 4.20: Mean ratings for Risk-Taking Style Questionnaire items by Age (Questions 7-12).

In addition to these Risk-Taking Style analyses, an overall Risk Score for each participant was also obtained by adding all of the individual item ratings. Two of the questionnaire items were flipped so that the "riskier" behavior was at the higher end of the scale and the "less risky" behavior was at the lower end of the scale, so that a higher Risk Score indicated participants with a higher propensity for risk-taking. The maximum possible Risk Score was 60, the minimum possible was 12. Mean Risk Scores for younger and older participants are graphed in Figure 4.21.

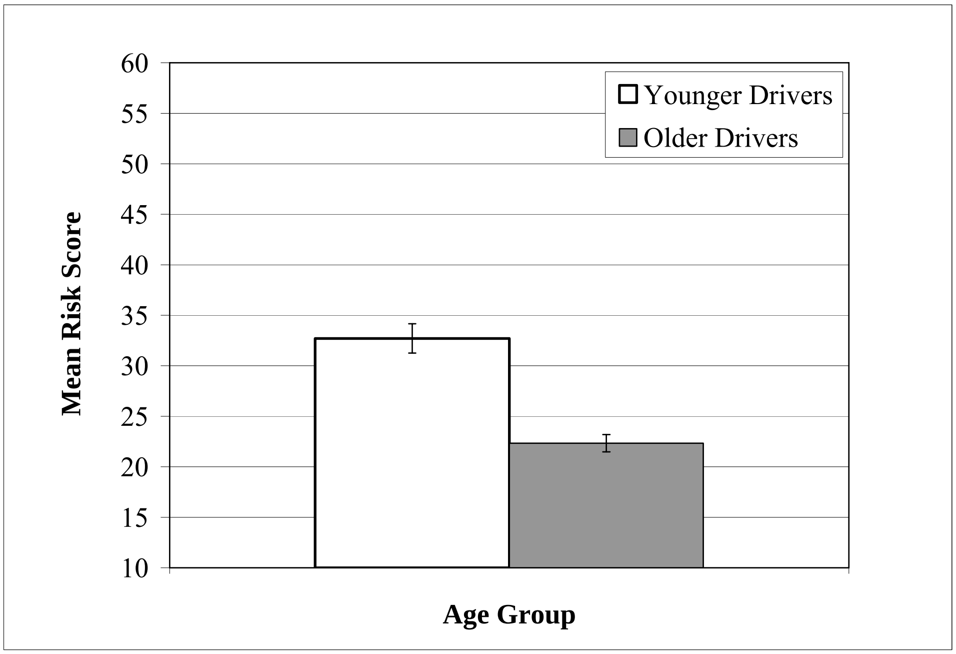


Figure 4.21: Mean Risk Scores by Age.

Risk-taking style questionnaire items were also compared with SR curve entry speed (SRspeed) and public road curve entry speed (PRspeed) to see if there was a relationship between risk-taking style and advisory speed compliance. A Pearson correlation indicated several significant relationships at $\alpha = 0.05$ (Table 4.14). Seven out of the 12 items correlated in a positive direction with PRspeed, thus ratings toward the "riskier" end of the scale corresponded with higher Public Road curve entry speeds. Only the item, "If you are a good driver it is acceptable to drive a little faster" correlated with the SR curve entry speed, though the Pearson coefficient was low at 0.36. Finally, Risk Score was weakly but significantly correlated with SRspeed, and Risk Score was positively correlated with PRspeed.

Table 4.14: Pearson Correlation for Risk-Taking Style Questionnaire Ratings and overall Score with Public and Smart Road Curve Entry Speeds (Significant cells are highlighted).

Risk-Taking Style Questionnaire Items		PRspeed	SRspeed
	Ignored	0.37	0.04
	p-value	0.0090	0.7737
	N	48	44
	Respected	0.17	0.09
	p-value	0.2454	0.5680
	N	48	44
	Restrictive	0.30	0.08
	p-value	0.0368	0.6002
	N	48	44
	Chances	0.51	0.19
	p-value	0.0002	0.2184
	N	48	44
	Faster	0.45	0.36
	p-value	0.0015	0.0151
	N	48	44
	Alcohol	0.12	0.14
	p-value	0.4291	0.3484
	N	48	44
	Risk Score	0.53	0.30
	p-value	0.0001	0.0458
	N	48	44

Risk-Taking Style Questionnaire Items (cont'd)		PRspeed	SRspeed
	Fifty	0.27	0.23
	p-value	0.0643	0.1383
	N	48	44
	Overtake	0.45	0.28
	p-value	0.0014	0.0622
	N	48	44
	Ignore	0.29	0.24
	p-value	0.0437	0.1164
	N	48	44
	Tailgate	0.51	0.24
	p-value	0.0002	0.1096
	N	48	44
	Tired	0.25	0.21
	p-value	0.0896	0.1648
	N	48	44
	Seatbelt	0.13	0.10
		0.3663	0.5048
		48	44

(shaded): *significant at* $\alpha = 0.05$

CHAPTER 5: DISCUSSION

Research Questions Revisited

Research Question 1: Stimulus Presentation and Performance

H1.1. *Participants presented with a curve warning stimulus will have quicker throttle and brake reaction times and greater speed compliance than those not receiving a warning.*

Not surprisingly, participants demonstrated significantly quicker reaction times and more appropriate curve entry speeds when presented with the curve warning stimuli (Audio-Visual and Haptic-Audio-Visual) than when receiving no stimuli (Baseline condition). This finding was consistent with previous literature showing improved performance with the presence of in-vehicle warnings (Comte & Jamson, 2000; Dingus et al., 1997; Hanowski et al., 1999; Neurauter, 2004; Uno & Hiramatsu, 2001). Interestingly, this was true when the measures were taken in the surprise stimulus presentation and when they were repeated within subjects after participants had previous experience with the curve. Participants, even when already aware of the curve, had quicker reaction times as well as more appropriate curve entry speed when presented with a warning. This may indicate that participants benefited from the warnings' explicit indication of the advisory speed. The results from Neurauter (2004) also showed that participants performed better as well as preferred stimuli that indicated the desired speed than those stimuli that did not provide instructions as per advisory speed. Additionally, the visual component of the warnings indicated the desired speed and the stimulus did not terminate until the driver reached the desired speed. Some participants expressed their awareness of this feature and the incentive it created to slow down to the advisory speed. Lee, Gore, and Campbell (1999) found that explicit command messages resulted in higher compliance than notifications, and warning design guidelines include the recommendation that warnings should indicate the desired response action (Wogalter et al., 2002).

Even though participants who received a stimulus had more appropriate curve entry speeds than those in the Baseline condition, their speeds remained higher than the advisory speed of 15 mph. Neurauter (2004) found this as well, where 75% were within 5 mph of the advisory, and 100% were within 10 mph, but most were above the advisory speed. In the current study, speed was only taken from one point, the curve entrance, rather than several points along the curve. Neurauter (2004) found that speeds for the curve apex and curve exit reflected the speed for curve entry. The formula used to calculate the advisory speed warning onset point utilizes the curve apex as the point of interest (Appendix L). By examining curve entrance speed rather than apex, the measure may not indicate the lowest speed the driver reached. The curve entrance measure, however, may point to the drivers' readiness to comply with the warning rather than abiding by physical necessity of the curve.

Another consideration in looking at these results is whether the difference between curve entrance speed for drivers who received a warning and drivers who did not, though significant, is a meaningful difference. The difference between the mean speeds for Baseline versus the warning presentation conditions was about 5 mph. Though this does not seem like a drastic change in curve entrance speed there are several issues to consider before deciding whether it is meaningful. First, as mentioned in previous sections, six of the participants required experimenter intervention to ensure a safe driving maneuver. Data from these participants were then removed from analyses, and thus the "poorest" driver performance responses were not included in the results. If the data from poorer drivers were able to be examined, a larger effect of warning presence may be seen, but because of the safety constraints of the project this hypothesis could not be proven.

Secondly, 5 mph is the difference between mean curve entrance speeds, not reflecting more extreme differences that resulted for individual drivers. For 16 out of 42 participants, or 38%, there was a difference of more than 10 mph between their Baseline condition and warning presentation, the most extreme being 34 mph in the baseline condition and then 12 mph in the warning condition. Using AASHTO calculations for curve characteristics and curve advisory speeds (AASHTO, 2001), 10 mph can mean the difference between being able to maneuver a curve and running off the road.

***H1.1. (cont'd).** Participants receiving the Haptic-Audio-Visual stimulus in the first "Surprise" stimulus presentation will not perform as well as those receiving the Audio-Visual stimulus.*

Contrary to the hypothesis, TRT and BRT were slightly slower for the Audio-Visual presentation, though differences between this presentation and the Haptic-Audio-Visual one were not significant. This hypothesis specifically referred to the results from the surprise stimulus presentation, and so the between-subjects analysis was used. Results also showed no significant differences between the two stimulus presentations in terms of SR curve entry speed.

Although some participants expressed surprise at the onset of the Haptic-Audio-Visual stimulus when the pedal moved, no participant expressed confusion in its meaning as predicted based on the results of Neurauter (2004) or Lloyd et al. (1999). This may be due to the presence of the auditory and visual modes in conjunction with the haptic stimulus, each providing more details pertaining to the proper driver response. No measurements were used to examine the driver interpretations of the haptic component when isolated.

***H1.2.** Overall, participants will demonstrate quicker reaction times and closer curve advisory speed compliance when receiving the Haptic-Audio-Visual stimulus than they will when receiving the Audio-Visual and Baseline conditions.*

Participant reaction times were slightly quicker and curve entrance speeds were closer to the advisory speed for the stimulus including the haptic mode; however these differences were not found to be significant as predicted based on Manser (2004) and Neurauter (2004). Part of the explanation for this may be the lack of detection of the stimulus by many of the drivers. A number of participants reported that they did not feel the haptic stimulus. Without noticing the push-back, the two warnings would be perceived as identical, and the results seem to indicate that interpretation. Though the pedal force was double that of previous simulator studies (Janssen & Nilsson, 1993; Neurauter, 2004), this design still may not be salient enough for application in a bumpy, on-road setting with many competing stimuli. Also, this form of haptic display may not be the most appropriate display for conveying curve warning information, and other haptic feedback designs such as pulses in the pedal or seat shakers should be considered for testing.

H1.3. *Participant performance will improve with each subsequent encounter with the curve and Stimulus Presentation.*

This hypothesis was only found to be true for the BRT measure. The first "surprise" stimulus presentation had slower mean BRT than the third stimulus presentations by about 1 second. Improved BRT may have been due to increased experience and comfort with the driving and warning situations. The lack of significant difference between SRspeed for the first and last runs, however, may mean that the change in BRT did not affect overall performance. Drivers were still able to comply with the warning on the first trip as well as they did on the last.

One interesting finding relating to subsequent runs was that even though the audio and visual components of the stimulus presentations were identical each time they were presented, a number of participants expressed the opinion that something about the warning had changed from their first surprise encounter with the stimulus. Fourteen of the possible 48 comments pertaining to the second experience of a warning, or 29%, indicated that something about the stimuli had changed. Specific comments included that the audio did not seem as loud, the visual did not seem as bright, or the warning was activated sooner the second time they experienced these stimuli as compared to the first time they experienced them. Though the stimuli were presented the same way each time, the surprise element associated with the first encounter may have amplified the sensation of the stimuli to the participants. As participants adapted to the presence of the warning and its display features, they may have found the display to be less harsh.

Research Question 2: Age and Performance

H2.1. *Older drivers will have slower reaction times but higher compliance with curve entry speed.*

Surprisingly, older participants did not have significantly slower reaction times than younger participants as shown in Neurauter (2004) and Warshawsky-Livne and Shinar (2002). Younger participants, who have been shown to exhibit lower compliance with warnings (Neurauter, 2004; Uno & Hiramatsu, 2001), may have been less inclined to follow warning instructions thus influencing their reaction times at stimulus onset as well.

Another difference in performance by age occurred in the experimenter safety controls executed in the participant sessions. Five of the 6 participants who received either a verbal "brake" or experimenter brake application to slow down were older participants. The necessity of this safety measure may have occurred because of slow reaction time, confusion, or a combination of both. Though the data for these participants were not included in analyses, the count of these occurrences suggests an age difference in performance. By removing these data, poorer drivers may have been deselected, and these drivers may be the ones who would benefit the most from a CWD. Due to the safety considerations involved with performing an on-road project, though, the interventions were necessary. By performing the study in a driving simulator, more dangerous scenarios could be allowed to examine the benefits of the device in close-call situations for poorer drivers.

As hypothesized, though, older drivers had significantly slower curve entry speeds than younger drivers. This may relate to some "person variables," such as risk-taking style, which will be discussed in following sections.

H2.2. Performance between stimulus presentations will stay consistent for both age groups, though younger participants may perform better with Haptic-Audio-Visual than older ones.

Age and stimulus interactions were not found to be significant except for TRT when examining Stimulus Presentation as a repeated measure. For this measure, older participants had a slower mean TRT than younger participants for the Baseline condition and then quicker mean TRT than younger drivers for the Haptic-Audio-Visual stimulus presentation. This may suggest that this curve warning stimulus was more of an aid to older drivers than younger drivers. As mentioned in the literature review, Uno and Hiramatsu (2001) previously found older drivers to benefit more than younger drivers when presented with early intersection warnings.

Research Question 3: Subjective Evaluation

H3.1. *The Audio-Visual stimulus will be rated more favorable than Haptic-Audio-Visual, especially in the area of "annoyance."*

For the subjective variable stimulus comprehension, Audio-Visual outperformed the Haptic-Audio-Visual stimulus. Participants had higher comprehension scores with the stimulus lacking the haptic mode; however this measure may not be isolating comprehension but instead including noticeability as well. Interestingly, older participants reported noticing the haptic stimulus less often than younger participants reported noticing the haptic stimulus; however older participants had better overall TRT with the haptic stimulus included than they did without it. The performance evaluation showed a significant interaction of Age and Stimulus Presentation, with older drivers exhibiting quicker TRT when presented with the H-A-V Stimulus Presentation than the A-V presentation. Also, older drivers had quicker TRT than the younger drivers when each group was presented with H-A-V. It may be that the haptic component physically influenced the driving performance somewhat as the distance the device pushed the throttle back was enough to begin to physically decrease acceleration. This possibility may help to explain the difference between the H-A-V and A-V Stimulus Presentations, but not the finding that older participants performed better with H-A-V than younger participants. Differences in reaction times between the stimulus presentations and age groups, though, were less than 0.5 seconds, and thus may not prove to be meaningful in the analysis and development of CWDs.

Contrary to the hypothesis, the Post-Condition Questionnaire item ratings for annoyance were not significantly different between the stimulus presentations. For this questionnaire, the only significant difference was that younger participants reportedly would "want" the Haptic-Audio-Visual stimulus more than their older counterparts if such a warning were installed in their car. As mentioned, older participants reported feeling the haptic stimulus less often than the younger participants did. At the end of the participant session, each component of the stimulus presentations were explained to them. Once they knew that a haptic stimulus was present, older participants' missing of the haptic component may have signified to them that such a faint component is unnecessary. Still, older drivers performed better in terms of TRT when the haptic component was present, though it was unlikely that the participants were aware of their improved performance in the presentations including haptic.

Open-ended responses for the Post-Condition Questionnaire were analyzed in terms of design guidelines. One interesting finding was the frequent occurrence of comments indicating that the speech component was too loud. Seventeen percent of the older participants and 23% of younger participants said that the warning was "too loud." The stimulus was designed to meet human factors criteria of auditory warning design, with all 1/3 octave bands 13 dbA above the masked threshold (Berger et al., 2000). The warning also met ISO criteria for in-vehicle message displays stating that the signal should stay in the range of 50 dBA to 90 dBA (International Organization for Standardization, 2003a). The perception that it was too loud may have been influenced by the "surprise" nature of the study.

The Curve Warning Acceptance Questionnaire resulted in a number of significant differences in rankings based on Age. Older participants ranked the CWD significantly more favorably than younger participants. Older participants may have seen the added benefit of such a system more than the younger participants. The more favorable opinion may be related to the concepts included in the following section, hazard perception and risk-taking style.

Research Question 4: Hazard Perception and Risk-Taking Style

H4.1. *Individuals with higher hazard perception scores will comply with curve advisory speeds more than individuals with low hazard perceptions.*

Interestingly, younger drivers did not have significantly different hazard perception ratings on individual Hazard Perception Questionnaire items from the ratings of older drivers. The mean HP Score for younger drivers was not significantly different than the mean HP Score for older drivers as well. In previous research, individuals with higher levels of hazard perception have been found to comply with warnings more than individuals with low hazard perceptions (Friedmann, 1988; Vredenburgh, 1995). When comparing hazard perception scores with performance measures using a Pearson correlation, no significant relationships existed between Hazard Score and PRspeed or SRspeed. This may mean that the hazard perception tool used for this study needs to be revised and validated. The lack of difference between the hazard perception scores for younger and older participants may also suggest that this population of participants shared other characteristics due to self-selection as they all chose to participate in this study. Individuals included in the study needed to be willing to have their driving behavior observed, drive after dark, and to drive at speeds of up to 55mph.

H4.2. Individuals with higher risk-taking style scores will comply with curve advisory speeds less than individuals with low risk-taking style scores.

In relating reported risk-taking styles to actual performance, a Pearson correlation found several significant relationships between questionnaire items and PRspeed and SRspeed. A sum of all of the items, to create a Risk-Taking Style Score, also significantly related to PRspeed and SRspeed. The "riskier" the tool found participants to be, the faster they drove on the curves. This speaks well for the validity of the risk-taking style tool previously tested by Iversen (2004) as it was found to relate to actual driver acts.

Limitations

Loss of Data Points

As discussed in the data reduction section, several performance measure data points were lost due to criteria set for the study. These criteria required that if experimenter guidance was provided, the data would be thrown away, and if the foot was not in the right position then some measures would be lost as well. Many "good" data points were collected, and a power analysis showed that the results were not substantially affected by the missing data. The main limitation comes from the possibility of non-random loss of data; in this case, five of the six missing points were from older participants, and the reduced representation of the older age group in this study may affect the ability of the data to accurately represent the older driving population.

Brief Study Duration

Participants in this study only experienced one exposure each of two different curve warning stimuli. Driver reactions, attitudes, and compliance with the warning may change if given the chance to experience the warning over a longer period. While the initial exposure is valuable in examining how drivers may react to the warning if they were unfamiliar with the warning, had not experienced the warning for a long time, or were distracted while driving, information on how drivers react to such a warning over time is necessary to further develop the design of this technology.

Test Highway

There are many "pros" to closed test highway studies, including real driving feel and feedback, and ability to exert control over many variables, such as traffic on the road, allowing a safe environment for driving tests. The SR provided these benefits, but also presented some challenges. Challenges included road architecture, such as the downhill slope of the approach to the curve, the size and shape of the curve, as well as the presence of only one curve suited to the experimental procedure. Performing the study with an experimenter on the SR also may have created demand effects for the participants. The presence of an experimenter may influence driving behavior so that the participant was more cautious, more compliant, or more eager to perform well than if the data were collected without an experimenter present.

CHAPTER 6: CONCLUSIONS

Summary of Findings

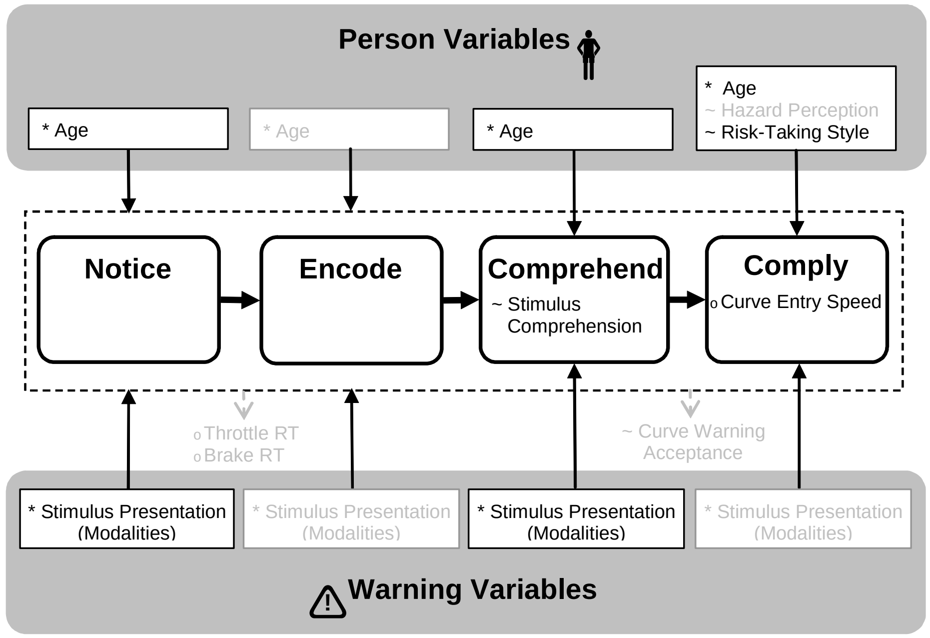
The goal of this research was to determine effective attributes of curve warning stimulus presentation combinations to make recommendations toward design guidelines. In determining effective attributes, objective performance and subjective preference were examined. Individual differences such as age, hazard perception, and risk-taking style were also considered. Objective results indicated that there was a significant improvement in performance when drivers were presented with a warning than when they received no warning. Whether the warning included a haptic stimulus, though, did not significantly affect driver performance. From the subjective results, participants ranked the presentation including the haptic component more favorably than the one without the haptic mode.

Results and the Warning Process Model

A model of the warning process (Rogers et al., 2000) was adapted in an earlier chapter to describe the variables examined in this research and their influence on the warning process (Figure 6.1). Previous research indicated that the warning process is affected by various person variables as well as warning variables. For this study, Age was predicted to influence each step of the warning process, however results indicated otherwise. Although not predicted, Age was a significant factor in whether the participant noticed all of the components of the stimulus. The striped arrow added from Age to Notice represents this finding (Figure 6.2). Age was also a significant main effect for Curve Warning Acceptance, and so the connection remained in the diagram for this relationship. Contrary to what was predicted, Age was not a significant main effect for TRT or BRT. Stimulus Presentation did not have a significant relationship with TRT or BRT either, and so TRT and BRT were removed from the model. One other component of the model to be removed was Stimulus Presentation as a Warning Variable that affects

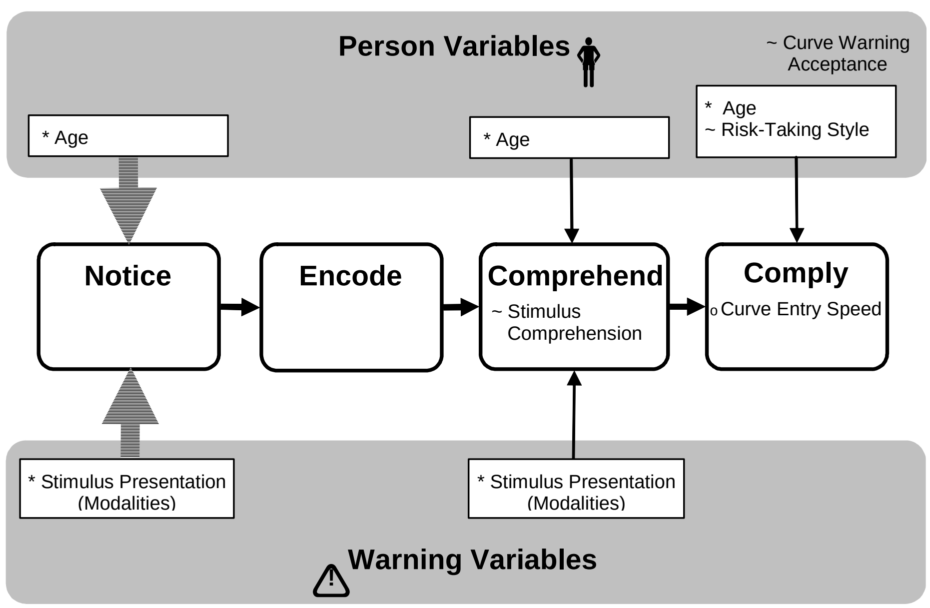
Compliance. In this study, no significant differences were found between the two warning stimulus presentations in terms of curve entry speed. It is important to keep in mind, though, that the two stimulus presentations used for this study were very similar, differing only by the presence of a haptic display. A study comparing more diverse stimuli may have increased the likelihood of seeing an effect of Stimulus Presentation, as demonstrated in Neurauter (2004). Stimulus Presentation, specifically the haptic modality, was significantly related to whether the warning was noticed, though, as represented by the striped arrow from Stimulus Presentation to Notice.

The other components of the model remained intact. These include Age as a variable significantly related to compliance, as older drivers had significantly lower curve entry speeds than younger drivers. Also, Risk-Taking Style measures were significantly linked with curve entrance speed. The original proposed model is included in Figure 6.1 to allow comparison with the modified concept map included in Figure 6.2.



* = Independent Variables
o = Objective Dependent Variables
~ = Subjective Dependent Variables

Figure 6.1: Original Warning Process Model developed for the current study (changes based on results of this study are highlighted).



* = Independent Variables
o = Objective Dependent Variables
~ = Subjective Dependent Variables

Figure 6.2: Warning Process Model modified to reflect results from the current study.

Recommendations toward Design Guidelines

The following recommendations were developed based on previous research as well as performance and ratings gathered from the current study:

1. Design the physical aspects of the auditory, visual, and haptic components properly.
    - Proper sound level, length, and possible precursor tone for the auditory
    - Brightness, flash rate, and location for visual
    - Force, direction, duration for haptic
2. Avoid startling the driver by properly designing the intensity and onset of the warning so that it does not overload the driver's sensing capabilities or evoke a startle response from the driver.
3. The CWD should be understandable and indicate the appropriate driver response to the situation.
4. The CWD should be adjustable to meet the individual demands of drivers without compromising system effectiveness.
5. Time the warning so that the device activates early enough to allow the driver to respond properly, but not so early that it produces many false alarms.

Future Research

Stimuli Design

The stimuli used in this study were designed following tested design specifications; however these specifications had not been tested as a curve warning device on-road. The focus of the current research was broader than fine-tuning stimuli specifications, but such work is necessary. Most notably, the haptic throttle push-back is a very new form for an in-vehicle warning system and needs dedicated research to produce proper design specifications. In this study, even though the haptic force was raised to double that used in simulator studies, many participants still did not perceive the stimulus. Also, even though visual and auditory stimuli have been present in vehicles for many years, the specific purpose and combination of these in a curve warning device requires dedicated testing as well.

Findings from this study suggest incorporating adjustability into the design of the stimuli. Further testing is needed to verify the adjustability ranges for the stimuli for dimensions such as luminance and size, sound level, and haptic force. Settings may then be adjustable, within determined parameters, for different driving assistance needs such as drivers' psychomotor and sensory abilities, age, experience, and driving environment (for example, urban vs. rural).

Naturalistic Study

Once CWD interface components have been developed, the device needs to be tested in a natural driving situation. Field studies examining everyday driving in vehicles equipped with this device would help to examine changes in annoyance, effectiveness, and preference. For example, participants preferred a speech auditory stimulus to a tone in the Neurauter (2004) simulator study, however driver opinions about speech stimuli may change if experienced in a real driving setting including passengers, multiple exposures, and possible false alarms.

In future studies, it would be beneficial to lengthen the study duration to increase driver exposures to the warning and to gather more data from these encounters over time. Lengthening the experimental session would also help to lessen the demand effects on the participants as they would increasingly drive as they normally would and become less aware of their participation in data collection. Another way to lessen demand effects is automating or removing the experimenter from the vehicle, for example using a virtual experimenter through recordings (Martin, 2000). Drivers may perform more naturally without the presence of an experimenter.

Variables to examine in future studies could include the number of times the warning is presented and what events preceded and followed the presentation. Driver performance measures would then be gathered in the seconds following warning presentation, including measures such as throttle and brake reaction times as well as curve entrance speed. Vehicle and video data similar to that collected in this study would be beneficial in a naturalistic one as well. Also, to examine changes in driver preference or annoyance over time, the naturalistic study could utilize a computerized rating prompt in the vehicle linked to warning activation with simple button inputs for the driver. This device would collect a database of drivers' reactions immediately following their experience of the warning. Further questioning and interviews could be used to gather driver evaluations of the warning as it performed for them in a natural setting over time.

The Potential for Multi-Modality Curve Warnings

One main question of interest for this research was the added value of the haptic component in a curve warning device as well as the effects of age. Using objective and subjective measures, the added benefit of this mode is not strongly convincing. A foundation for methods of testing this mode in an on-road environment was developed through this research. Potential exists for development of this type of technology to be used by drivers of different ages with varying personal traits, but more testing of the modalities in a naturalistic setting is necessary.

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APPENDICES

Appendix A: Balanced Latin Square

YF		Participant (S)											
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
Presen-tation Order (O)	O1	A1	A2	A3	A3	A1	A2	A1	A2	A3	A3	A1	A2
	O2	A2	A3	A1	A2	A3	A1	A2	A3	A1	A2	A3	A1
	O3	A3	A1	A2	A1	A2	A3	A3	A1	A2	A1	A2	A3

YM		Participant (S)											
		S13	S14	S15	S16	S17	S18	S19	S20	S21	S22	S23	S24
Presen-tation Order (O)	O1	A1	A2	A3	A3	A1	A2	A1	A2	A3	A3	A1	A2
	O2	A2	A3	A1	A2	A3	A1	A2	A3	A1	A2	A3	A1
	O3	A3	A1	A2	A1	A2	A3	A3	A1	A2	A1	A2	A3

OF		Participant (S)											
		S25	S26	S27	S28	S29	S30	S31	S32	S33	S34	S35	S36
Presen-tation Order (O)	O1	A1	A2	A3	A3	A1	A2	A1	A2	A3	A3	A1	A2
	O2	A2	A3	A1	A2	A3	A1	A2	A3	A1	A2	A3	A1
	O3	A3	A1	A2	A1	A2	A3	A3	A1	A2	A1	A2	A3

OM		Participant (S)											
		S37	S38	S39	S40	S41	S42	S43	S44	S45	S46	S47	S48
Presen-tation Order (O)	O1	A1	A2	A3	A3	A1	A2	A1	A2	A3	A3	A1	A2
	O2	A2	A3	A1	A2	A3	A1	A2	A3	A1	A2	A3	A1
	O3	A3	A1	A2	A1	A2	A3	A3	A1	A2	A1	A2	A3

YF = Younger Female
YM = Younger Male
OF = Older Female
OF = Older Male

A1 = HDD + Speech
A2 = HDD + Speech + Throttle
A3 = Baseline

Appendix B: Participant Recruitment Flyer

Virginia Tech Transportation Institute

PARTICIPANTS NEEDED FOR DRIVING STUDY

$20.00 PER HOUR FOR UP TO 2 HOURS

Are you 18-25 or 60+ years old?
Do you have a valid driver's license?

If you answer yes to both of these questions, please call
Melinda McElheny @ 231-1557
or e-mail: mcelheny@vt.edu

Smart Road
A VIRGINIA SMART TRAVEL PROJECT

Virginia Tech
TRANSPORTATION INSTITUTE

Appendix C: IRB

Request for Expedited Approval of Research Involving Human Subjects
[please print or type responses below]
Investigator(s): Myra Blanco, Tonya Smith-Jackson, Melinda McElheny

Department(s): Virginia Tech Transportation Institute_ Mail Code: 0536 E-mail: mblanco@vtti.vt.edu

Project Title: Multidimensional Warnings: Evaluating Curve Warning Stimuli in an On-Road Environment.
Source of Funding Support: ____ Departmental Research X Sponsored Research (OSP No.: 447053)

[X] All investigators of this project are qualified through completion of the formal training program or videotape program provided by the Virginia Tech Office of Research Compliance.

Note:To qualify for Expedited Approval, the research activities must: (a) present not more than minimal risk to the subjects, (b) not involve any of the special classes of subjects, except children as noted, and (c) involve only procedures listed in one or more of the following categories. The full description may be found in the Expedited Review section of the instructions: "*Application for Approval of Research Involving Human Subjects*" or 45 CFR 46.110 (http://grants.nih.gov/grants/oprr/humansubjects/45cfr46.htm#46.110)

Please mark/check the appropriate category below *which qualifies the project for expedited review:*

[ ] 1. Clinical studies of drugs and medical devices when proscribed conditions are met [see item (1), page ___].

[ ] 2. Collection of blood samples by finger, heel or ear stick, or venipuncture subject to proscribed limitations [see item (2), page ___].

[ ] 3. Prospective collection of biological specimens for research purposes by noninvasive means. Examples: hair and nail clippings, deciduous teeth, permanent teeth, excreta and external secretions, uncannulated saliva, placenta, amniotic fluid, dental plaque, muscosal and skin cells and sputum [see item (3), page ___].

[ ] 4. Collection of data through noninvasive procedures routinely employed in clinical practice, excluding procedures involving x-rays or microwaves [see item (4), page ___].

[ ] 5. Research involving materials (data, documents, records or specimens) that have been collected or will be collected solely for non-research purposes (such as medical treatment or diagnosis [see item (5), page ___].

[X] 6. Collection of data from voice, video, digital, or image recordings made for research purposes [see item (6), page ___].

[X] 7. Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language communication, cultural beliefs or practices, social behavior), or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies [see item (7), page ___].

Myra Blanco, Tonya Smith-Jackson, Melinda McElheny9/7/04 .
Investigator(s)Date

Departmental ReviewerDate

Chair, Institutional Review BoardDate

***This project is approved for ____ months from the approval date of the IRB Chair*.**

Appendix C: IRB

Outline for Protocol to Accompany IRB Request

Justification of Project

The purpose of this project is to determine the best way to present a curve warning to a driver. In the future, this device would have the ability to calculate an appropriate, vehicle-specific curve speed. If the vehicle speed is too fast for the upcoming curve, this system would need to communicate to the driver that he/she needs to slow down. This study will compare two combinations of warnings which include visual, auditory, and haptic components. Intelligent Transportation Systems such as curve warning devices can be effective in reducing crashes and fatalities, but only if they are designed effectively. The driver must be able to readily identify the warning and to understand the action to be taken, without being distracted by the warning. This research will contribute to the current body of knowledge regarding Intelligent Transportation Systems. The results of the research will also provide guidelines for future test methods.

Procedures

Recruitment will be conducted via posted flyers (Appendix B) and contact through word-of-mouth. Participants will be recruited to represent the male and female driving population. Two different age groups will be recruited for this research. One group will represent the younger population and will include drivers between the ages of 18 and 25. The other group will consist of drivers over the age of 60. Drivers who have participated in similar studies will not be eligible. A total of approximately 55 participants will be recruited.

Screening

Prior to coming in for testing, participants will be provided with description of the study eligibility requirements. Participants will be screened initially with a verbal questionnaire to determine if they are licensed drivers and if they have any health concerns that should exclude them from participating in the study. The Screening Questionnaire can be seen in Appendix M.

The phone interviewer will tell each eligible participant what time to arrive and how long the experimental session will take. Participants will be scheduled for one session that will last roughly two hours.

Once the participant arrives for an experimental session, he/she will be asked to show a valid driver's license and then to read and sign an informed consent form (ICF) (Appendix N). After the participant signs the form, the experimenter will sign the form. Both the experimenter and participant will keep a signed copy of the form. The participant will also review and complete a tax form if they have been paid over $75.00 for participating in VTTI-related research (Appendix O).

Next, a brief vision test will be conducted. Two vision tests will be administered to ensure that vision acuity is within the legal driving limit (corrected to 20/40) and to check for color blindness (Appendix P). Participants will not be disqualified if color blind. If the participant's vision is not acceptable, he/she will be paid $20.00, thanked, and dismissed. Finally, an informal hearing test will be administered during which four tones at 1KHz, 2KHz, 3KHz, and 4KHz will be presented (Appendix P). If the participant is unable to detect any of the tones, he/she will be paid $20.00, thanked, and dismissed.

Data Collection

Following the initial vision and hearing tests, the experimenter will orient the participant to the study and to the research vehicle. Description of the study will be concise and will not reveal that the participant will be presented with curve warning displays. Instead, the experimenter will indicate that the participant will be testing the use of cellular phones while driving. This deception is necessary to gain information on how people initially react to warnings. Participants will not, however, perform any cellular phone tasks.

After receiving instructions and asking any questions they may have, the participant will be asked to drive a short public highway route. The experimenter will be in the vehicle with the participant at all times. The highway route is chosen to help familiarize the participants with the vehicle features and handling, and to help them become comfortable driving at 55 mph without revealing the curvature of the Smart Road. Participants will be told that they will not be asked to perform any cellular phone tasks while on public roads.

Upon completion of the highway loop used for orientation, the participant will enter the Smart Road and drive the length at 55 mph. The road is straight for approximately 2 miles and designed for speeds of 100 km/h or about 62 mph. At the end of the road is a 92 ft diameter turnaround loop. Participant vehicle headlights will meet SAE standards and illuminate the curve prior to reaching it. At the first encounter of the Bottom Turn, curve warning presentation Stimulus 1, Stimulus 2, or a Baseline condition with no stimulus, will be presented to the driver at the determined distance from the curve entrance. Stimulus 1 consists of a flashing visual icon on the dash, or Heads Down Display (HDD), plus an auditory warning of a female voice saying, “Curve ahead. Reduce speed to 20 mph”. Stimulus 2 is the same HDD and speech warning, plus a haptic throttle push-back display.

Following the surprise stimulus presentation, the experimenter will ask the participant to park the vehicle at the end of the Bottom Turn. She will then administer a debriefing statement (Appendix T) and ask if the participant consents to keeping the data from the first trial and would like to continue in the study. She will administer a second informed consent form (Appendix U) and several questionnaires pertaining to the stimulus presentation just encountered (Appendices E, F, and H). Once ready, the participant will drive the loop from the Bridge Turn to the Bottom Turn for a total of two more times to experience the other stimulus presentations. After each stimulus presentation the participant will park and complete the questionnaires. Following all data collection, the experimenter will escort the participant back to the VTTI building; administer several more questionnaires (Appendices G and E), and a short debriefing as well as payment (Debriefing form and payment receipt are in Appendix W).

Appendix C: IRB

Risks and Benefits

There are risks or discomforts to which test participants are exposed to in volunteering for this research. They include the following:

1. The risk of an accident normally associated with driving an unfamiliar automobile after dark at speeds of up to 55 miles per hour without other traffic present, and with low traffic flow on a rural highway route.
2. Possible fatigue due to the length of the experiment. However, they will be given rest breaks during the experimental session.
3. Participants who have had previous eye injuries and/or surgeries are at an increased risk of further eye injury by participating in this study where risks, although minimal, include the possibility of collision and airbag deployment.

The following precautions will be taken to minimize the risks listed above:

1. Participants may take breaks or decide not to participate at any time.
2. If participants decide to discontinue participation, the experimenter will drive the participant back to VTTI.
3. The experimenter will be in the vehicle with participants at all times.
4. The vehicle is equipped with a driver's side and passenger's side airbag supplemental restraint system, fire extinguisher and first-aid kit.
5. All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to the participant in any foreseeable case.
6. The experiment will not be run during severe weather conditions.
7. Participants are required to wear the lap and shoulder belt restraint system while in the car.
8. In the event of a medical emergency, or at the participant's request, VTTI staff will arrange medical transportation to a nearby hospital emergency room.
9. Participants will not have any medical condition that would put them at a greater risk, including but not restricted to epilepsy, balance disorders, and lingering effects of head injuries and stroke.

There are no direct benefits to the participant from this research other than payment for participation. No promise or guarantee of benefits will be made to encourage participants to participate. Participant participation will provide additional data related to the field of Intelligent Transportation Systems and In-Vehicle Warnings.

Confidentiality/Anonymity

The data gathered in this experiment will be treated with confidentiality, and data collected will be used for research purposes only. Shortly after participants have participated, their name will be separated from their data. A coding scheme will be employed to identify the data by participant number only (e.g., Participant No. 3). Participants will be allowed to withdraw their data from the study if they so desire. Participants must inform the experimenter immediately of this decision, as the data will be difficult (if not impossible) to track once the session is over.

While the participant is driving the vehicle, cameras will videotape the participants and video views will include the participant's face, throttle and brake pedals, an over-the-shoulder view of the steering wheel and dash, and a forward road view. The purpose of the video recordings is to provide backup and verification methods for the in-vehicle data collection system. Videotapes will be stored in a locked room at the Virginia Tech Transportation Institute. Video tapes will be converted to digital video and stored on a password protected server. Access to video will be under the supervision of Dr. Myra Blanco, an investigator for the project. Participants will be asked for their permission to allow VTTI to turn over the videotape including their data and image to the client. Participants may refuse to allow the videotape of their image to be given to the client, and still be eligible to participate in the study.

Informed Consent

Please see attached appendices labeled *VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY: Informed Consent for Participants of Investigative Projects (two separate consent forms).* (For this document, Informed Consent Forms are in Appendix M and Appendix U).

Appendix C: IRB

Approval Letter

Virginia Tech
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Institutional Review Board

Dr. David M. Moore
IRB (Human Subjects)Chair
Assistant Vice President for Research Compliance
CVM Phase II Duckpond Dr., Blacksburg, VA 24061 0442
Office: 540/231-4991; FAX: 540/231-6033
email: moored@vt.edu

DATE: March 11, 2005

MEMORANDUM

TO: Myra Blanco VTTI 0536
Tonya L. Smith-Jackson ISE 0118
Melinda McElheny

FROM: David Moore

SUBJECT: **IRB Expedited Approval:** "Multidimensional Warnings: Evaluating Curve Warning Stimuli in an On-Road Environment" IRB # 05-189

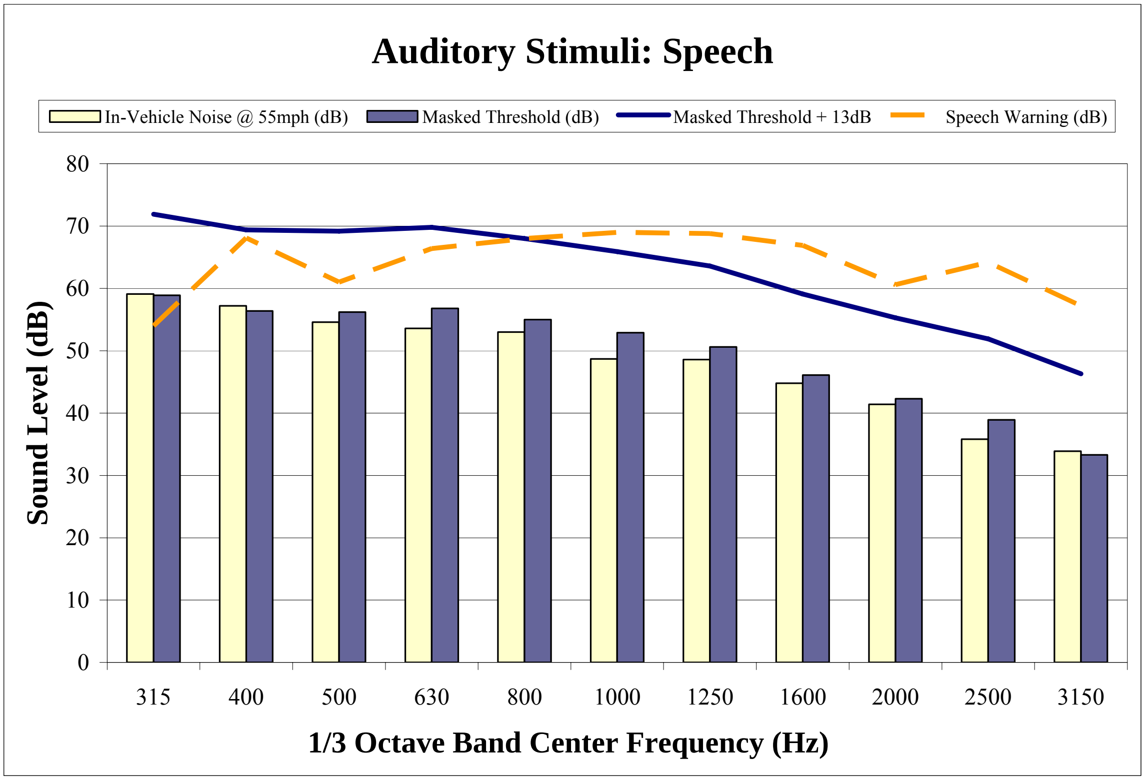
This memo is regarding the above-mentioned protocol. The proposed research is eligible for expedited review according to the specifications authorized by 45 CFR 46.110 and 21 CFR 56.110. As Chair of the Virginia Tech Institutional Review Board, I have granted approval to the study for a period of 12 months, effective March 10, 2005.

Virginia Tech has an approved Federal Wide Assurance (FWA00000572, exp. 7/20/07) on file with OHRP, and its IRB Registration Number is IRB00000667.

cc: File
Department Reviewer: Suzanne E. Lee
OSP 0170

A Land-Grant University - Putting Knowledge to Work
An Equal Opportunity/Affirmative Action Institution

Appendix D: Sound Measurements of the Speech Stimulus



Appendix E: Haptic Pedal Maintenance Protocol

VIRGINIA TECH TRANSPORTATION INSTITUTE
Testing Haptic Force and Maintaining Nitrogen Cylinder

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1. **Measure throttle push-back force**
   - Hold straight end of metal rod into center line of accelerator pedal and push down until can place bent end of metal rod to the middle of the duct tape square on center console
   - Hold green portion strong and steady up against the car
   - Take starting reading (should be around 2 lbs)
   - Type "w" to forcewarn and continue to hold green portion tightly while pedal pushes back
   - Take ending reading (should be around 14 lbs)
   - Subtract start reading from end reading and force should be 6 lbs.

2. **In right side of trunk, large gauge is for Emergency Brake**
   - Open valve by turning to the left (as if looking at from above)
   - Hear short hiss, gauge should read 200 psi
     - If hiss continues, close valve again by turning all the way to the right
     - Try activating emergency brake once while parked, push handle forward
   - Green light should go on indicating tank is open and filled and brake is ready to go
     - If red light stays on:
       (1) Check that valve has been opened all the way by turning more to the left (valve can be opened half-way or all the way, does not matter)
       (2) Check if level is 200 psi
       (3) If neither check works, change tank (see below)
   - Do not adjust the nut on side of large tank (knob has been removed so cannot adjust)
   - Close the valve (all the way to right) at the end of each night

2. **Small gauge is for Haptic Pedal**
   - Gauge should read <u>100 psi</u> (or level decided upon)
     - If gauge does not read 100 psi, pull black knob out to rotate
     - Rotate to the left to increase psi
     - If increase level too much, rotate back to the right and must manually decrease by activating pedal several times (see warning system test procedures in Experimenter and Greeter protocols)

3. **Changing the large tank:**
   - Close valve (turn all the way to right) completely

- Use wrench to loosen nut below valve (lefty loosey)
  - If hear continuous hissing, tighten nut back up, and tighten valve to the right completely
- Unscrew nut rest of the way by hand
- Loosen strap on cylinder and pull old cylinder out
- Erase chalk on cylinder and write, “Empty”
- Replace with cylinder located in Simbay entrance in blue steel holding rack
  - Make sure same size as one replacing
- Slide new tank into strap and tighten
- Replace valve and screw in nut by hand
- Give a couple tightening twists of nut with wrench, but do not force too much
- Open valve to left and green light should go on
  If red light remains on, repeat previous steps and make sure valves have been tightened/loosened appropriately

Appendix F: Stimulus Comprehension Interview

Sample Probes:

(The stimulus comprehension interview will not be administered after the Baseline condition)

1. "Did you notice anything just now?"

If Yes:

2. "Can you describe what you noticed?"

3. "What did it mean to you?"

Appendix G: Post-Condition Questionnaire

Please rate the following statements on a scale from 1 to 5 (circle the applicable number).

1. This type of warning conveyed a sense of urgency (requiring immediate attention).

   1………………..2………………..3………………..4………………..5

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

2. This type of warning was annoying.

   1………………..2………………..3………………..4………………..5

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

3. This type of warning was appropriate for a curve warning device.

   1………………..2………………..3………………..4………………..5

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

4. This type of warning interfered with my driving.

   1………………..2………………..3………………..4………………..5

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

5. If my car was equipped with a curve warning device I would want this type of warning to be presented.

   1………………..2………………..3………………..4………………..5

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

6. Would you change something about this warning? If yes, what would it be?

Appendix H: Curve Warning Acceptance Questionnaire

Please mark each statement with an X anywhere between the lines (see example):

|____|____|__X__|____|____|

My judgments of the Curve Warning system are…

useful |____|____|____|____|____| useless

pleasant |____|____|____|____|____| unpleasant

bad |____|____|____|____|____| good

nice |____|____|____|____|____| annoying

effective |____|____|____|____|____| superfluous

irritating |____|____|____|____|____| likeable

assisting |____|____|____|____|____| worthless

undesirable |____|____|____|____|____| desirable

raising alertness |____|____|____|____|____| sleep-inducing

- Of the warnings presented today, which condition did you most like and why?

- Of the warnings presented today, which condition did you least like and why?

Appendix I: Hazard Perception Questionnaire

Page 1: To be administered verbally.

Please answer the following to the best of your knowledge:

- On my first drive down the Smart Road, I first became aware of the sharp curve (turnaround loop) at the end of the Smart Road *(circle one)*:

  1 Prior to the warning **2** During the warning **3** After the warning

For each of the following statements, please circle the number above the rating that best matches your opinion.

1. I often (at least several times per month) drive on roads with two or more tight curves.

   1………………..2………………..3………………..4………………..5

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

2. Once I noticed a curve at the end of the Smart Road, the curve seemed like it could be a dangerous driving maneuver.

   1………………..2………………..3………………..4………………..5

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

3. I usually drive above the speed limit posted on curves.

   1………………..2………………..3………………..4………………..5

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

4. Roadway curves are hazardous.

   1………………..2………………..3………………..4………………..5

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

5. Posted advisory speeds for curves are usually much slower than they need to be.

   1………………..2………………..3………………..4………………..5

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

Appendix J: Risk-Taking Style Questionnaire

For each of the following statements, please circle the number next to the rating that best matches your opinion.

1. Many traffic rules must be ignored to ensure traffic flow.

   1………………..2………………..3………………..4………………..5

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

2. Traffic rules must be respected regardless of road and weather conditions.

   1………………..2………………..3………………..4………………..5

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

3. Speed limits are exceeded because they are too restrictive.

   1………………..2………………..3………………..4………………..5

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

4. It is acceptable to take chances when no other people are involved.

   1………………..2………………..3………………..4………………..5

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

5. If you are a good driver it is acceptable to drive a little faster.

   1………………..2………………..3………………..4………………..5

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

6. I would never drive after drinking alcohol.

   1………………..2………………..3………………..4………………..5

Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

Appendix J: Risk-Taking Style Questionnaire (continued)

For each of the following statements, please circle the number that best describes *__your__* driving behavior (from 1 - Never– to 5 – Very Often).

7. Break 50 mph speed limits by more than 10 mph.

1………………..2………………..3………………..4………………..5

Never Very Often

8. Overtake the car in front even when it keeps the appropriate speed.

1………………..2………………..3………………..4………………..5

Never Very Often

9. Ignore traffic rules to proceed faster.

1………………..2………………..3………………..4………………..5

Never Very Often

10. Drive too close to the car in front to be able to stop if it should brake.

1………………..2………………..3………………..4………………..5

Never Very Often

11. Keep driving when I am tired and actually need a break.

1………………..2………………..3………………..4………………..5

Never Very Often

12. Drive long distances in a car without wearing a seatbelt.

1………………..2………………..3………………..4………………..5

Never Very Often

Appendix K: Advisory Speed Calculation

$$V = \sqrt{Rg\frac{e+f}{1-ef}}$$

Where: V = vehicle speed (ft/s)
R = radius of curve (92 ft)
g = gravitational constant (32.2 ft/s^2)
e = rate of superelevation (6%)
f = side friction factor (0.21)

Therefore:

$$V = \sqrt{92(32.2)\frac{.06+0.21}{1-(.06)(.21)}}$$

$$V = \sqrt{2962.4\frac{.27}{.9874}}$$

$$V = \sqrt{810.05468}$$

$$V = 28.461459\,ft/s \approx 17.46499mph * 0.9 = 15.7mph$$

$$V = \underline{\underline{15mph}}$$

Appendix L: Warning Distance Onset Calculations

$$a = \frac{V^2 - V_c^2}{2(d - t_r V)}$$

Where: a = deceleration (4.92 ft/s^2)
V = vehicle speed (55 mph or *1.468 = 80.67 ft/s)
V_c = maximum safe speed for curve (16.67 mph or *1.468 = 24.47 ft/s)
d = distance to curve apex (ft)
t_r = reaction time (2.5s)

$$d = \frac{V^2 - V_c^2}{2a} + t_r V$$

Therefore:

$$a = \frac{V^2 - V_c^2}{2(d - t_r V)} \Leftrightarrow d = \frac{V^2 - V_c^2}{2a} + t_r V$$

$$d = \frac{(80.67)^2 - (24.47)^2}{2(4.92)} + 2.5(80.67)$$

$$d = \frac{6507.65 - 598.78}{9.84} + 201.68$$

$$d = 600.49 + 201.68 = 802.2$$

$$d \approx \underline{\underline{802\ ft}}$$

Appendix M: Participant Screening Questionnaire

Individual’s Name: ________________________ Gender: M or F Age: ___________

Phone #: (H) __________________ (W) __________________

Note to Researcher:
Initial contact between participants and researchers may take place over the phone. If this is the case, read the following Introductory Statement, followed by the questionnaire. Regardless of how contact is made, this questionnaire must be administered verbally before a decision is made regarding suitability for this study.

Introductory Statement:
After prospective participant calls or you call them, use the following script as a guideline in the screening interview.

Hello. My name is _______________ and I'm a re’earcher with the Virginia Tech Transportation Institute in Blacksburg, VA. We are currently running a study to examine cellular phone usage while driving. The majority of this study will take place after dark on the Smart Road, with about 15 minutes of driving on public Blacksburg roads. The study will take approximately 2 hours of your time. You will be paid $20.00 per hour. Does this sound like something you may want to do?

1. Do you have a valid driver’s license? [Exclude if ‘NO’]
   Yes ____No _____Expiration Date:_______________
2. How long have you held your driver's lice’se?_________________
3. How old are you? ______ (stop if not 18-25 or 60+ years old.)
4. Are you eligible for employment in the United States? [Exclude if ‘NO’]
   Yes ____No _____
5. Are you able to drive an automatic transmission without assistive devices or special equipment?
   Yes ____No _____ [Exclude if ‘NO’]
6. How often do you drive per week? _____________ [Exclude if less than 2]
7. Have you participated in any experiments at the Virginia Tech Transportation Institute? If "yes," “leas” briefly describe the study, including when it occurred.
   No ____Yes ____

8. Have you had any moving violations in the past 3 years? If so, please explain. [Exclude if more than 3]
   No ____Yes ____

9. Have you been involved in any accidents within the past 3 years? If so, please explain.
   No ____Yes ____

10. Do you have a history of any of the following? If yes, please explain.

Heart ondition No____
Yes________________________________

Stroke	No____	Yes________________________________
Brain tumor	No____	Yes________________________________
Head injury	No____	Yes________________________________
Epileptic seizures	No____	Yes________________________________
Respiratory disorders	No____	Yes________________________________
Motion sickness	No____	Yes________________________________
Inner ear problems	No____	Yes________________________________
Dizziness, vertigo, or other balance problems		
	No____	Yes________________________________
Diabetes	No____	Yes________________________________
Migraine, tension headaches		
	No____	Yes________________________________

11. (Females only) Are you currently pregnant? [Exclude if 'YES']

12. Are you currently taking any medications on a regular basis? If yes, please list them.
    No ___

    _Yes ____

13. Do you have normal or corrected to normal hearing and vision? If no, please explain.
    Yes ____No ____

    [If participant wears glasses, please ask him/her to bring them, even if they are only reading glasses.]

<u>If the participant is eligible, schedule him/her for the study.</u>

Give directions to VTTI and indicate where to park. Say, "We ask that all participants refrain from drinking alcohol and taking any substances that will impair their ability to drive prior to participating in our study."

Appendix M: Participant Screening Script

Criteria for Participation:

1. ***Must hold a valid drivers license.***
2. ***Must be 18-25 or >60 years old.***
3. ***Must be eligible for employment in the U.S.***
4. ***Must be able to drive an automatic transmission without special equipment.***
5. ***Must drive at least 2 times a week.***
6. ***Must not have participated in a similar study within the last year (driving stretch of Smart Road)***
7. ***Must not have more than two driving violations in the past three years.***
8. ***Must not have caused an injurious accident in the past two years.***
9. ***Cannot have lingering effects of heart condition, brain damage from stroke, tumor, head injury, recent concussion, or infection. Cannot have had epileptic seizures within 12 months, current respiratory disorders, motion sickness, inner ear problems, dizziness, vertigo, balance problems, diabetes for which insulin is required, chronic migraine or tension headaches.***
10. ***Cannot be pregnant.***
11. ***Cannot currently be taking any substances that may interfere with driving ability (cause drowsiness or impair motor abilities).***
12. ***Must have normal (or corrected to normal) hearing and vision.***

If a volunteer is	**And**	**Proceed by**
Eligible	------	Scheduling a study session.
NOT Eligible	Exclusion is TEMPORARY	Saying “I am not able to schedule you at this time, however, if you are interested you can volunteer again when _______ (fill in the restriction). We will be glad to reconsider you in a study at that time. We appreciate your interest and hope to hear from you in the future.”
NOT Eligible	Exclusion is PERMANENT	“I am not able to schedule you for this study because of _________ (i.e., susceptibility to motion sickness). Understand that we do this with your best interest in mind. We appreciate your willingness to volunteer.”

Scheduled day and time: _______________________________
Notes:

Appendix N: Informed Consent Form I

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Informed Consent for Participants of Investigative Projects

Title of Project: In-Vehicle Technology

Investigator(s): Melinda McElheny, Myra Blanco, and Tonya Smith-Jackson

I. Purpose of this Research/Project

The purpose of this research is to gather information about using a cell phone while driving a vehicle on the Smart Road.

II. Procedures

During the course of this experiment you will be asked to perform the following tasks:

1. Show your valid driver's license
2. Read and sign an Informed Consent Form
3. Complete simple vision tests
4. Complete an informal hearing test
5. Fill out questionnaires
6. Drive a vehicle on a short rural free way route and then on the Smart Road, obeying a 55 mile per hour speed limit while performing cellular phone tasks as instructed by the experimenter. The session will be videotaped.
7. Listen to the instructions regarding any tasks you may perform.

The experiment will last approximately one hour. You will be asked to drive one vehicle during that time. The experimenter will be present with you at all times. First, you will drive on several Blacksburg roads to become familiar with the vehicle. It is important that you follow all traffic laws and speed limits. You will not be asked to perform any cellular phone tasks while driving on public roads. We will then return to the Smart Road for the remainder of the study. No other vehicles will be present with you on the Smart Road. The experimenter will give instructions at various times and you will complete several questionnaires and ratings while on the road and once you return to the building.

It is important for you to understand that we are evaluating the technology, not you. You will be expected to drive as you would normally, while obeying the speed limits of at most 55mph during the straight portions of the road and following traffic lane markings. Any tasks you perform, mistakes you make, or opinions you have will only help us do a better job of designing the systems. Therefore, we ask that you perform to the best of your abilities. The information and feedback that you provide is very important to this project.

Appendix N: Informed Consent Form I

III. Risks

There are risks or discomforts to which test participants are exposed to in volunteering for this research. They include the following:

1. The risk of an accident normally associated with driving an unfamiliar automobile after dark at speeds of up to 55 miles per hour without other traffic present, and with low traffic flow on a rural highway route.
2. Possible fatigue due to the length of the experiment. However, you will be given rest breaks during the experimental session.
3. Participants who have had previous eye injuries and/or surgeries are at an increased risk of further eye injury by participating in this study where risks, although minimal, include the possibility of collision and airbag deployment.

The following precautions will be taken to minimize the risks listed above:

1. You may take breaks or decide not to participate at any time.
2. The experimenter will be in the vehicle with you at all times.
3. The vehicle is equipped with a driver's side'and passenger's side'airbag supplemental restraint system, fire extinguisher and first-aid kit.
4. All data collection equipment is mounted such that, to the greatest extent possible, it does not pose a hazard to you in any foreseeable case.
5. The experiment will not be run during severe weather conditions.
6. You are required to wear the lap and shoulder belt restraint system while in the car.
7. In the event of a medical emergency, or at your request, VTTI staff will arrange medical transportation to a nearby hospital emergency room.
8. You do not have any medical condition that would put you at a greater risk, including but not restricted to epilepsy, balance disorders, and lingering effects of head injuries and stroke.

Please remember that you are free to withdraw if you feel uncomfortable at any time.

In the event of an accident or injury in an automobile, the automobile liability coverage for property damage and personal injury is provided. The total policy amount per occurrence is $2,000,000. This coverage (unless the other party was at fault, which would mean all expense would go to the insurer of the other party's vehicle) would apply in case of an accident for all volunteers and would cover medical expenses up to the policy limit.

Participants in a study are considered volunteers, regardless of whether they receive payment for their participation; under Commonwealth of Virginia law, workers compensation does not apply to volunteers; therefore, if not in an automobile, the participants are responsible for their own medical insurance for bodily injury. Appropriate health insurance is strongly recommended to cover these types of expenses.

IV. Benefits

While there are no direct benefits to you from this research, you may find the experiment interesting. No promise or guarantee of benefits is made to encourage you to participate. Participation in this study will contribute to the improvement of advanced vehicle systems.

V. Extent of Anonymity and Confidentiality

The data gathered in this experiment will be treated with confidentiality. Shortly after participation, your name will be separated from your data. A coding scheme will be employed to identify the data by participant number only (e.g., Participant No. 1). You will be allowed to see your data and withdraw the data from the study if you so desire, but you must inform the experimenters immediately of this decision so that the data may be promptly removed. At no time will the researchers release data identifiable to an individual to anyone other than VTTI staff working on the project without your written consent. VTTI will not turn over the video of your image to the client without your permission.

VI. Compensation

You will receive $20.00 per hour for your participation in this study. This payment will be made to you in cash at the end of your voluntary participation in this study.

VII. Freedom to Withdraw

As a participant in this research, you are free to withdraw at any time without penalty. The experimenter will drive you back to VTTI. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated. Furthermore, you are free not to answer any question or respond to experimental situations without penalty.

VIII.Approval of Research

Before data can be collected, the research must be approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Virginia Tech Transportation Institute. You should know that this approval has been obtained.

IX. Parpant's Responsibilities

If you voluntarily agree to participate in this study, you will have the following responsibilities:

1. To follow the experimental procedures as well as you can.
2. To inform the experimenter if you have difficulties of any type.
3. To wear your seat and lap belt.
4. To abide by the 55 mph speed limit and traffic laws.
5. To abstain from any substances that will impair your ability to drive.
6. To drive the test vehicle in a safe and responsible manner.

Appendix N: Informed Consent Form I

X. Papant's Acknowledgments

Check one of the following:

- ☐ I have **not** had an eye injury/eye surgery (including, but not limited to, LASIK, Radial Keratotomy, and cataract surgery.)
- ☐ I **have** had an eye injury/eye surgery and I've hav' been informed of the possible risks to participants who have had eye surgery. I choose to accept this possible risk to participate in this study.

Check one of the following:

- ☐ VTTI **has my permission** to give the videotape including my image to the client who has sponsored this research. I understand that the client will only use the videotape for research purposes.
- ☐ VTTI **does not have my permission** to give the videotape including my image to the client who has sponsored this research. I understand that VTTI will maintain possession of the videotape, and that it will only be used for research purposes.

XI. Participant's Permission

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.
If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

Participant Signature Date

Experimenter Signature Date

Should I have any questions about this research or its conduct, I may contact:

Melinda McElheny	(540) 231-1557
Myra Blanco	(540) 231-1500
Tonya Smith-Jackson	(540) 231-4119
David Moore, Chair, IRB	(540) 231-4991

Appendix O: Virginia Tech W-9 Tax Form

Please check one:

❑ I am a U S citizen, **or**

❑ I have been granted permanent residency (green card holder), **or**

❑ I am a Resident Alien for tax purposes and have contacted Martha Mullen at 540-231-3754 or mlaster@vt.edu to discuss the additional documentation that is required by federal law.

1. Name

First:________________________Middle:________________Last: _______________________________

2. U.S. taxpayer identification number (required)

________ess (number, street, and apt. or suite no.)

________tate and ZIP code

______**cation:**

Under the penalties of perjury, I declare that to the best of my knowledge and belief, the above statements are true, correct, and complete and that:

1. The number shown on this form is my correct taxpayer identification number, **and**
2. I am not subject to backup withholding because: (a) I am exempt from backup withholding, or (b) I have not been notified by the Internal Revenue Service (IRS) that I am subject to backup withholding as a result of a failure to report all interest or dividends, or (c) the IRS has notified me that I am no longer subject to backup withholding, **and**
3. I am a U.S. person (including a U. S. resident alien).

Certification Instructions. You must cross out item 2 above if you have been notified by the IRS that you are currently subject to backup withholding because you have failed to report all interest and dividends on your tax return.

Signed:____ Date: __________________

Revised 8/01

VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY
EMPLOYEE/INDEPENDENT CONTRACTOR EVALUATION FORM

Vendor Name: Research Participant. Not a contractor
Work to be performed: Participate in a research experiment

If the University already employs the person you are considering, **stop** now. (He/she cannot be paid as a contractor.) Otherwise, answer each of the following questions. If the question is not applicable, mark it as "n/a." University, as used below, refers to the office/department/principal investigator who has responsibility for the activity which requires this work to be performed. "Yes" answers generally designate workers to be employees under IRS rules.

	YES	No	N/A
1. Work substantially full-time for the University.		X	
2. Must comply with the University's instructions about where, when and how the work is to be performed.		X	
3. Receive training from or at the direction of the University.		X	
4. Provide services that are integrated into the regular activities of the University.		X	
5. Provide services that must be rendered personally.		X	
6. Do not hire, supervise and pay their own assistants.		X	
7. Have a continuing relationship with the University.		X	
8. Must follow hours of work set by the University.		X	
9. Do their work on the premises of the University.		X	
10. Must do their work in a sequence set by the University.		X	
11. Must submit regular reports to the University.		X	
12. Receive payments of regular amounts at set intervals.		X	
13. Receive payments for business and/or traveling expenses.		X	
14. Rely on the University to furnish tools and materials.		X	
15. Lack a major investment in facilities used to perform the service.		X	
16. Cannot make a profit or suffer a loss from their services.		X	
17. Work for one employer at a time.		X	
18. Do not offer their services to the general public on a regular and continuing basis.		X	
19. Can be fired by the University.		X	
20. May quit work any time without incurring liability for nonperformance.	X		

Evaluation: The questions above are intended to measure the extent of control which the University may exercise over the worker. Generally, if there is a good deal of control over what the worker does and how the worker does the work, there should be an employee relationship established. If there are few elements of control, a contractor (consultant) relationship may be appropriate.

CERTIFICATION: Based on the above, it is my determination that the proper classification of this individual is employee or contractor (circle one). Note: A misclassification may result in taxes, interest, and penalties being assessed by the IRS. If this happens, departments will be billed for their proportional taxes, interest, and penalties.

____________________ ____________________
Printed Name Date

____________________ ____________________
Signature Phone

____________________ ____________________
Title Department Name & Number

Submit completed form with Accounting Voucher to Controller's Office for payment.

Appendix P: Vision and Hearing Tests Form

Participant Number: __________

Vision & Hearing Tests

I – Acuity Test

Acuity Score:________

II – Ishihara Test for Color Blindness

1._____4._____7.____

2._____5._____

3._____6._____

III – Hearing Test

During this informal hearing test, the participant will have his/her back turned to the experimenter while four tones are presented; 1) 1KHz, 2) 2KHz, 3), 3KHz, and 4) 4KHz. The participant will be told to raise his/her hand when a tone is heard, which will be presented at 10 dB(A) above the masked threshold in one or more of the octave bands based on the room where this will be performed. If a participant is unable to hear any of the tones, he/she will be excluded.

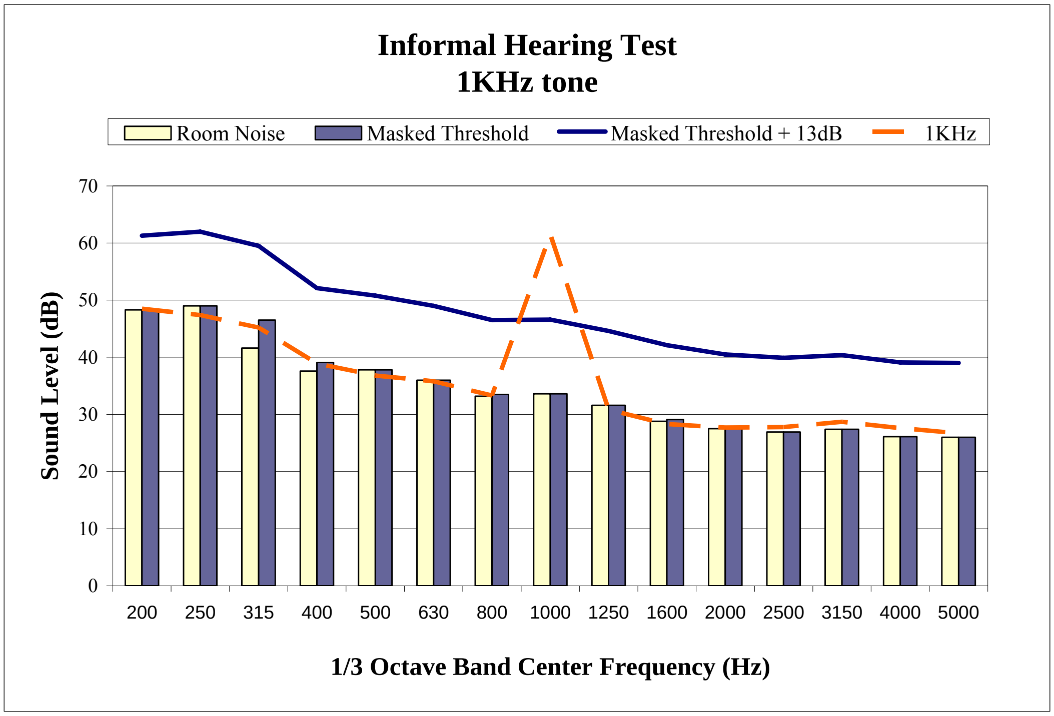
1KHz ______

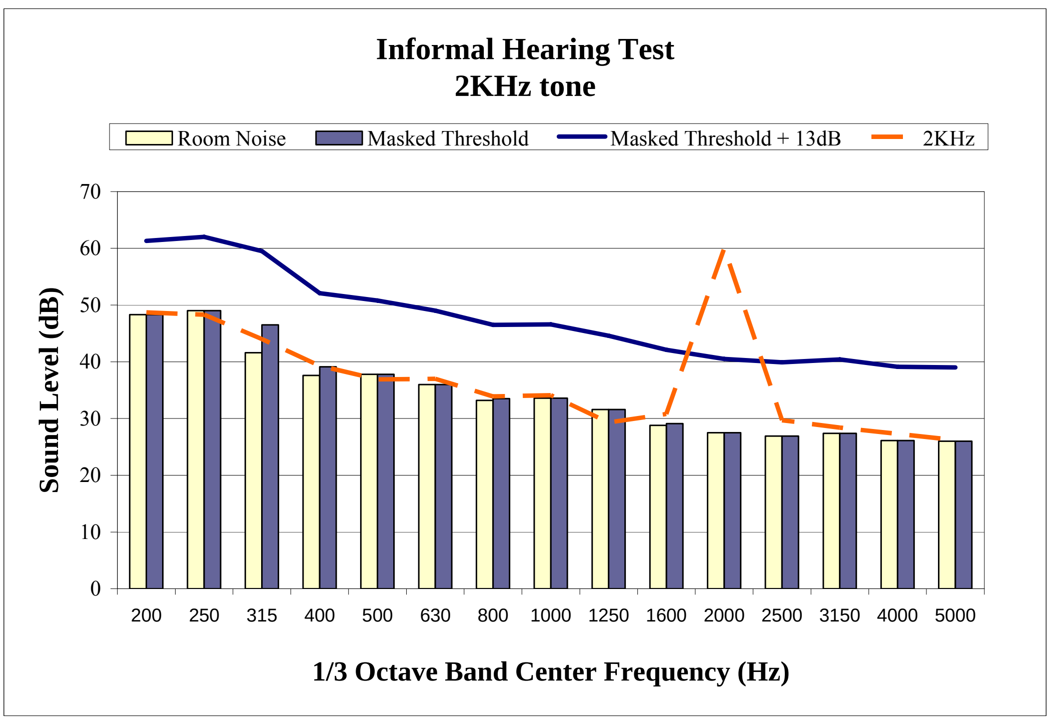
2KHz ______

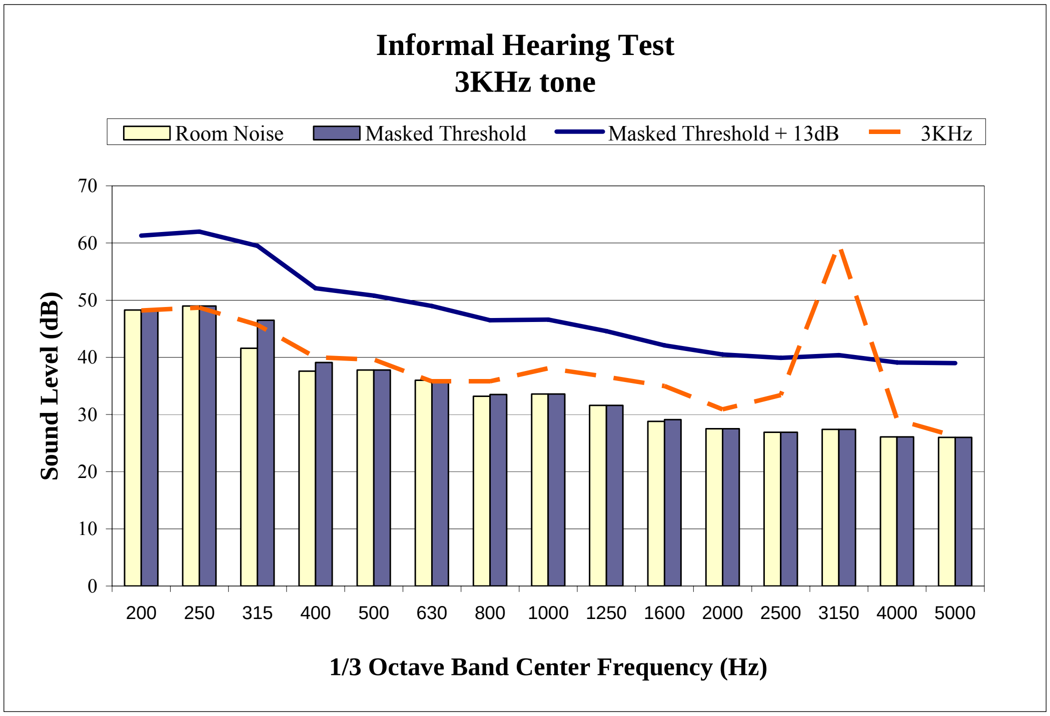
3KHz ______

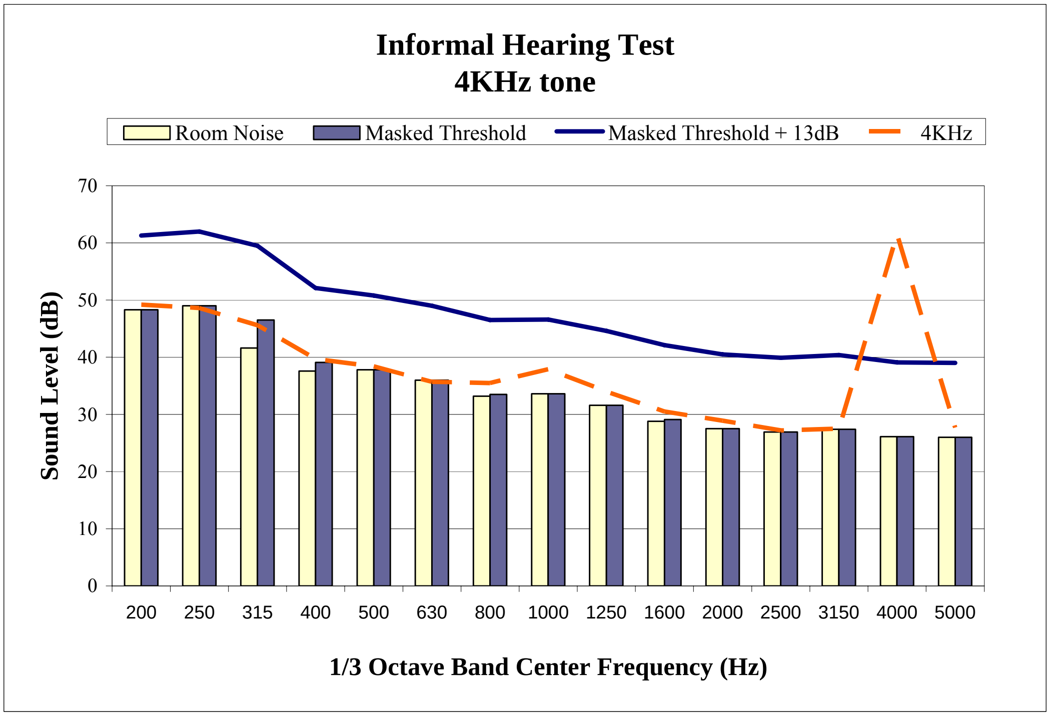
4KHz ______

Appendix Q: Sound Level Measurements for Each Hearing Test Tone






Informal Hearing Test
3KHz tone
Room Noise
Masked Threshold
Masked Threshold + 13dB
3KHz
Sound Level (dB)
70
60
50
40
30
20
10
0
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
1/3 Octave Band Center Frequency (Hz)


Informal Hearing Test
4KHz tone
Room Noise
Masked Threshold
Masked Threshold + 13dB
4KHz
Sound Level (dB)
70
60
50
40
30
20
10
0
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
1/3 Octave Band Center Frequency (Hz)

Appendix R: Greeter Protocol

---

1. **Get headset and two radios - set to Channel 1.**
2. **Vehicle Setup**
   - Check that fuel tank is full.
   - Clean windshield, mirrors, and back window.
   - Set fan speed to low.
   - Set tape player volume to 4 bars (go to 5 bars, then set back 1 as there are 2 levels under 4 bars – set to upper level.
   - Make sure night-vision is OFF (sliding button to bottom left of steering wheel)
   - Check tire pressure – fill to 35 lbs.
   - Check that illuminance meter, 2 red flashlights, 1 regular flashlight, green force gauge, and voice recorder are in the back seat pockets.
   - Turn on power by flipping second toggle switch UP on electrical housing in trunk
   - Check brake cylinder pressure in trunk (should be 200 on big gauge, 100 on small gauge).
   - Green light (not red light) near cylinders in trunk should be on.
     - If red light is on, see "Brake Cylinder Protocol."
3. **System checks (Experimenter and Greeter together):**
   - **Software**

Category	Command	Function
RUN LOKI?	y/n, Enter	Runs Loki program
SUBJECT_ID	+/-	Scrolls up or down to participant number
RUN_NUM	u/d	Sets run number for 3 Smart Road runs
TRIP_TYPE	t	Smart_Road / Public_Road (need to stop recording the file ('f') to switch between the two trip types)
NUMBER_COLUMN	0-9	Flags data with a number
WARN_MODE	m	Baseline / Audio_Visual / Haptic_Audio_Visual
RECORD_FILE	s / x	s = starts recording, x = stops recording
MDW_LASER_STATE	r	Standby / Ready (stays on ready until tripped by laser)
FORCE_WARN	w	Off / On (will activate whichever Warn_Mode is selected
Headings ("MDW," "Main," "Streams," etc)	< , >	("Shift - ," and "Shift - .") Check status.
Quit	Shift – q	Quits program (do after typing 'x' to stop recording data)

   - **Warnings (while parked)**
     - Keep vehicle off but plug in generator

Command	Function
Type "m"	Set to "Baseline"
Type "w"	Activates all warnings (while parked)

* While driving, warnings are only activated using 'w' to forcewarn if the vehicle is traveling above 15mph

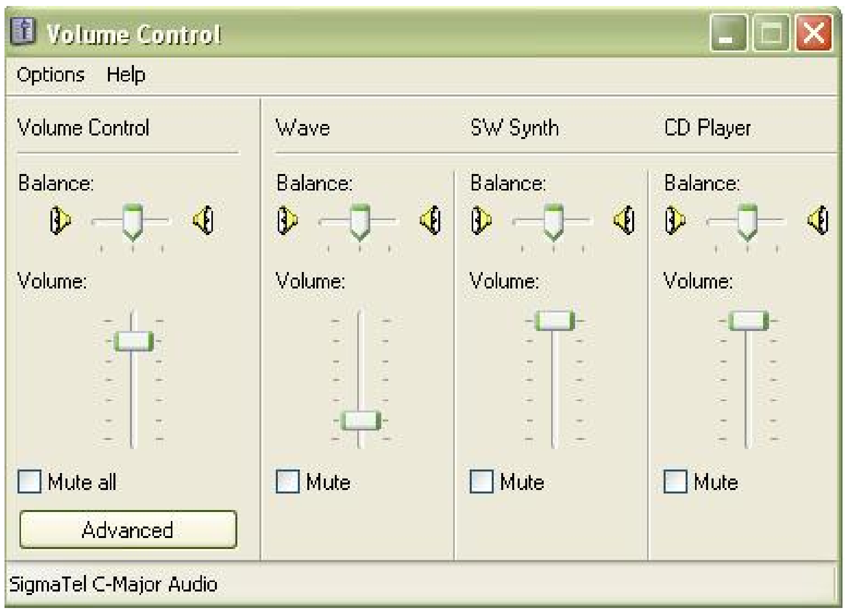
- **Measure throttle push-back force**
    - o Hold straight end of metal rod into center line of accelerator pedal and push down until can place bent end of metal rod to the middle of the duct tape square on center console
    - o Hold green portion strong and steady up against the car
    - o Take starting reading (should be around 2 lbs)
    - o Type “w” to forcewarn and continue to hold green portion tightly while pedal pushes back
    - o Take ending reading (should be around 8 lbs)
    - o Subtract start reading from end reading and force should be 6 lbs.
- **Secondary Brake**
    - Greeter drives vehicle (with Experimenter in the back seat, passenger side) to the Smart Road and radios Dispatch that MDW has one vehicle entering the road.
    - Greeter drives at 55mph and Experimenter applies secondary brake to test stopping.
    - *Once get out of car to set up laser, pop trunk and check cylinder tank levels again*
- **Laser on Road**
    - Set up laser
        (a) Take gray case out to location (just at end of Wilson Creek Bridge, on the left when facing the bottom turn)
        (b) Set two prongs of laser into stationary base
        (c) Plug cord into outlet on ground near road
        (d) Put gray case on the ground and tuck remaining cord into it for protection
        (e) Check for 2 lights to be lit on laser (while nothing in path of laser), if not, check the plug
        (f) Check receptor in back windshield of car to make sure light is on as well

Command	Function
Type “m”	Set to “Haptic_Audio_Visual”
Type “r”	Set laser state to “Ready”

    - Make sure all warnings are activated once drive past laser.

- **Smart Road Cone setup:** During laser checks will also place cones.
    - 1 orange cone with reflector just on other side of top turnaround.
    - 1 orange cone with reflector next to bridge turnaround.
    - 3 cones in turnaround 3 (2 at either opening of turnaround, one with purple arrow flag, 1 at exit of turnaround)
    - 3 gray cones at the bottom turn around (set to indicate orientation of the curve)
    - 1 cone at warning onset point past bridge (outside of guard rail)
    - 1 cone at emergency brake point before curve (outside of guard rail)
    - RPM bump at curve entrance

4. **Set up the greeting room.**
   - Turn on all overhead lights.
   - Close the shades.
   - Turn off the halogen lights.
   - Put stationary chair (not rolling chair with adjustments) for seated eye height measurements against wall by the tape measure.
   - Bring out Participant Payment Log from CASS cabinet.
   - Set up laptop for hearing test.
     - Type “win” into Dos command to start Windows.
     - Double click the speaker icon in the task bar and set to the following levels: “Volume Control”: 5 notches up, “Wave”: 3.5 notches up, “SW Synth”: highest notch, “CD Player”: highest notch.



     - Open Sound Recorder from accessories
     - Place laptop with screen and speakers facing middle of table centered above the right table leg. Place chair on opposite side of table facing away from laptop.

5. **Greet participant, record time that the participant arrived on the <u>Debriefing (Payment) Form</u>**. [If 10 minutes have passed from the time they were supposed to arrive and you have not heard from them re-check the phone in the CASS lab for any messages. If none, go into the Participants folder in MDW2 to find their contact information, or use printed version in MDW2 Participant Binder. Call the numbers listed.

6. **Check the participant’s driver’s license.**

- Must be a valid driver's license to proceed with the study. Out of state is fine. Make sure it has not expired.

7. Give the participant two copies of the <u>Informed Consent</u>.

- Encourage him/her to read it.
- Answer questions (see Notes at end).
- Make sure they check a box regarding history of eye injury.
- Make sure they check a box regarding consent to release the tape.
- Regardless of which box a participant checks, he/she may still participate in study.
- Have participant sign and date the form.
- Give the participant a copy of the informed consent (also signed).

8. Have participant complete front of <u>Tax Form</u> and initial two statements at top back of form.

9. Conduct Hearing Test.

- Check that volume is set as described in #4;
- <u>Procedure:</u> *Please sit in this chair with your back toward me. I will now play a series of sounds, please notify me when you hear a tone by raising your hand.*
- Play each tone in succession, but make sure volume setting is correct (*make sure no clicks are heard, use the finger pad to 'double-click' so that participant cannot hear when the tone is about to play*):
    - <u>1Khz – 5 notches up (should already be set)</u>
    - <u>2Khz – 3 notches up</u>
    - <u>3Khz – 1.5 notches up (half way between 1 and 2)</u>
    - <u>4Khz – 1.5 notches up (half way between 1 and 2)</u>
- <u>Participant must be able to hear all four tones presented to participate in the study.</u>

10. Vision Test (Snellen eye chart test)

- Take the participant over to the eye chart test area.
- Line up their toes to the line on the floor (20 feet).
- Participants can leave on their glasses if they wear them for driving.

Procedure: *Look at the wall and read aloud the smallest line you can comfortably read.*

- <u>If the participant gets every letter correct</u> on the first line they try, ask him or her to try the next smaller line. Continue until they miss a letter. At that time, record the one that they were able to read in full (line above) on the Vision/Hearing/Measurement Form.

- If they get the first line they attempt incorrect, have them read the previous line. Repeat as needed until they get one line completely correct. Record this acuity on the Vision/Hearing/Measurement Form.
- If participants do not have 20/40 vision or better, pay them $20.00 and explain that they do not qualify for this research project.

11. Contrast Sensitivity Test

- Take the participant over to the eye chart test area.
  Line up their toes to the line on the floor (10 feet).
  Participants can leave on their glasses if they wear them for driving.
- Procedure*: It is VERY IMPORTANT you do not squint or lean forward while you are taking the test.*
- Point out the sample patches at the bottom of the chart with the three possible responses (left, right, or straight).
- Cover one eye with an occluder. (DO NOT let the participant use his/her hand to cover the eye since pressure on the eye may cause erroneous contrast sensitivity test results).
- Instruct the participant to begin with Row A and look across from left to right. Ask the participant to identify the last patch in which lines can be seen and tell you which direction they tilt. If the response is incorrect, have the patient describe the preceding patch.
- Use the Vision Test Key in the binder to determine if participant's answers are correct.
- Each vertical column of numbers on the second part of the Vision Test form corresponds to a horizontal row on the chart. Record the last patch the participant correctly identifies in each row by marking the corresponding dot on the form.
- *Cover the other eye and repeat all the steps above.*

12. Vision Test for Color Blindness.

- Take the participant back to his/her desk.
- Place the book containing the plates on the testing apparatus

Procedure: *Please hold the red end of this handle to your nose and read the number on the following plates.*

- Record the participants answers on the Vision/Hearing Form
- Participants will not be disqualified based on the results of this test.

13. Record participants vision correction description on the Vision/Hearing Form.

14. Take standing height and seated eye height measurement.

- Ask participant to stand with his/her back to the tape measure on the wall and record the standing height on the Vision/Hearing Form.

- Ask participant to sit in the chair (non-adjustable stationary chair), back up against backrest, facing the counter and sink in the conference room, and record their seated eye height on the Vision/Hearing Form.

15. Bring participant out front and orient him/her to the vehicle (point out restrooms and drinking fountains).
- *Make sure buckle seat belt and are not wearing a hat.*
- *Power seat: when sitting in seat controls are on the left side of the seat.*
- *Steering wheel: can be positioned forward, backward, up, and down using knob on the left side of the steering wheel column.*
- *Power mirrors: controls are on the arm rest of the door.*
- *Point out the location of the gear shift and tell him/her the experimenter will ask him/her to drive in 3rd gear at certain times.*
- *Point out the cell phone in between the seats, but let them know they won't need to use it until later on.*
- *Point out the dome light and how to push on and off.*
- *Explain to participant that they will not need nor should they use the cruise control.*

At no time will you be using the cruise control, and at no time during the study should you turn off the vehicle.

16. Enter any data already gathered (see Data Entry Protocol) while waiting for the next participant.

17. Keep radio with you, make note of the time Melinda radios Dispatch that they are heading for the familiarization route.
- If more than 30 minutes go by before returning and radioing the Smart Road, please call Melinda's cell phone (250-2486) to verify the location (and safety) of the experimenter and participant.

18. Assemble all forms in packet for participant, have Risk-Taking Style (rt) Questionnaire and Debriefing (Payment) Form ready when return from road.
- Administer the Risk-Taking Style Questionnaire (2 pages)

19. Pay participant and thank them for their time!
- Experimenter will retrieve payment
- Ask participant to fill out payment log
- Give payment and debriefing form to participant

20. After last participant, collect items from road.
- Purple arrow flag from turnaround 3 (can leave cones)

- Laser (put in trunk)
- Take Illuminance Measure
  i) Illuminance meter and flash light should be in back seat.
  ii) Turn on meter and cover so that calibrates to dark
  iii) Set meter up at specified point on bottom turn (middle of road at curve entrance point, near RPM), place on pavement and press side button to freeze reading
  iv) Record reading on MDW2 Order Sheet

21. Vehicle shut-down

- Fuel Silvia
- Park and lock the vehicle in the Simbay; put the keys in the lockbox

22. Shut-down and clean up (along with Lead Experimenter):

- Illuminance meter, pedal force gauge, and flashlights stay in seat pockets.
- Voice recorder, and red data stick, and hearing test laptop go back into CASS cabinet.
- Organize Main Conference Room and VDOT Conference Room
- Close and lock all doors (Simbay, preprooms, CASS lab, front door)
- Put all packets and forms in the "In" box in the CASS cabinet

NOTES:

- This is a surprise study. It is VERY important that details about the true nature of the study (testing curve warnings) are not revealed to the participant. Participants are told that they will be testing cell phone usage while driving. Please do not mention any of the following to the participant:
  - The short length of the Smart Road
  - The turnaround loop at the end of the Smart Road
  - Warning devices in the vehicle
- Please read through the MDW2 Informed Consent Form II to understand what the study is about.
- If the participant asks a question that you don't know how to answer without potentially biasing him or her, for example, "How long is the Smart Road?," you can answer by saying, "I'm not sure."
  - Other responses to "How long is the road," or "What's at the end," etc.:
    (1) *Well, you may have heard, eventually it will meet highway 81.*
    (2) *You will be driving a pretty good section of the road.*
    (3) (Pretend that you have been radioed over headphones) *"What's that Melinda/Miguel? Oh, ok, right, good."*

Appendix S: Experimenter Protocol

VIRGINIA TECH TRANSPORTATION INSTITUTE

Lead Experimenter Protocol

MDW2

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1. **Prior to the participant's arrival, make sure that all the needed forms are available.**
   a. 4 Informed Consent forms (2 of Informed Consent, 2 of Informed Consent II)
   b. Vision/Hearing/Measurement Form
   c. Tax Form
   d. Experimenter Order and Comments Sheet
   e. Stimulus Comprehension Interview
   f. On-Road Debriefing Script
   g. 2 Post-Condition Questionnaires
   h. Hazard Perception Questionnaire
   i. Curve Warning Acceptance Questionnaire
   j. Risk-Taking Style Questionnaire
   k. Debriefing (Payment) Form
   l. Payment Log (kept inside building)

2. **Get radio and headphones from greeter (set to Channel 1).**
   a. Radio dispatch to check on status of road (any wildlife, etc).

3. **Check that the vehicle equipment has been prepared by the Greeter.**
   - **Computer:**
     - Hard drive should be in place and power on, solid green "0" showing
     - Beginning screen should say, "Run Loki? y/n"
   - **Vehicle:**
     - Check brake cylinder pressure in trunk (should be 200 on large gauge, 130 on small gauge).
     - Green light (not red light) near cylinders in trunk should be on.
       - If red light is on, see "Brake Cylinder Protocol."
     - Illuminance meter, flashlights, green force gauge, and voice recorder are in backseat, secured in seat pockets.
     - Cell phone turned on in front seat, attached to Velcro near cup holder.
     - Tape player volume is set to 4 bars (just one step below 5).
     - Fan speed is set to low.
     - Night vision is OFF.

4. **System checks (Experimenter and Greeter together):**
   a. **Software**

Category	Command	Function
RUN LOKI?	y/n, Enter	Runs Loki program
SUBJECT_ID	+/-	Scrolls up or down to participant number
RUN_NUM	u/d	Sets run number for 3 Smart Road runs
TRIP_TYPE	t	Smart_Road / Public_Road (need to stop recording the file ('f') to switch between the two trip types)
NUMBER_COLUMN	0-9	Flags data with a number
WARN_MODE	m	Baseline / Audio_Visual / Haptic_Audio_Visual
RECORD_FILE	s / x	s = starts recording, x = stops recording
MDW_LASER_STATE	r	Standby / Ready (stays on ready until tripped by laser)
FORCE_WARN	w	Off / On (will activate whichever Warn_Mode is selected
Headings ("MDW," "Main," "Streams," etc)	< , >	("Shift - ," and "Shift - .") Check status.
Quit	Shift – q	Quits program (do after typing 'x' to stop recording data)

   b. **Warnings (while parked)**
      - Keep vehicle off but plug in generator

Command	Function
Type "m"	Set to "Baseline"
Type "w"	Activates all warnings (while parked)

      * While driving, warnings are only activated using 'w' to forcewarn if the vehicle is traveling above 15mph

5. **Measure throttle push-back force**
   a. Hold straight end of metal rod into center line of accelerator pedal and push down until can place bent end of metal rod to the middle of the duct tape square on center console
   b. Hold green portion strong and steady up against the car
   c. Take starting reading (should be around 2 lbs)
   d. Type "w" to forcewarn and continue to hold green portion tightly while pedal pushes back
   e. Take ending reading (should be around 8 lbs)
   f. Subtract start reading from end reading and force should be 6 lbs.

6. **Secondary Brake**
   a. Greeter drives vehicle (with Experimenter in the back seat, passenger side) to the Smart Road and radios Dispatch that MDW has one vehicle entering the road.
   b. Greeter drives at 55mph and Experimenter applies secondary brake to test stopping.
   c. *Once get out of car to set up laser, pop trunk and check tank levels again*

7. **Laser on Road**
    a. Set up laser
        i. Take gray case out to location (just at end of Wilson Creek Bridge, on the left when facing the bottom turn)
        ii. Set two prongs of laser into stationary base
        iii. Plug cord into outlet on ground near road
        iv. Put gray case on the ground and tuck remaining cord into it for protection
        v. Check for 2 lights to be lit on laser (with nothing in path of laser), if not, check the plug
        vi. Check receptor in back windshield of car to make sure light is on as well

Command	Function
Type "m"	Set to "Haptic_Audio_Visual"
Type "r"	Set laser state to "Ready"

    b. Make sure all warnings are activated once drive past laser.

8. **Smart Road Cone setup:** During laser checks will also place cones.
    - 1 orange cone with reflector just on other side of top turnaround.
    - 1 orange cone with reflector next to bridge turnaround.
    - 3 cones in turnaround 3 (2 at either opening of turnaround, one with purple arrow flag, 1 at exit of turnaround)
    - 1 cone at warning onset point past bridge (outside of guard rail)
    - 1 cone at emergency brake point before curve (outside of guard rail)
    - RPM bump at curve entrance

9. **After participant arrives and has completed all forms/tests with Greeter, Greeter will orient the participant to the vehicle.**
    a. Make sure buckle seat belt and are not wearing a hat.
    a. Power seat: when sitting in seat controls are on the left side of the seat.
    b. Steering wheel: can be positioned forward, backward, up, and down using knob on the left side of the steering wheel column.
    c. Power mirrors: controls are on the arm rest of the door.
    d. Point out the location of the gear shift and tell him/her the experimenter will ask him/her to drive in 3rd gear at certain times.
    e. Point out the cell phone in between the seats, but let them know they won't need to use it until later on.
    f. Point out the dome light and how to push on and off.
    g. Explain to participant that they will not need nor should they use the cruise control.

10. Begin computer program

Category	Command	Function
RUN LOKI?	y, Enter	Runs Loki program
SUBJECT_ID	+/-	Set to participant number
RUN-NUM	u/d	Will set for Smart Road runs
TRIP_TYPE	t	Set to Public_Road
WARN_MODE	m	Baseline
RECORD_FILE	s	Begins recording
Headings ("MDW," "Main," "Streams," etc)	>	Scroll to "Streams" MPEG_STREAM[ON] is displayed at the top

11. Orient the participant to the study (while parked).

The experiment will last approximately one hour. You will only be driving this vehicle during that time. I will be present with you at all times. First, you will drive on several Blacksburg roads to become familiar with the vehicle. It is important that you follow all traffic laws and speed limits. You will not be asked to perform any cellular phone tasks while driving on public roads. We will then return to the Smart Road for the remainder of the study. I will give instructions at various times and you will complete several questionnaires and ratings while on the road and once you return to the building.

It is important for you to understand that we are evaluating the technology, not you. You will be expected to drive as you would normally, while following all traffic markings and obeying the speed limits of at most 55mph. Any tasks you perform, mistakes you make, or opinions you have will only help us do a better job evaluating cell phone usage while driving. Therefore, we ask that you perform to the best of your abilities. The information and feedback that you provide is very important to this project.

If at any time you feel uncomfortable you can let me know that you wish to stop and I will drive us back to the VTTI building. Please remember that cell phone usage is being evaluated, not you or your performance.

Do you have any questions before we head out to the road?

12. Radio Dispatch for safety – notify going to begin orientation drive.

I am going to radio the Control Center dispatch to let them know that we are leaving for the public roads and so that they can monitor our location. -Dispatch, this is Melinda with the Cell Phone Study. We are heading out to the familiarization part of the study. I'll keep you posted on our location.

13. Inform participant that he/she will not need to use the cell phone for this local road drive.

14. Ask participant to drive orientation route, making sure that the windows are rolled up, the participant is not wearing a hat, and that all passengers have their seat belts buckled.

I will let you know where to turn as we go along the route. Please follow all traffic rules, signs, and speed limits.

15. Orientation Route Directions:

i. *Left on Industrial Park Dr.*
ii. *Straight through light crossing 460 Business*
iii. *Left at light onto 460 Bypass East*
iv. *Right onto Pepper's Ferry exit*
v. *Right at Stop sign*
vi. *Right at light, left into DMV – park.* Do you have any questions about how the vehicle handles in highway driving? ***Turn ON file at this point (record).***
vii. *Go back out to light and take a left.*
viii. *Straight and follow left curve to stay on service road*
ix. *Right at Stop Sign onto Cinnabar Rd.* Speed limit for this road is 35mph.
x. *Left onto Yellow Sulfur Spring Rd. (just over hill at bottom of a valley)* Please put the vehicle in 3rd gear. Speed limit for this road is 35mph.
xi. *Right onto 460 Business*
xii. *Right onto Industrial Park Dr.*

- **Flag data once on sharp left curve to service road – Press 1.**

Command	Function
Type "1"	Flags data with this number

- **Document any unexpected events.** Make a note if the computer needed to be restarted, if there are events that might influence data (e.g. wildlife on the road), etc.

16. Return to the Smart Road, radio dispatch and enter the road.

- Set beams to either high or low.

17. Set up computer.

Command	Function
Type "t"	Set to Smart_Road
Type "u"	Set to Run_Num 1
Type "m"	Set to warning mode for Condition 1
Type "r"	Set laser state to Ready

18. Ask participant to park near orange cone (facing down the road.)

Now we're going to drive down the Smart Road so that you can get used to driving on this road. Please maintain a speed limit of 55 mph. You will not perform any cell phone tasks until we park and I give you more instructions, but I will ask you to stop at one point so that I can show you the training area for the cell phone tasks. Once we are driving I will not be able to talk to you. Please put the car into 3rd gear, and you may start down the road when you're ready. Please try to stay as close to 55 mph as possible.

- Check that participant is set in 3rd gear on dash

- **Once vehicle reaches the start of the small bridge prior to the Willow Creek Bridge, ask the participant to slow down and then stop once they reach the flagged cone near the Bridge Turn on the right.**

Please begin to slow the vehicle; I'm going to ask you to come to a complete stop when you reach an orange cone with a reflector located on the right side of the road. This is the training area we will use to learn different cell phone tasks. OK, please leave the vehicle in 3rd gear and continue down the road at 55mph.

- Check that participant is set in 3rd gear on dash

19. * Watch the data and if the laser is not triggered,

- **And Warn_Mode is Baseline:**

Command	Function
Type "1" at 1st cone	Flags data when reach warning onset
Say "brake" and apply brake at 2nd cone if no sign of slowing	Slows vehicle
Type "2" at rpm bump on curve	Flags data when reach curve entrance

- **And Warn_Mode 1 or 2 is set:**

Command	Function
Type "w" at 1st cone	Activates warning manually
Say "brake" and apply brake at 2nd cone if no sign of slowing	Slows vehicle
Type "2" at rpm bump on curve	Flags data when reach curve entrance

20. * If laser is triggered, but no warning goes off once "DISTANCE_TO_CURB" reaches 0.0000:

Command	Function
Type "w"	Activates warning manually

21. *** If the participant does not apply the brake once the safety point on the road is reached, say, "Brake!" If participant does not begin braking, apply the secondary brake. ***

Command	Function
Say "brake" and apply brake if no sign of slowing once Distance_to_curb = -414 (2nd cone along the road)	Slows vehicle

- If the participant seems shaken up, explain what happened and offer to drive him or her back to the building.

  After participant has passed apex of loop:

  What you just experienced is part of the study, I will explain more once we park. Please stop the car and put it in park once we get to the other side of the loop and are facing back up the road.

22. Park and perform debriefing.

- Conduct Stimulus Comprehension Interview. (*Did you notice anything just now? Can you describe what you noticed? What did it mean to you?)*
  - Record participant's responses with Olympus Voice Recorder DS-330

Command on Recorder	Function
Slide "Hold" to down position	Turns recorder on
Switch microphone cord mounted on back of seat rest to "On"	Turns microphone on
Press side "Folder/Menu" button	Will save file in desired folder
Press Rec. on side	Records
Press Stop on front	Stops recording
Press New on side whenever want to start a new file	Starts new file

- Administer Post-Condition Questionnaire if participant received a warning.

- Administer Hazard Perception Questionnaire (1st page verbal, second in q binder).
  - Before the written portion, ask the following:
    - For participants who **did** receive a warning:

    (1) *Would you say that you first became aware of the sharp curve (turnaround loop) at the end of the Smart Road:*
      - (a) *Prior to the warning*
      - (b) *During the warning*
      - (c) *After the warning*

- Read on-road debriefing script (plastic sheet in Experimenter Binder).
- Ask the participant to read over and sign the Informed Consent Form II and ask for any questions they have.

- If participant chooses not to continue the study, offer to drive them back to the building or let the participant drive back to the building.
- Fill out the Debriefing Form and pay them for their time.

23. **If the participant chooses to continue, instruct him or her to head back up the road.**

Please drive back up the road and I will let you know where to turn so that we can head back down the road just a few more times.

Please turn into the turnaround entrance just after you see the red/purple reflective flag ahead. Go through and continue back down the road.

a. Have the participant turn around at Turn 3; once they are facing down the road instruct them to continue down the road until they reach the orange cone near the bridge turn.
b. Ask them to stop the vehicle when reach bridge turn cone, and then have them proceed again from that point at 55mph in 3^{rd} gear.
c. Administer Stimulus Comprehension Interview after *each* remaining stimulus presentation. (Record participants comments with Sound Editor)
d. Administer Post-Condition Questionnaire after each remaining *warning* stimulus presentation.
e. Administer Curve Warning Acceptance Questionnaire once at end.
f. Once 3 runs have been completed, review the 3 stimulus presentations.
   - If he/she never mentioned the pedal, ask if he/she felt anything different while driving to the curve.
   - Summarize the three different "trips" to the curve, and what were involved with the warnings at each one.
   - Ask him/her to rank the three different trips, note rankings on order sheet
g. Ask participant to head back up to the building at a comfortable speed but at least 40mph.

24. Save data and stop program.

Command	Function
Type "x" to set to "Off"	Stops recording file
Type Shift - q	Quits program
Once screen says "Power Down" type Ctrl-Alt-Delete	Restarts program
Insert MDW2 flash drive into slot in trunk	
Type "n" when screen says 'Run Loki?'	Starts save copy script
Type "1" to Copy Data	While blank, data is still copying (data stick should be flashing)
Wait until list of 3 options reappears	Copying has finished
Type "3" to Shut Down	When screen says "Power Down," can

	remove flash drive
After remove flash drive, type Ctrl-Alt-Delete	Restarts program
Type "y" when screen says 'Run Loki?'	Sets up for next participant

25. **Once back at the building, greeter will administer <u>Risk-Taking Style Questionnaire</u>.**

26. **Payment and debriefing.** At the end of the study pay the participant ($20.00 per hour, rounding up to the nearest ½ hour). Complete the <u>Debriefing (Payment) Form</u> and give to the participant. Have the participant sign the <u>Payment Log</u>, and thank them for their participation!

27. **Save data from data stick onto the server under "CASS - MDW2 – Data-Raw" folder. Put files into individual participant folders.**
    - Check the data with Peeping Tom – look at the video, speed, accel, and brake views to makes sure data was recorded properly.

28. **Shut-down and clean up (along with Greeter):**
    - Park and lock the vehicle in the Simbay; put the keys in the lockbox
    - Voice recorder, red data stick, and hearing test laptop go back into CASS cabinet
    - Download voice recorder files
    - Organize Main Conference Room and VDOT Conference Room
    - Close and lock all doors (Simbay, preprooms, CASS lab, front door)

<u>NOTES:</u>

- This is a surprise study. It is VERY important that details about the true nature of the study (testing curve warnings) are not revealed to the participant. Participants are told that they will be testing cell phone usage while driving. Please do not mention any of the following to the participant:
  - The short length of the Smart Road
  - The turnaround loop at the end of the Smart Road
  - Warning devices in the vehicle
- Please read through the MDW2 Informed Consent Form II to understand what the study is about.
- If the participant asks a question that you don't know how to answer without potentially biasing him or her, for example, "How long is the Smart Road?," you can answer by saying, "I'm not sure."
  - Other responses to "How long is the road," or "What's at the end," etc.:
    (1) *Well, you may have heard, eventually it will meet highway 81.*
    (2) *You will be driving a pretty good section of the road.*
    (3) (Pretend that you have been radioed over headphones) *"What's that Melinda/Miguel? Oh, ok, right, good."*

Appendix T: On-Road Participant Debriefing Script

The following is to be read after the FIRST stimulus presentation in which a warning stimulus is presented:

1. Stimulus Comprehension Interview (general examples of probe questions)

Did you notice anything just now?

Can you describe what you noticed?

What did it mean to you?

2. Debriefing Statement

"Now I would like to tell you that the purpose of this study is to gather drivers' reactions to a curve warning device. There will be no cell phone tasks for you to perform. You will be asked to drive a short portion of the Smart Road several more times and to give your opinions about the driving task and the warning. The reason we do not inform participants of the warning before driving on the Smart Road is so that we can see how the warning performs for drivers that are not expecting the situation. There will be no more surprises; would you like to continue with the study?

3. Administer Second Informed Consent Form

4. Permission to Keep Data from Trial 1

Now that you are aware of the purpose of this study, is it all right for us to keep the data collected from the first trial?

Yes or **No**

Do you have any questions before we continue?

Appendix U: Informed Consent Form II

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Informed Consent for Participants of Investigative Projects

Debriefing and Informed Consent for Participants of Investigative Projects

Title of Project: Multidimensional Warnings
Investigators: Melinda McElheny, Myra Blanco, and Tonya Smith-Jackson

THE PURPOSE OF THIS RESEARCH

The true purpose of this research is to gather driver reactions to and opinions about in-vehicle curve warnings. This device would have the ability to calculate an appropriate, vehicle-specific curve speed. If the vehicle speed is too fast for the upcoming curve, this system would communicate to the driver that he/she needs to slow down. This research will contribute to the current body of knowledge regarding Intelligent Transportation Systems. The results of the research will also provide guidelines for future test methods. One aspect of the research project deals with how people might respond to such a warning the first time they encounter it. To do this, we needed to create a situation where you were presented with the warning without expecting it. If you had anticipated the warning, the data would not have been as useful. There was no "correct" or "incorrect" information in the data that you provided. We needed to compare your response to others who were presented with the same situation. All known precautions were taken to ensure your complete safety throughout this session and during the presentation of the scenario. We would like to thank you for your participation in this study, as the results may contribute to future development of in-vehicle warning devices. **We would also like to ask that you do not talk about the details of this study to others for at least 3 months after your participation as this may invalidate future data that may be collected.**

We again assure you that all data will be treated with complete anonymity. Shortly after participating, your name will be separated from the data. A coding scheme will be employed to identify the data by subject number only (for example, Subject No. 3).

We will continue running the experiment, and you will be presented with additional curve warning displays. You will also complete a few more questionnaires.

All other aspects of the earlier informed consent you signed, including risks, benefits, safety precautions, and your responsibilities, continue to apply to the remainder of this experiment.

I hereby acknowledge the above and give my voluntary consent for my data to be used in this project.

____

Participant's SignatureDate

Should I have any questions about this research or its conduct, I may contact:

Melinda McElheny(540) 231-1557
Myra Blanco(540) 231-1500
Tonya Smith-Jackson(540) 231-4119
David Moore, Chair, IRB(540) 231-4991

Appendix V: Participant Debriefing and Payment Form

NAME:______________________________

Virginia Tech 1872

TRANSPORTATION INSTITUTE

Thank you for your collaboration and interest in this study. The time that you have taken to evaluate these new technologies is greatly appreciated. The results of this evaluation process will help refine the design of in-vehicle warning systems. We appreciate your cooperation to keep the details of this study including the displays confidential.

If you have any questions please do not hesitate to contact us. Melinda McElheny and Myra Blanco will be glad to answer all your questions related to this evaluation process.

Date:	___/__/__
Time In:	____:____
Time Out:	____:____
Time	____:___

TOTAL TIME:___________________

TOTAL PAYMENT*:_______________

VTTI Staff Signature:_______________

*Please note that payments you receive in accordance with this research are considered taxable income. If payment exceeds $600.00 in any one calendar year, Virginia Tech is required to file a 1099 form with the IRS. For amounts less than $600.00, you are responsible for reporting additional income, but no 1099 tax forms will be filed with the IRS.

Virginia Tech Transportation Institute
3500 Transportation Research Plaza (0536)
Blacksburg, Virginia 24061
Phone: (540) 231-1500 Fax: (540) 231-1555

Appendix W: ANOVA Tables

W.1. Between-Subjects Design

Throttle Reaction Time

Source	DF	SS	MS	F value	P value
Between					
AGE	1	0.3	0.3	0.20	0.6585
SURPRISE STIMULUS PRESENTATION	2	57.5	28.8	20.65	<.0001 *
AGE X SURPRISE STIMULUS PRESENTATION	2	4.3	2.1	1.53	0.2303
PARTICIPANT(AGE SURPRISE STIMULUS PRESENTATION)	37	51.5	1.4		
TOTAL	42	113.6			

Brake Reaction Time

Source	DF	SS	MS	F value	P value
Between					
AGE	1	1.3	1.3	1.22	0.2761
SURPRISE STIMULUS PRESENTATION	2	21.2	10.6	9.85	0.0004 *
AGE X SURPRISE STIMULUS PRESENTATION	2	1.5	0.8	0.71	0.4971
PARTICIPANT(AGE SURPRISE STIMULUS PRESENTATION)	37	39.8	1.1		
TOTAL	42	63.8			

Smart Road Curve Entry Speed

Source	DF	SS	MS	F value	P value
Between					
AGE	1	166.5	166.5	9.05	0.0046 *
SURPRISE STIMULUS PRESENTATION	2	444.2	222.1	12.08	<.0001 *
AGE X SURPRISE STIMULUS PRESENTATION	2	6.6	3.3	0.18	0.8356
PARTICIPANT(AGE SURPRISE STIMULUS PRESENTATION)	38	698.8	18.4		
TOTAL	43	1316.1			

* $p < 0.05$ (significant)

W.2. Mixed Factors Design

Throttle Reaction Time

Source	DF	SS	MS	F value	P value
Between					
AGE	1	1.9	1.9	2.46	0.1238
PARTICIPANT(AGE)	45	35.6	0.8		
Within					
STIMULUS PRESENTATION	2	262.1	131.1	160.32	<.0001 *
AGE X STIMULUS PRESENTATION	2	6.4	3.2	3.90	0.0242 *
STIMULUS PRESENTATION X PARTICIPANT(AGE)	80	65.4	0.8		
TOTAL	130	371.4			

Brake Reaction Time

Source	DF	SS	MS	F value	P value
Between					
AGE	1	3.4	3.4	3.29	0.0763
PARTICIPANT(AGE)	45	46.0	1.0		
Within					
STIMULUS PRESENTATION	2	206.8	103.4	104.10	<.0001 *
AGE X STIMULUS PRESENTATION	2	1.2	0.6	0.61	0.5442
STIMULUS PRESENTATION X PARTICIPANT(AGE)	81	80.4	1.0		
TOTAL	131	337.8			

Smart Road Curve Entry Speed

Source	DF	SS	MS	F value	P value
Between					
AGE	1	176.0	176.0	7.42	0.0091 *
PARTICIPANT(AGE)	46	1091.0	23.7		
Within					
STIMULUS PRESENTATION	2	1327.5	663.7	54.48	<.0001 *
AGE X STIMULUS PRESENTATION	2	22.5	11.2	0.92	0.4016
STIMULUS PRESENTATION X PARTICIPANT(AGE)	86	1047.7	12.2		
TOTAL	137	3664.7			

* $p < 0.05$ (significant)

W.3. Run Number Within-Subject Design

TRT

Source	DF	SS	MS	F value	P value
Between					
PARTICIPANT	46	43.7	1.0		
Within					
RUN	2	9.8	4.9	1.26	0.2881
RUN XPARTICIPANT	82	318.7	3.9		
TOTAL	130	372.2			

BRT

Source	DF	SS	MS	F value	P value
Between					
PARTICIPANT	46	53.7	1.2		
Within					
RUN	2	25.1	12.6	3.97	0.0225 *
RUN XPARTICIPANT	83	262.5	3.2		
TOTAL	131	341.3			

SRspeed

Source	DF	SS	MS	F value	P value
Between					
PARTICIPANT	47	1320.3	28.1		
Within					
RUN	2	24.1	12.1	0.45	0.642
RUN XPARTICIPANT	88	2383.0	27.1		
TOTAL	137	3727.4			

* $p < 0.05$ (significant)

W.4. Post-Condition Questionnaire

1. This type of warning conveyed a sense of urgency (requiring immediate attention).

Source	DF	SS	MS	F value	P value
Between					
AGE	1	0.2	0.2	0.29	0.5953
PARTICIPANT(AGE)	46	26.8	0.6		
Within					
STIMULUS PRESENTATION	1	0.0	0.0	0.08	0.7739
AGE X STIMULUS PRESENTATION	1	0.0	0.0	0.00	1
STIMULUS PRESENTATION X PARTICIPANT(AGE)	46	23.0	0.5		
TOTAL	95	50.0			

2. This type of warning was annoying.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	2.0	2.0	1.03	0.3148
PARTICIPANT(AGE)	46	90.9	2.0		
Within					
STIMULUS PRESENTATION	1	0.7	0.7	1.52	0.2238
AGE X STIMULUS PRESENTATION	1	0.2	0.2	0.38	0.5406
STIMULUS PRESENTATION X PARTICIPANT(AGE)	46	20.2	0.4		
TOTAL	95	114.0			

3. This type of warning was appropriate for a curve warning device.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	0.4	0.4	0.23	0.6341
PARTICIPANT(AGE)	46	75.1	1.6		
Within					
STIMULUS PRESENTATION	1	0.4	0.4	0.86	0.3574
AGE X STIMULUS PRESENTATION	1	0.7	0.7	1.54	0.2214
STIMULUS PRESENTATION X PARTICIPANT(AGE)	46	20.0	0.4		
TOTAL	95	96.6			

* $p < 0.05$ (significant)

W.4. Post-Condition Questionnaire (cont'd)

4. This type of warning interfered with my driving.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	2.7	2.7	1.61	0.2102
PARTICIPANT(AGE)	46	76.0	1.7		
Within					
STIMULUS PRESENTATION	1	0.0	0.0	0.00	1.0000
AGE X STIMULUS PRESENTATION	1	0.4	0.4	0.51	0.4775
STIMULUS PRESENTATION X PARTICIPANT(AGE)	46	33.6	0.7		
TOTAL	95	112.7			

5. If my car was equipped with a curve warning device I would want this type of warning to be presented.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	8.8	8.8	4.65	0.0364 *
PARTICIPANT(AGE)	46	86.7	1.9		
Within					
STIMULUS PRESENTATION	1	0.0	0.0	0.02	0.8846
AGE X STIMULUS PRESENTATION	1	3.0	3.0	6.16	0.0168 *
STIMULUS PRESENTATION X PARTICIPANT(AGE)	46	22.5	0.5		
TOTAL	95	121.0			

* $p < 0.05$ (significant)

W.5. Curve Warning Acceptance Questionnaire

1. Useful - Useless

Source	DF	SS	MS	F value	P value
Between					
AGE	1	2.1	2.1	3.35	0.0736
PARTICIPANT(AGE)	46	28.6	0.6		
TOTAL	47	30.7			

2. Pleasant - Unpleasant

Source	DF	SS	MS	F value	P value
Between					
AGE	1	6.1	6.1	6.45	0.0147 *
PARTICIPANT(AGE)	46	42.8	1.0		
TOTAL	47	48.9			

3. Bad - Good

Source	DF	SS	MS	F value	P value
Between					
AGE	1	1.0	1.0	1.4	0.2422
PARTICIPANT(AGE)	46	33.5	0.7		
TOTAL	47	34.5			

4. Nice - Annoying

Source	DF	SS	MS	F value	P value
Between					
AGE	1	4.1	4.1	2.88	0.0963
PARTICIPANT(AGE)	46	65.2	1.4		
TOTAL	47	69.3			

5. Effective - Superfluous

Source	DF	SS	MS	F value	P value
Between					
AGE	1	2.1	2.1	2.69	0.1076
PARTICIPANT(AGE)	46	35.6	0.8		
TOTAL	47	37.7			

* $p < 0.05$ (significant)

W.5. Curve Warning Acceptance Questionnaire (cont'd)

6. Irritating - Likeable

Source	DF	SS	MS	F value	P value
Between					
AGE	1	6.0	6.0	4.95	0.031 *
PARTICIPANT(AGE)	46	56.0	1.2		
TOTAL	47	62.0			

7. Assisting - Worthless

Source	DF	SS	MS	F value	P value
Between					
AGE	1	0.5	0.5	0.96	0.3323
PARTICIPANT(AGE)	46	25.0	0.5		
TOTAL	47	25.5			

8. Undesirable - Desirable

Source	DF	SS	MS	F value	P value
Between					
AGE	1	9.2	9.2	8.78	0.0048 *
PARTICIPANT(AGE)	46	48.1	1.0		
TOTAL	47	57.3			

9. Raising Alertness - Sleep-Inducing

Source	DF	SS	MS	F value	P value
Between					
AGE	1	0.2	0.2	2.01	0.163
PARTICIPANT(AGE)	46	4.3	0.1		
TOTAL	47	4.5			

* $p < 0.05$ (significant)

W.6. Hazard Perception Questionnaire

1. I often (at least several times per month) drive on roads with two or more tight curves.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	0.1	0.1	0.07	0.7975
PARTICIPANT(AGE)	46	57.6	1.3		
TOTAL	47	57.7			

2. Once I noticed a curve at the end of the Smart Road, the curve seemed like it could be a dangerous driving maneuver.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	1.0	1.0	1.48	0.2304
PARTICIPANT(AGE)	46	31.2	0.7		
TOTAL	47	32.2			

3. I usually drive above the speed limit posted on curves.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	2.5	2.5	2.25	0.1402
PARTICIPANT(AGE)	46	51.5	1.1		
TOTAL	47	54.0			

4. Roadway curves are hazardous.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	1.7	1.7	2.31	0.1355
PARTICIPANT(AGE)	46	33.6	0.7		
TOTAL	47	35.3			

5. Posted advisory speeds for curves are usually much slower than they need to be.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	0.0	0.0	0.05	0.8329
PARTICIPANT(AGE)	46	48.0	1.0		
TOTAL	47	48.0			

* $p < 0.05$ (significant)

W.7. Risk-Taking Style Questionnaire

1. Many traffic rules must be ignored to ensure traffic flow.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	2.1	2.1	1.87	0.1778
PARTICIPANT(AGE)	46	51.2	1.1		
TOTAL	47	53.3			

2. Traffic rules must be respected regardless of road and weather conditions.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	3.0	3.0	2.35	0.132
PARTICIPANT(AGE)	46	58.7	1.3		
TOTAL	47	61.7			

3. Speed limits are exceeded because they are too restrictive.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	8.3	8.3	7.15	0.0103 *
PARTICIPANT(AGE)	46	53.6	1.2		
TOTAL	47	61.9			

4. It is acceptable to take chances when no other people are involved.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	2.5	2.5	2.5	0.121
PARTICIPANT(AGE)	46	46.5	1.0		
TOTAL	47	49.0			

5. If you are a good driver it is acceptable to drive a little faster.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	8.3	8.3	7.19	0.0102 *
PARTICIPANT(AGE)	46	53.3	1.2		
TOTAL	47	61.6			

6. I would never drive after drinking alcohol.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	2.5	2.5	1.8	0.1859
PARTICIPANT(AGE)	46	64.3	1.4		
TOTAL	47	66.8			

* $p < 0.05$ (significant)

W.7. Risk-Taking Style Questionnaire (cont'd)

7. Break 50 mph speed limits by more than 10 mph.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	30.1	30.1	60.39	<.0001 *
PARTICIPANT(AGE)	46	22.9	0.5		
TOTAL	47	53.0			

8. Overtake the car in front even when it keeps the appropriate speed.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	17.5	17.5	22.21	<.0001 *
PARTICIPANT(AGE)	46	36.3	0.8		
TOTAL	47	53.8			

9. Ignore traffic rules to proceed faster.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	31.7	31.7	55.44	<.0001 *
PARTICIPANT(AGE)	46	26.3	0.6		
TOTAL	47	58.0			

10. Drive too close to the car in front to be able to stop if it should brake.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	13.0	13.0	17.13	<.0001 *
PARTICIPANT(AGE)	46	35.0	0.8		
TOTAL	47	48.0			

11. Keep driving when I am tired and actually need a break.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	13.0	13.0	12.23	0.0011 *
PARTICIPANT(AGE)	46	49.0	1.1		
TOTAL	47	62.0			

12. Drive long distances in a car without wearing a seatbelt.

Source	DF	SS	MS	F value	P value
Between					
AGE	1	1.7	1.7	2.38	0.1298 *
PARTICIPANT(AGE)	46	32.6	0.7		
TOTAL	47	34.3			

* $p < 0.05$ (significant)

W.7. Risk-Taking Style Questionnaire (cont'd)

Risk-Taking Style Score

Source	DF	SS	MS	F value	P value
Between					
AGE	1	1291.7	1291.7	38.23	<.0001 *
PARTICIPANT(AGE)	46	1554.3	33.8		
TOTAL	47	2846.0			

* $p < 0.05$ (significant)

Appendix X: Stimulus Comprehension Interview Participant Comments and SC Score

#	Stimulus	Run	Comments	Noticed Warning	ID all components correctly	ID proper response action	SC Score
Participant Number	1=A.V., 2=H.A.V.	Number of run down road	Participant comments recorded during interview				
1	1	1	I noticed anything…the thing (pointed to visual) came on? It talked to me. I mean, it was just shocking, I don't know. Oh ok, it was just kind of all of a sudden out of no where, so, kind of like had to react to it I guess. Is that good, I don't know what you want?	1	1		**2**
1	2	2	I think it was more before the turn, and the I guess the accelerator pedal, it popped, like when the warning went off. I noticed the gray cones you were talking about. I think that's…it didn't startle me at all, because I was looking forward to it I guess.	1	1		**2**
2	1	3	Um, there was a yellow light, black arrow, and 15 miles per hour and the voice that told me to reduce it to 15.	1	1	1	**3**
2	2	1	That light. It's orangish yellow. And black arrow. Said 15 miles an hour I think. That voice. Um, meant to slow down.	1		1	**2**
3	1	2	Yes, the car alerted me that there was a curve a head and to slow down to 15 mph. Um, it's kind of loud. The announcement.	1		1	**2**
3	2	3	Um, the gas turned off. And the audible warning again, and visual. Um, the audible and visual was the same as last time, but the gas coming up really caught me off-guard.	1	1		**2**
4	1	3	Um, well it seemed like it was a little different than the first time but I don't know if that was because I was more expecting it. But the same thing with the flashing light and the voice telling me to slow down.	1	1	1	**3**
4	2	2	Um, there was a flashing light, and um, the voice or whatever said to slow down to 15. And the flashing light wouldn't go off until I got down to 15.	1		1	**2**
5	1	1	Uh, yeah. The terrible light and voice. I don't know [what they meant], they just scared me, I thought something was wrong with the car.	1	1		**2**
5	2	3	Blinking light, and the gas pedal, like, let off itself or something. I needed to slow down.	1		1	**2**
6	1	2	OK, definitely noticed obviously the sound again, um as ironic as it seems it didn't seem as loud this time as the first time. I did see the orange background I did see the black arrow and the black 15, but this time I saw the curve as the warning was going on, not after.	1	1	1	**3**
6	2	1	Ha, yeah, um, I actually heard the sound before I saw the orange flash. There was an orange flash somewhere near the speedometer. It was an orange flash but there was a curve symbol and I think the number 15 in black, so it was black on an orange background. Um, I heard the sound and saw the whatever was going on in here in orange and black.	1		1	**2**
7	1	1	um the flashing light and the sound, um I was pretty surprised and I guess it meant that there was something coming up	1	1	1	**3**
7	2	2	Um flashing light again, and sound again, and like the pedal came up I guess	1	1		**2**
8	1	3	Well, I'm not sure if this messes with it, but I did look down and see that I was going 60, so I was already braking a little bit to slow my pace down because I was going to fast, so I don't know if that screwed it up at all. But I liked it better because I didn't feel a jolt at my foot. I just saw the light and the voice and I think the foot thing is what, maybe also because I knew what was going to happen, but the first time the foot thing really freaked me out more. If you changed the order I might have a different opinion, but I liked it better without the feet. The light was good and the voice was good too, although I still think I might turn that off. If this was my car and I knew what this light warning thing was, and I knew that that light meant "curve ahead" but I guess this could be used for more than one thing so the voice might be good. Anyway, it was better.	1	1	1	**3**

Appendix X: Stimulus Comprehension Interview Participant Comments and SC Score (cont'd)

#	Stimulus	Run	Comments	Noticed Warning	ID all components correctly	ID proper response action	SC Score
Parti-cipant Num-ber	1=A.V., 2=H.A.V.	Number of run down road	Participant comments recorded during interview				
8	2	1	Um, a bright light that like just about scared me to death, and then the car braking, or it felt like the car was braking, I got like a pulse through my foot too, um, and then, or maybe that was the braking, I don't know, my foot felt it on the brake pedal, and then the voice obviously saying curve ahead, please slow down or whatever it said, but the yellow light was really what shocked me. The light was probably the best thing and it's also probably what I noticed first, but normally I drive with my music too loud, and so I may not even hear the voice talking, and it might actually be something that I would rather just have the light because the voice was like, "eee!" but that would maybe be something you could turn on or off depending on what kind of person you are. But I think it was bright enough that if I was looking away I would still see that brigth yellow light flashing on my dashboard, so anyway, I have the music loud, I'm not sure I would hear the voice, but the light was good.	1	1	1	**3**
9	1	2	Um, the warning. Just the flash of light and the voice. To slow down.	1	1	1	**3**
9	2	3	A warning came on before the curve, the flash of light and the voice. It was better than the first time.	1			**1**
10	1	3	There was a visual flashing light and audio telling me to slow down. That I should slow down because there was a curve ahead.	1	1	1	**3**
10	2	2	It pushed my foot off the gas pedal, and flashed a light, and told me to go like 15 mph. That I should slow down and there's a curve ahead.	1	1	1	**3**
11	1	1	Yeah, the uh, this little sign here flashed me and told me to reduce my speed. No, I think that's it. That there was a turn coming up.	1		1	**2**
11	2	3	.				**.**
12	1	2	I noticed the orange flashing thing popped up with the 15 and the arrow.	1			**1**
12	2	1	I noticed that there was this orangish blinking that popped up. The, um, it was like the voice also. That um, something was coming up and I should respond. It was kind of startling, but it was (Did not mention haptic until prompted - then said felt it.)	1		1	**2**
13	1	1	Yeah, was I supposed to go left? That little thing was pointing left, 15 mph, and said 15mph. It meant turn, I figured it wanted me to turn left at those cones, but I was in the right lane, so I didn't want to mow it over.	1	1		**2**
13	2	2	There was something in the foot pedal. Once that light came on it jumped something at me. The light came on again. Lady came on the radio.	1	1		**2**
14	1	3	Um, the warning came on again, but the light stayed on during the whole turn. I didn't feel it pop. But I'm wondering if that was just me jumping when it came on the first time.	1		1	**2**
14	2	1	Uh yeah, the car talked. The foot, I it was the gas that popped, maybe the brake. I forget what my foot was on, the pedal popped. Flashing light in front of me. Slow down to 15.	1	1	1	**3**
15	1	2	Uh, the flashy sign and the voice. I thought that flashy light was kind of annoying, and the voice actually startled me when I first heard it, but it worked. Does that go off when I reach 15?	1	1	1	**3**
15	2	3	I felt the accelerator pedal like pop back or something, on top of the flashing light and the voice.	1	1		**2**
16	1	3	Um, just that the blinker stayed on until I got to 15, or below 15, and then it turned off. Yeah, I noticed the pedal.	1		1	**2**
16	2	2	Um, just that sensor went off telling me to slow down. Just the blinking sensor that said there was a right turn, or a turn at 15 miles per hour. Telling me to slow down. Surprised me when all three things happened.	1		1	**2**

Appendix X: Stimulus Comprehension Interview Participant Comments and SC Score (cont'd)

#	Stimulus	Run	Comments	Noticed Warning	ID all components correctly	ID proper response action	SC Score
Parti-cipant Num-ber	1=A.V., 2=H.A.V.	Number of run down road	Participant comments recorded during interview				
17	1	1	What when I put it in park, or? Um, the voice, ha, yeah, it kind of took me by surprise. It was a little crackly. And there was a light flashing with an arrow telling me which direction the turn was. It was a little loud, it kind of made me jump at first.	1	1	1	**3**
17	2	3	Um, the warning came on again, I think uh, I think it was about the same time as the last time. Um, the other thing I noticed is like, I'm curious if the arrow always points in the same direction, because the curve originally you start out going to the right and then it curves around to the left. And it was flashing and it said curve ahead, 15 mph, and it had a little 15 under the arrow.	1		1	**2**
18	1	2	Flashing thing again. Um, the sound, seemed like it, I don't know, I was ready for it, so.	1	1		**2**
18	2	1	No. I don't think so. Anything out of place, or? Well, the turning thing. Um the flashing light and the sound.	1			**1**
19	1	1	You mean like the little light thing? Yeah, it started flashing and this woman started talking. Um, there was a curve. Um, yeah, it scared me more than anything.	1	1	1	**3**
19	2	2	Um, since I knew the curve was coming up, it wasn't as, I didn't have as much of a reaction to the light or anything. It didn't seem as loud, and it didn't get to me as much. Yeah, it was all the same.	1		1	**2**
20	1	3	There was a voice and a blinking sign that said 15 with an arrow showing me the direction of the curve.	1	1	1	**3**
20	2	1	Uh, there was a bunch of lights in one area. That's about it. Uh, the sign said to slow down to 15 mph, um the voice, other than that, no.	1		1	**2**
21	1	2	It was obscenely loud, I'll put it like that. Not loud, but the warning was almost more distracting than the curve. I noticed first that voice that was kind of crackly, went "shhhhcrr", and then I saw the blinker with the curve symbol on it.	1	1	1	**3**
21	2	3	That is the best one with the actual driving, the gas, I could tell if it, I think it just lessened the gass, like the gas pedal came up at me, and the voice and indicator all at the same time.	1	1		**2**
22	1	3	Yeah, it was just the voice and the light this time, it wasn't the foot pedal.	1	1		**2**
22	2	2	There was a visual signal flashing, and the physical signal touch on the foot on the brake, it popped. It grabbed my attention. It was more effective than one or the other when combined. Oh yeah, there were 3 things - sound too.	1	1		**2**
23	1	1	Yeah. A warning that there was a curve ahead. And a notice to please slow down. The notices? A light with an arrow came on indicating the dirction of the curve although I didn't note the direction, and advising me that I should slow down to 15mph out loud.	1	1	1	**3**
23	2	3	Yes, the warning was issued and the gas pedal disengaged, and the warning light indicated the direction of the curve, but not of the initial curve.	1	1	1	**3**
24	1	2	Yeah, I saw, actually I saw the speed limit for that curve, not only was the voice like last time, but also saw it on the flashing light. The first time I saw the flashing light I was like, whoa.	1	1	1	**3**
24	2	1	Uh, not in particular, other than the flashing light that was flashing in front of me, and the curve. We turned around. Uh, did the air conditioner come on? I wasn't noticing anything. Yes, noticed the flashing light in front of me. No, didn't notice anything else besides the flashing light. Well, the voice.	1			**1**

Appendix X: Stimulus Comprehension Interview Participant Comments and SC Score (cont'd)

#	Stimulus	Run	Comments	Noticed Warning	ID all components correctly	ID proper response action	SC Score
Participant Number	1=A.V., 2=H.A.V.	Number of run down road	Participant comments recorded during interview				
25	1	1	No. No, not particularly. (about questionnaire, "By the warning, they're referring to the light and the voice, right?")	1	1		**2**
25	2	2	The light inside with the curve on it. (Anything else?) No.	1			**1**
26	1	3	Well, the light came on and said there was a curve ahead. I was familiar with the road by this time, so I expected that curve ahead. And I'm assuming putting it in the third is what set off that alarm signal. That's about it, and the light on the dash board going off and saying, you know, that there was a curve ahead.	1	1	1	**3**
26	2	1	Well this light flashed on and said 15 mph, and it scared the wits out of me when it first came on. But that's it, and I slowed down and made the turn. I was mainly watching the road because it was really hard to see in that curve.	1		1	**2**
27	1	2	The light flashed that there was a curve. And I think the speed did say 15 mph. It meant slow down.	1	1	1	**3**
27	2	3	The light came on, arrow to the left and 15mph. I guess I was a little more prepared for it. And what I noticed, this is a blind spot here. This is blinding out when you turn the curve. The mirror and this. I guess I was expecting it to come on, it didn't frighten me as much as it did when you're not expecting it.	1		1	**2**
28	1	3	A voice came on, and a light flashed, and it didn't startle me so much because I'd heard it once before. It didn't seem as loud as the first time. It may be because I was kind of expecting it, you know.	1	1		**2**
28	2	2	Yes, the speaker came on and the light flashed and it said sharp curve, slow down to 15mph. Well, just that there was a sharp curve there.	1		1	**2**
29	1	1	Yeah, um, the voice came on and said 15mph, well that startled me. It was a very sharp turn. Other than that, no (very staticky, hard to hear)	1	1	1	**3**
29	2	3	The warning was not as startling. It said 15. Took me longer to get down to 15 the first time, but this time I knew what to do.	1		1	**2**
30	1	2	The light, the orange light started blinking in the front. And I heard the announcement that we were approaching the sharp curve.	1	1	1	**3**
30	2	1	Yeah, I noticed that the car slowed down very quickly. And, um, it was an abrupt change in the curve in the road. It came up quickly. A light blinking. And I heard the clicking of the vehicle when it slowed down.	1			**1**
31	1	1	Did I notice anything? Outside, inside? Inside, when it came on and told me about the curve? Slow down, 15mph. It meant slow down! Ha, be careful.	1		1	**2**
31	2	2	That scares you! It startles you when it comes onbut if I had it in my own car I would know it's there - I don't think it would be as startling.	1			**1**
32	1	3	It startled me again. The flashing light. And the voice of course, at the same time.	1	1		**2**
32	2	1	I'm not sure what I was supposed to be looking for. When they said slow down, ahah, that really caught my attention. It was just, you know, this, somebody saying slow down and the light came on.	1			**1**
33	1	2	Yeah, there was something up here blinking that said 15mph. And there was a voice that said something about 15mph. It kickstarted my heart when it came on.	1	1		**2**

Appendix X: Stimulus Comprehension Interview Participant Comments and SC Score (cont'd)

#	Stimulus	Run	Comments	Noticed Warning	ID all components correctly	ID proper response action	SC Score
Parti-cipant Num-ber	1=A.V., 2=H.A.V.	Number of run down road	Participant comments recorded during interview				
33	2	3	There was a flashing light and arrow with 15. That one was less annoying and frightening.	1			**1**
34	1	3	Well I noticed that the warning came on. It seemed more pleasant than the last one. Not quite as loud.	1			**1**
34	2	2	Oh, that thing that came on! I noticed it all right! Well, there's a light with something written in it but I don't know what. And it said slow to 15, so I did. It scared me.	1			**1**
35	1	1	In the vehicle? Not really. A flash, ok, Just that it was a light of some sort. That's all. And then I realized it was a curve. The cones were there.	1		1	**2**
35	2	3	The voice, was different, course I was more aware of the reflectors. I did see a light somewhere.	1			**1**
36	1	2	Well, we had the warning again. The dash lighting up and telling me that there was a sharp curve ahead, that's about it I guess. It was a kind of loud sound, I can't describe what it was. I was concentrating again too much I guess.	1	1	1	**3**
36	2	1	Must not have been paying attention. No, I guess I wasn't paying attention. I was being so careful of the road that I wasn't paying attention to anything in here. No. Yes, I did notice a flash and voice and it meant I should be alert.	1		1	**2**
37	1	1	That it would stay one speed all the way through. Once I got it up to 55, or 54 I think it was, it would stay that all the way through down. That was the main thing I noticed. The road seemed rougher. Yeah, the flashing light, am I supposed to obey it or you? Well it came on and said to slow down to 15. I noticed I was coming into a curve so I slowed down. It told me to slow down to 15.	1	1		**2**
37	2	2	When it came on I knew to slow down that time, and to come around reasonable, and it gave me enough time to slow down to maneuver properly. The flashing thing about the curve and the speed. I didn't notice anything else. It did have a speed limit in there. (when asked abou the haptic said) Yes, I did notice that.	1		1	**2**
38	1	3	Other than the sign that had me slow down? (anything else?) Nope.	1			**1**
38	2	1	What I noticed? Not a whole lot other than the road, than the road markers and the lane markers. Well, yeah, it gave me a signal that it was going to be a slight left turn and to slow down to 15mph.	1		1	**2**
39	1	2	Yeah, I mean I got the notice that it was a curve ahead which was good. I really liked that, it scared me the first time, I wasn't expecting it. It was pretty abrupt going 55 with the low beams on. So that would be good. Yeah, I saw the flashing light which showed which way the curve was too the left. I don't know whether it first flashed to the right or not, I didn't notice that, but actually the curve first went to the right and then.	1	1	1	**3**
39	2	3	Well yeah, I think it actually warned me earlier. Because I reacted I Think about the same rate, but it seemed to have more time to get ready for the curve. Yeah, I haven't been able to tell whether this is always the same, always points left or not, I'm too busy to notice, I see a blinking but I'm too busy to look at it until I get it slowed down and into the curve. I don't even remember what the words said either, except slow down there's a curve ahead, but I don't know whether they said right or left. I think the visual workload is pretty high, so you really depend on the audio, or maybe it would be nice if it were a heads up or something, I don't know if that would distract from driving. It would be nice to know which way the curve was. I don't know if the audio message said that. Did notice haptic - took foot off right away, but didn't know car, so not sure if it registered.	1		1	**2**

Appendix X: Stimulus Comprehension Interview Participant Comments and SC Score (cont'd)

#	**Stimulus**	**Run**	**Comments**	**Noticed Warning**	**ID all components correctly**	**ID proper response action**	**SC Score**
Parti-cipant Num-ber	1=A.V., 2=H.A.V.	Number of run down road	Participant comments recorded during interview				
40	1	3	Well, it didn't look like the gas pedal kicked out, and it looked like it wasn't as shrill a warning as it was the first time. The first time, maybe because I sort of expeced it the second time, but the first time it really seemed shrill. The second time it seemed more gental. And it looked like it came earlier.	1			**1**
40	2	2	Well, it looked like the gas pedal kicked up on me just before the sound and the 15mph speed limit thing popped up. And I never expected that, so that was a surprise. Well, it certainly meant that it wanted me to slow down. I think 15mph was probably a little slow, but I'm not sure about where it happened, probably based on the speed I was going and where it happened it was giving me enough time to slow down to get into the curve, but I was hoping that I could have slowed down a little further along before I got into the curve.	1	1	1	**3**
41	1	1	There was the light coming on up here blinking and the voice. The yellow light said I better slow down, and then it said something about turn to the right, 15mph.	1	1	1	**3**
41	2	3	Ok, it came on sooner that time, and I guess I understood the message that time, but it may not have been any different. But I guess I was expecting a voice this time and I wasn't before, but it seemed like it came on sooner.	1		1	**2**
42	1	2	Same thing, the light went on, curve went on, probably about the same distance from the curve. Wasn't as sharp this time. I reacted I think a little better. The first time I was surprised by the yellow light. I was a little more familiar to the curve, and since I knew the curve now, I knew the speed that I wanted to get down to and how to negotiate the curve better. I think that the warning light again was an asset - to me, I'm driving an unfamiliar road, driving at night without too many lights on. I think although you drove me down the same road and I knew the curve was coming again, I'm concentrating on getting it up to 55 in third gear, and getting it up to 55 means I've got to take my eyes off the road slightly to observe the speedometer and makes sure I don't go over 55. When the light went on, curve ahead, lower your speed, safely negotiate the road, I didn't have the anxiety I had the first time I heard it. Much lower level of anxiety. Once again, if I had this kind of device on my own car, on an area in which the road was unfamiliar to me, and it could tell me that a curve was ahead	1	1	1	**3**
42	2	1	When the light went on and asked me to slow down for the sharp curve? A yellow light went on and I think it said slow down. Verbally it said, 'sharp curve ahead, slow down to 15mph' to in effect negotiate the curve safely. I was surprised, I didn't know whether I was going to have that kind of surprise. Testing for reaction time obviously, I imagine that was a reaction time test. The car handled well. No problem. I was watching the light when I would have seen the curve. ON a dark country road, I would not be doing 55 with low beams. I did not find the pushback obvious. Had I felt it, it would have been useful.	1		1	**2**

Appendix X: Stimulus Comprehension Interview Participant Comments and SC Score (cont'd)

#	Stimulus	Run	Comments	Noticed Warning	ID all components correctly	ID proper response action	SC Score
Participant Number	1=A.V., 2=H.A.V.	Number of run down road	Participant comments recorded during interview				
43	1	1	Yes I did, that thing right there came on and about scared me out of my pants? I saw a thing come on in here that had a curve, had an orange light, and had an arrow pointing to the left. And it said to brake to 15 mph.	1	1	1	**3**
43	2	2	Yeah, I noticed the light came on and the person said there's a curve up above, reduce your speed to 15mph, and also the acclerator, I guess you might say it cut off. I felt it under my foot, I felt the accelerator cut off. I think it's a good advice, I think that all cars ought to have it.	1	1	1	**3**
44	1	3	This time I noticed that the flashing light had a left turn arrow and a 15mph speed indicating on it. Well, the audible, the voice telling me slow speed ahead.	1	1	1	**3**
44	2	1	You mean about the car acceleration? The only thing was the car decelerated on its own. And of course the light came on telling me to slow down to 15. The light was like an orangish light, I forgot what it said. It had writing on it, I was listening to the voice and it told me to slow down. I can't say that I recall anything else.	1	1	1	**3**
45	1	2	I noticed this indicator saying there's a curve ahead, but I was surprised that the arrow points to the left when in fact this curve turns to the right. I could have turned to the left, haha, but I don't think I was supposed to do that. Well, that was the speed, said 15mph. No, I think it's ...	1	1	1	**3**
45	2	3	Well, I noticed it seemed like to me the same thing, the warning indicator. I think I responded a little quicker to it. I think the warning works fine, other than the fact the arrow would lead you to believe you turn left here, but I don't think I'm supposed to be doing that. Oh, I heard, of course, I heard the talk that said curve ahead, reduce your speed. The blinking light, the audio was good and clear. I think it works fine.	1		1	**2**
46	1	3	That time I didn't sense the accelerator backing off. This time, I didn't notice it the first time because I was so annoyed by the light, but this time I saw that there was a 15 in the light. And whether that was there last time or not I don't know. I noticed that as I reached 15 visually, it stopped flashing.	1		1	**2**
46	2	2	Well, the accelerator released in some way. It pulsed and started to back the gas off, and then a light system started to flash and a voice instructed us to slow for a curve. It meant that that was the warning system kicking in, and I didn't know what it was going to be, and it meant that there was a curve. It didn't tell me which direction it was going to be in, but it warned me of the scenario coming up.	1	1	1	**3**
47	1	1	Yeah, this signal came on. Haha, caught me as a surprise. I first saw the cones just about the time it said "15mph"	1	1		**2**
47	2	3	The yellow sign came on, something jumped on the brake pedal! Is that normal? Then I was in the curve by then. There was a reflector that disappeared, I thought there was one up there on the right, I started out from up there, but then it…	1			**1**
48	1	2	Yeah, it was still a left arrow and a warning for 15mph, except the arrow was a lot smaller. The voice might have been a little, not quite as high.	1	1	1	**3**
48	2	1	Just now? Well the only thing I noticed I guess was the voice that came on. It was recorded voice which said curve up ahead, and it did have an arrow, a left hand arrow, and it said slow down 15mph. It meant obviously that there was a pretty sharp curve coming up ahead.	1		1	**2**

Appendix Y: Post-Condition Questionnaire Open-Ended Responses

Audio-Visual Stimulus Presentation, Younger Participant Comments

#	Run	Would you change something? What would it be?	Time Correctly	Avoid Startling	Be Detectible/ Discriminable	Be Understandable / Indicate Proper Action	Not Distract Driver	Convey Urgency Approp-riately	Be Adjustable	Train Properly	Design Auditory Properly		Design Visual Properly	Design Haptic Properly	Remove Auditory	Remove Visual	Remove Haptic
												too loud					
1	1	Not so out of the blue	1														
2	3	too loud										1					
3	2	The announcement is too loud										1					
4	3	I would use a blue light to be less distracting to the actual driving					1						1				
5	1	yes, not as flashy, alarming or loud						1				1					
6	2	Tone of voice of the speaker, sounds like a computer									1						
7	1	Flash the light before the sound so there is less of a shock		1							1		1				
8	3	Maybe the option to turn the audio part off (If this was for multiple things (curve ahead, stopped cars ahead, etc), the audio is helpful.							1								
9	2	The warning kind of startled me when it came on		1													
10	3	Not as effective without the brake working as well. Especially the radio were on, it would be hard to get as effective a warning			1												
11	1	Make it less surprising and loud so it does not startle the driver		1								1					
12	2	Make it smaller, make the direction of the curve more apparent somehow				1							1				
13	1	Should have come on sooner	1														
14	3	Make the warning appear a little more before the curve. Because I didn't have much time to slow down. Also lower the volume of the warning voice.	1									1					
15	2	Not have the flash + maybe use a tone to "prime" the driver before the voice so it would not be as startling		1							1					1	
16	3	No sound warning, only visual													1		
17	1	Slightly lower the volume										1					
18	2	(no answer)															
19	1	Yes, I would not have it as loud										1					
20	3	Get rid of the voice, just a blinking sign is enough													1		
21	2	The volume and clarity of voice being played.									1	1					
22	3	(no answer)															
23	1	If the distance to/sharpness of warned curves was configurable I would like such warning							1								
24	2	1)Voive and voice location 2) Bright light (flashing) seems like overkill						1			1						
Total			3	4	1	1	1	2	2	0	5	8	3	0	2	1	0

Audio-Visual Stimulus Presentation, Older Participant Comments

#	Run	Would you change something? What would it be?	Time Correctly	Avoid Startling	Be Detectible/ Discriminable	Be Understandable / Indicate Proper Action	Not Distract Driver	Convey Urgency Approp-riately	Be Adjustable	Train Properly	Design Aud Properly		Design Vis Properly	Design Haptic Properly	Remove Aud	Remove Vis	Remove Haptic
												too loud					
25	1	It was frightening-too loud. Perhaps the light would be enough.		1								1			1		
26	3	(no answer)															
27	2	It was too sudden- very frightening. Was not expecting it. Could have been softer. My reaction would have been different if I had known a device was in place.	1	1						1		1					
28	3	no															
29	1	I was glad to receive the sharp warning before such a tight curve. I would not like to be warned constantly, with just minor road curves, however.							1								
30	2	(no answer)															
31	1	(no answer)															
32	3	very loud										1					
33	2	Delete sound-visual would have been just as effective and not startling		1											1		
34	3	This warning was adequate without frightening the driver		1													
35	1	More distinctive			1												
36	2	(no answer)															
37	1	(no answer)															
38	3	Eliminate it													1	1	
39	2	Yes, initially warning earlier, then a second kind of warning right before the curve	1					1									
40	3	No voice!													1		
41	1	Perhaps a tone before the verbal message									1						
42	2	My familiarity after the first "surprise" resulted in a lower anxiety level and a better response, I feel, as a safety factor the volume did not bother me as much									1						
43	1	No-If I had known vehicle had this, then would have expected it to let me know ahead of time w/ enough time-strongly think would like my car to have that-drive at night a lot in fog	1							1							
44	3	The arrow could be confussing. It indicated a left curve but a slight right turn was necessary before entering left				2											
45	2	Direction of warning arrow should be in of curve in high way				1											
46	3	Yes, light flashes too long & too bright. Distract from curve detection visually. Missed accelerator act-best part of previous system					1						1				
47	1	No															
48	2	(no answer)															
Total			3	4	1	3	1	1	1	2	2	3	1	0	4	1	0

Haptic-Audio-Visual, Younger Participant Comments

#	Run	Would you change something? What would it be?	Time Correctly	Avoid Startling	Be Detectible/ Discriminable	Be Understandable / Indicate Proper Action	Not Distract Driver	Convey Urgency Approp-riately	Be Adjustable	Train Properly	Design Aud Properly		Design Vis Properly	Design Haptic Properly	Remove Aud	Remove Vis	Remove Haptic
												too loud					
1	2	no talking, just blinking light warning											1		1		
2	1	It was too abrupt	1														
3	3	(no answer)															
4	2	The light is a bit distracting at night. Maybe make the light a different color or size					1						1				
5	3	Yes, blinking light & loud voice										1	1				
6	1	The warning is too loud when the radio is not on. The volume should be proportionate to the stereo volume			1				1			1					
7	2	I would make the sound less abrupt- maybe even remove the sound	1												1		
8	1	I am not sure I would change anything other than familiarizing drivers with what its like so it doesn't totally startle them the first time		1						1							
9	3	(no answer)															
10	2	If I was used to the visual light sign beign in my car, I would not need it to be so large (especially w/ the pedal and voice indicators as well				1											
11	3	I wouldn't change much about the warning other than which direction the arrow is pointing. Otherwise, it is very beneficial				1											
12	1	I wouldn't want it on all curves, and I would want the warning to be less startling, maybe smaller		1					1				1				
13	2	(no answer)															
14	1	Make it happen a bit sooner b/c I didn't have much time to slow the car down to 15 mph	1														
15	3	Basically the same as the large type if warning, use a more subtle approach, the accelerator pedal felt like it pops and while it was unexpected it was not as bothersome as the light + voice						1			1		1				
16	2	Speed of the turn															
17	3	Volume adjustability							1								
18	1	Can't read what is an blinking light at first should get louder-not so abrupt, maybe blink first		1	1						1		1				
19	2	Yes, not as loud										1					
20	1	Just a light, no voice													1		
21	3	Yes, perhaps the gas pedal should not disengage , it was slightly startled. However, If I was used to a device that did this, then perhaps it would be no more distracting then anti-lock breaks		1			1										1
22	2	Change nothing															
23	3	By interfered with my driving, I mean the system disengaged the gas pedal															
24	1	1)Less abrupt (perhaps 500 feet in advance) 2)Light not as bright 3) Voive localized to the driver seat area/dashboard, Note: high beam vs low beam (i.e. over driving light) was this intended?	1								1		1				
Total			4	4	2	2	2	1	3	1	3	3	7	0	3	0	1

Haptic-Audio-Visual, Older Participant Comments

#	Run	Would you change something? What would it be?	Time Correctly	Avoid Startling	Be Detectible/ Discriminable	Be Understandable / Indicate Proper Action	Not Distract Driver	Convey Urgency Approp-riately	Be Adjustable	Train Properly	Design Aud Properly		Design Vis Properly	Design Haptic Properly	Remove Aud	Remove Vis	Remove Haptic
												too loud					
25	2	Light is ok, but too loud										1					
26	1	Found it distracting, but it were more familiar, maybe wouldn't be as distracting may have noticed pedal-said yeah, didn't feel right					1										
27	3	Probably just the light w/ the speed limit, no sound.				1									1		
28	2	not so loud										1					
29	3	I reacted in a much more calm manner this time															
30	1	(no answer)															
31	2	(no answer)															
32	1	Not quite so loud										1					
33	3	Sound still anoying but not as startling		1													
34	2	A warning system not so loud and sudden be better	1									1					
35	3	Maybe a few feet sooner	1														
36	1	(no answer)															
37	2	no															
38	1	Less size											1				
39	3	More information early about which direction the curve was going (at least the initial direction)	1			1											
40	2	No voice, 15 mph indication only				1									1		
41	3	(no answer)															
42	1	Slightly lower volume_the flashing was good										1					
43	2	NO															
44	1	Perhaps a "beep" or audible tone just ahead of verbal warning									1						
45	3	If a warning system was installedit would show detection of the incoming curve				1											
46	2	Get rid of flashing light-continous flashing--light off scale for my point of view-was in way of seeing curve-wanted to say, "stop this crap" voice + pedal were fine														1	
47	3	No															
48	1	Would make the turn arrow smaller											1				
Total			3	1	0	4	1	0	0	0	1	5	2	0	2	1	0

Melinda McElheny — Curriculum Vita

EDUCATION

Virginia Polytechnic Institute and State University
Blacsksburg, VA
2002 – 2005
Master of Science, Industrial and Systems Engineering
Human Factors Engineering and Ergonomics

Cornell University, College of Human Ecology
Ithaca, NY
1998 - 2002
Bachelor of Science with Honors,
Design and Environmental Analysis,
Concentration in Human Factors and Ergonomics

WORK EXPERIENCE

Senior Research Specialist
Virginia Tech Transportation Institute
Aug 2003-present
Center for Automotive Safety Research
-Designed usability testing -Developed experimenter protocols -Lead in-vehicle experimenter -Conducted literature reviews -Authored reports -Delivered presentations to colleagues and clients

Research Assistant
University of Regina, Regina, Saskatchewan, Canada
Jun 2002-Aug 2002
Under the direction of Daryl Hepting, Ph.D., Department of Computer Science
-Developed computer-aided visualization questionnaire
-Produced user-friendly tutorial for Avid® software
-Examined eyewitness facial composites techniques

Human Factors Intern
Naval Air Warfare Center, China Lake, CA
Jun 2001-Jun 2002
-Participated in developmental testing of helmet-mounted display as well as other cockpit displays for the F-A/18 program -Secret Clearance status -Surveyed aircrew -Compiled data -Authored official reports to Boeing and NAVAIR

Administrative Assistant
College of Human Ecology, Cornell University, Ithaca, NY
Jan 2001-May 2002
Human Ecology Office of Alumni Affairs and Development
-Participated in general office operations -Performed research -Maintained databases -Completed special projects including event planning and publication design

Research Assistant
Cornell University, Ithaca, NY
Jan 2001-Dec 2001 Under the direction of Dr. Gary Evans
-Studied effects of living environment on elderly of Tompkins County -Designed criteria -Collected data from over 100 sites -Trained new assistants

AWARDS

-2004 Federal Highway Administration Eisenhower Graduate Transportation Fellowship
-2004 American Society of Safety Engineers (ASSE) Deurmier Safety Scholarship
-2003 HFES Outstanding Student Chapter Award while serving as Vice President
-2002 National Institute of Occupational Safety and Health (NIOSH) Fellowship, year's tuition and stipend
-Cornell University Dean's List, each semester 1999 to 2002
-Honors program in The College of Human Ecology, Cornell University

ACTIVITIES AND COMMUNITY SERVICE

-Active member, past President of the VT American Society of Safety Engineers
-Active member, past Vice President of the VT Human Factors and Ergonomics Society
-Member, Virginia Tech Society of Women Engineers
-Past President, Cornell Human Factors and Ergonomics Society
-Volunteer for the Montgomery County Christmas Store and Blacksburg Food Pantry
-Certified in scuba diving, first aid, and CPR