Multidimensional Warnings: Determining an Appropriate Stimulus for a Curve-Warning Device

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Abstract

An average of 42,000 fatalities occur on the United States of America's roads each year as a result of motor-vehicle crashes (National Highway Traffic Safety Administration, 2003). The dangers with respect to curves exist, from late notification of direction and speed, varying methods for determining advisory speeds, as well as driver unfamiliarity and/or over confidence. A curve-warning device, a device that notifies the driver of an upcoming curve and, possibly, conveys its vehicle-specific advisory speed and even direction, has the potential to drastically reduce the dangers of curve navigation. This study was performed as a proof of concept with regard to appropriate modalities and respective stimuli for a curve warning application.

For this study, objective and subjective measurements were collected in a simulator environment to compare conditions comprised of multiple stimuli from the auditory (icon, tone, and speech), visual (Heads Down Display and Heads Up Display), and haptic (throttle push-back) modalities. The results of the study show that the speech stimulus was the most appropriate of the auditory stimuli 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 in their subjective ratings. The throttle push-back did little to positively impact the performance measurements, and based on participant comments and ratings, it is not recommended for a curve-warning application. Of the stimulus conditions (combinations of two and three modalities), the Speech and HDD condition provided performance gains and subjective acceptability above the rest of the conditions.

Dedication

First and foremost, I dedicate this report to my parents. Your support and guidance throughout all my years of education have gotten me where I am today. I can only hope to continue to bring respect and appreciation to the Neurauter name. This is also dedicated to my grandfather, H.R. Stanley II. Although you may no longer be with us, I know you are with me every step of the way. Upon completion of this report, I have gained a whole new appreciation for your lifetime of research, and I would like to think that I'm carrying on the torch!

Most of all, this is dedicated to my wife, Viki, and son, Joseph. Your support and love have gotten me through it all. You two are my reason for being, and I hope to continue making you proud. I love you both.

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Chapter 1 : Introduction

1.1 Motivation

An average of 42,000 fatalities occur on the United States of America's roads each year as a result of motor vehicle crashes (National Highway Traffic Safety Administration, 2003). According to the Insurance Institute for Highway Safety (2002), roadside-hazard crashes account for roughly 30% of these fatalities. Deaths resulting from crashes on curves are particularly problematic, as they accounted for 42% of all roadside-hazard crashes in 2001. Additionally, according to the Fatality Analysis Reporting System (FARS), rollovers are 2.15 times more likely to occur during single-vehicle crashes on curves than during crashes on straight sections of roadway (Farmer and Lund, 2002). Advisory signs are often posted to prevent such accidents, but many of these warnings go unnoticed because of their ineffectiveness at drawing the driver's attention. A study performed by Drory and Shinar (1982) showed that, on average, only 5 to 10% of drivers could accurately recall a warning sign when stopped 200 meters after passing it.

Many other scenarios may contribute to crashes involving a curve. For example, drivers often become overly confident behind the wheel and assume that their vehicles can navigate through a set of turns faster than the posted speed. Moreover, drivers may be unfamiliar with the roads and may be either unaware of the sharp bend in the road ahead or distracted as a result of their lack of familiarity. The use of Intelligent Transportation Systems (ITS) could potentially lessen these dangers, thus avoiding a significant number of crashes on curves and possibly saving thousands of lives per year on our nation's roads alone. However, research is needed to determine the most effective method for alerting drivers to an upcoming curve.

1.2 Review of Literature

1.2.1 Background: Setting Advisory Speeds Today

Two main methods for setting advisory speeds for curves, commonly referred to as horizontal alignments, are described by the American Association of State Highway and Transportation Officials (AASHTO) in its Policy on Geometric Design of Highways and Streets (AASHTO, 2001): 1) the ball-bank method and 2) the standard curve formula.

To perform a ball-bank measurement, the instrument is mounted in a vehicle that makes numerous passes through a curve. The user must subjectively determine the starting speed, defined as a speed that will be slower than the maximum safe speed for the majority of vehicles, and must then increase the speed by increments of 5 mph (Hood, 2001). The advisory speed would then be determined based on the following criteria identified by AASHTO:

- For speeds below or equal to 20 mph: ball-bank reading of 14° [friction ~ 0.21]
- For speeds between 25 and 30 mph: ball-bank reading of 12° [friction ~ 0.18]
- For speeds between 35 and 50 mph: ball-bank reading of 10° [friction ~ 0.15]

The second method, known as the standard curve formula is as follows (Table 1.1):

Table 1.1 Standard Curve Formulas (AASHTO, 2001)

Metric	**US Customary**
$\frac{0.01e+f}{1-0.01ef}=\frac{v^2}{gR}=\frac{0.0079V^2}{R}=\frac{V^2}{127R}$	$\frac{0.01e+f}{1-0.01ef}=\frac{v^2}{gR}=\frac{0.067V^2}{R}=\frac{V^2}{15R}$
where: e = rate of roadway superelevation, percent; f = side friction (demand) factor; v = vehicle speed, m/s; g = gravitational constant, 9.81 m/ s^2; V = vehicle speed, km/h; R = radius of curve, m;	where: e = rate of roadway superelevation, percent; f = side friction (demand) factor; v = vehicle speed, ft/s; g = gravitational constant, 32.2 ft/s^2; V = vehicle speed, mph; R = radius of curve, ft;

The term "1-0.01ef" is approximately equal to one; therefore it is commonly omitted during roadway design, resulting in the following equation to solve for the friction factor (Table 1.2):

Table 1.2 Friction Factor Formulas (AASHTO, 2001)

Metric	US Customary
$f = \frac{V^2}{127R} - 0.01e$	$f = \frac{V^2}{15R} - 0.01e$

AASHTO cites research recommending that the side friction factors should be kept at less than 0.16 for speeds less than 60 miles per hour and at no more than 0.10 for speeds greater than 70 miles per hour. However, this recommendation leaves a large gap between the speeds for which the curves are designed and those speeds at which modern vehicles can handle the curves. For perspective, AASHTO states that at a speed of forty-five miles per hour the friction factor of an imminent skid is 0.35. This imminent skid value has an inverse relationship with speed, decreasing as the speeds increase.

According to Chowdhury, Warren, Bissel, and Taori (1998), both the ball-bank measurement and standard curve formula methods are based on characteristics of 1930s era vehicles. While modern vehicles are able to maneuver through curves at much higher rates of speed than were vehicles in the 1930s, the recommended acceptable friction factors remain based on 1930s designs in today's road-design handbooks because they are based on driver comfort. With respect to a curve, driver comfort is dependent on lateral acceleration. Too much lateral acceleration may make the driver feel as if he/she is maneuvering through the curve too quickly, resulting in discomfort. Therefore, the current argument is that even though these values are based on vehicles from the 1930s and modern vehicles are much more advanced, the lateral acceleration values with respect to driver comfort have changed very little.

Once the advisory speed for a curve is determined, the Manual on Uniform Traffic Control Devices (MUTCD; Federal Highway Administration, 2001) has specific guidelines for placement of signs, which consider the posted speed limit of the road in relation to the advisory speed determined for the curve, as shown in Table 1.3.

Table 1.3 Revised Advance Placement Distances for Warning Signs (Ranck, Personal Communication, August 22nd, 2003)

Posted or 85th-Percentile Speed	Advance Placement Distance								
	Condition A: Speed reduction and lane changing in heavy traffic	Condition B: Deceleration to the listed advisory speed (mph) for the condition							
		0	10	20	30	40	50	60	70
20 mph	225 ft	N/A	N/A	N/A	---	---	---	---	---
25 mph	325 ft	N/A	N/A	N/A	---	---	---	---	---
30 mph	450 ft	N/A	N/A	N/A	---	---	---	---	---
35 mph	550 ft	N/A	N/A	N/A	N/A	---	---	---	---
40 mph	650 ft	125 ft	N/A	N/A	N/A	---	---	---	---
45 mph	750 ft	175 ft	125 ft	N/A	N/A	N/A	---	---	---
50 mph	850 ft	250 ft	200 ft	150 ft	100 ft	N/A	---	---	---
55 mph	950 ft	325 ft	275 ft	**225 ft**	175 ft	100 ft	N/A	---	---
60 mph	1100 ft	400 ft	350 ft	300 ft	250 ft	175 ft	N/A	---	---
65 mph	1200 ft	475 ft	425 ft	400 ft	350 ft	275 ft	175 ft	N/A	---
70 mph	1250 ft	550 ft	525 ft	500 ft	425 ft	350 ft	250 ft	150 ft	---
75 mph	1350 ft	650 ft	625 ft	600 ft	525 ft	450 ft	350 ft	250 ft	100 ft

In addition to the distances listed in Table 1.3, the MUTCD assumes sign legibility of 250 ft for curves (appropriate for symbol warning sign). For example, if an advisory speed for a curve on a road with a speed limit of 55 mph is determined to be 20 mph, then according to the guidelines, the warning sign and advisory plaque must be placed 225 feet ahead of the entrance to the curve (Ranck, Personal Communication, August 27, 2003). This posting location also represents the point at which the driver is to have decelerated to the recommended speed. In addition, the accepted sign legibility of 250 ft gives the driver a total of 475 ft in which to decelerate from 55 to 20 mph, with the assumption that he/she is traveling at the speed limit. Assuming that a driver's average reaction time to an unexpected event is 2.5 seconds (AASHTO, 2001), over 200 ft would be traveled before deceleration could even begin. The driver would then be left with roughly 275 ft in which to decelerate from 55 to 20 mph, resulting in a deceleration of approximately 5 ft per second, based on the equation shown in Table 1.4 (using 55 mph for design speed during brake reaction time, but using 35 mph (55-20 mph) for the V^2 deceleration; see Appendix A for full calculations).

Table 1.4 Rate of Deceleration (AASHTO, 2001)

Metric	US Customary
$d = 0.278Vt + 0.039\frac{V^2}{a}$	$d = 1.47Vt + 1.075\frac{V^2}{a}$
where: t = brake reaction time, 2.5 s; V = design speed, km/h; a = deceleration rate, m/s^2	where: t = brake reaction time, 2.5 s; V = design speed, mph; a = deceleration rate, ft/ s^2

This rate of deceleration is below the acceptable maximum rate of 11.2 ft/s^2 (AASHTO, 2001). However, the inverse relationship between sign legibility (distance) and deceleration (rate) can pose a serious problem if the sign goes unnoticed, or the reaction time is larger than 2.5 seconds. The 2.5 second recommendation by AASHTO is based on results from multiple studies, including a recent study by Fambro, Fitzpatrick, and Kopp (1997), in which three separate braking studies, with a total number of 43 participants (with a 55/45 older/younger ratio %), showed that 95% of the participants had perception-brake reaction times of less than or equal to 1.98 seconds for unexpected objects. A curve-warning device would not be affected by external visibility conditions, and, if designed properly, could decrease this brake reaction time, allowing for more time and distance in which the deceleration could take place, assuming that the warning is noticed.

1.2.2 Curve Dangers

A potentially fatal problem with curves is the lack of consistency between the advisory speeds set by states, for some states are more conservative than others. Therefore, a driver residing in one state may become accustomed to the consistent underestimation of safe speeds through curves, resulting in their automatically entering curves at a speed higher than the advisory speed. The problem arises when this same driver travels to another state where the advisory speeds are a more realistic estimation of the maximum safe driving speed. If this driver assumes his/her normal practice of "adding" mph to the advisory speed, he/she may be creating a dangerous driving situation. This scenario does not even take into account differences between countries, especially the differences between the U.S. and Mexico, two countries in which great discrepancies in road design exist. An in-vehicle curve-warning system would provide even more of a benefit for drivers traveling between countries with different road design standards.

A recent study by Chowdhury et al. (1998) illustrates the problems caused by inconsistencies in advisory speeds. For the study, researchers collected data on curve geometry, observed vehicle speeds, and performed ball-bank readings at 28 locations within Maryland, Virginia, and West Virginia. When the data were averaged, the results suggested that 50% of drivers chose a speed that was equal to or greater than 135% of the advisory speed (85th percentile resulted in 149%). For example, if the advisory speed was 30 mph, 50% of the drivers entered the curve traveling over 40 mph. When analyzed by state, Virginia had the highest average 50th and 85th percentile speeds with respect to the advisory speed (145% and 161% respectively), followed closely by Maryland (130% and 145% respectively), and West Virginia, a distant third (108% and 119%). Additionally, the ball-bank measurements and standard curve formula calculations performed were also compared to the posted advisory speeds. For all twenty-eight locations, the posted advisory speeds, based on the ball-bank measurements and the speed curve formula calculations, were 87% and 84% of the recommended speed, respectively. Individual state results indicate that Virginia is the largest underestimator, with advisory speeds that are, on average, 79% of the recommended ball-bank measurement and 77% of the curve formula. West Virginia was found to be close to target goals with 103% and 100% for the ball-bank and curve formula, respectively.

The results of this study also showed that there is doubt concerning the validity of using the ball-bank method as a means for determining advisory speeds. Additionally, with respect to the standard curve formula, the friction factors based on the 50th and 85th percentile speeds were roughly twice the currently accepted values used in the formula. The results of this study show that a driver accustomed to the advisory speeds in Virginia may enter a curve too quickly in West Virginia because of his/her past experience. This common problem can be referred to as proactive interference, meaning that the information that the driver learned first (additional speed allowance in Virginia) interferes with information learned later (no speed allowance in West Virginia), therefore making it difficult for the driver to adjust. This scenario is potentially fatal and could be avoided with standardization between states and vehicle-specific curve-warning devices.

Another common problem concerns the large percentage of drivers who underestimate the speed at which they believe they are taking a curve. In a study performed by Milosevic and Milic (1990), a curve with a radius of 246 ft and a length of 669 ft was observed. When drivers approached the curve, they were first presented with a sign warning of a "Double Bend" ahead. Approximately 30 m (9.1 ft.) following that first sign, a warning sign communicated to the driver that the speed limit for the upcoming curves was 50 km/h (30 mph). During part of the experiment, this sign was replaced with one that set the limit at 60 km/h (37 mph) for comparison purposes. Finally, the last sign before the curves warned of a "Sharp Change of Direction." Radar was placed at the central part of the curve to measure vehicle speed. After exiting the curve, drivers were stopped by a police officer and, if willing, were interviewed by experimenters. Overall, the measured speeds were greater than their estimated speeds ($p < .02$). Those drivers to whom the 60 km/h sign was presented significantly underestimated their speed, whereas those presented with the 50 km/h sign did not. Perhaps the most alarming finding, however, was that 74% (153/206) of the drivers questioned were not able to recall either of the signs (double bend and speed limit). These drivers also underestimated their speed significantly ($p < .01$): in fact, much more so than the group of drivers that could recall both or even just one of the signs ($p < .05$). This finding further addresses the need for an in-vehicle device to communicate important roadside information, such as warning signs concerning curves.

1.2.3 Curve Warnings

There are many warning devices in use today that offer promising advantages over basic road signs. One device was recently tested on a series of turns on Interstate 5 (I-5) in California. On average, this series of five turns had more than six tractor-trailer truck collisions per year (Wehnham, 2000). Because of the large number of I-5 travelers and the lack of any convenient detour, the California Department of Transportation (Caltrans) decided to develop a more intuitive warning device. In 1999, specially designed light-emitting diode (LED) signs (known as changeable message signs or CMS) mounted with radar-detection devices were placed along the route. These signs were able to detect the speed of an oncoming vehicle and to display one of four messages (e.g., "YOUR SPEED XX mph," "XX mph CURVES") based on the vehicle's speed. Since the implementation of the CMS, the average number of annual tractor-trailer collisions has dropped to less than one and a half.

A similar test was performed during the mid-to-late 1990s in parts of Northern Virginia and Maryland, most notably the Springfield interchange between the D.C. beltway and 395 South (Strickland and McGee, 1998). This study also incorporated a radar device mounted on a message sign, but its focus was on reducing tractor-trailer rollovers on exit ramps. The signs were shown to be effective and were left in place after the study was concluded. Although both of these studies were developed with tractor trailers in mind, communicating safe cornering speeds for passenger vehicles is equally important.

Comte and Jamson (2000) performed a study that incorporated and compared four traditional and advanced techniques for reducing speed in a curve approach. Using a simulator, drivers encountered curves with either no measure (baseline) or one of the following measures: 1) transverse bars with decreasing spacing; 2) a Liquid Crystal Display (LCD), which was located to the left of the vehicle's instrument panel and presented the curve-specific advisory speed; 3) a Variable Message Sign (VMS) that displayed the vehicle speed and license plate; and finally, 4) a Speed Limiter (SL) that automatically decelerated the vehicle until it reached the advisory speed. With respect to the curves with smaller radii, all of the systems except for the VMS had a significant effect on the percentage of speed reduction ($p < .01$). The SL was the most effective at reducing the approach speeds; however, it was the least-accepted system based on the subjective post-study questionnaires. In this particular study, there were no significant differences between the traditional (bars) and remaining advanced (VMS, LCD) solutions, although they all proved to be effective.

1.2.4 In-Vehicle Curve Warning Solutions

Currently, DaimlerChrysler has a curve-warning system under development. This system utilizes the navigation system and road-map data to calculate the geometry of the curve; it then uses this information to determine the optimal vehicle speed. The company's web site offers the following information regarding the type of warning being used:

> 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 (Mercedes Online Magazine, 2002).

In addition to systems like the one being developed by Mercedes, there is also the possibility of using roadside communication beacons that would transmit relevant information to the vehicle (Transportation Research Board, 1998), which would then calculate the information to determine a vehicle-specific acceptable speed.

One important factor to consider is the advantage an in-vehicle curve-warning system has over external signs at night or in environments with low visibility. A Federal Highway Administration (FHWA) sponsored workshop held in 2002 brought together almost 100 public-agency officials to provide feedback on retroreflectivity levels of traffic signs (Hawkins, Carlson, Schertz, and Opiela, 2002). A standard right-handed-curve sign was one of the signs tested, and it was presented at four different levels of retroreflectivity: new type III (with a retroreflectivity of 246), new type I (retroreflectivity = 70), partially degraded type I (retroreflectivity = 36), and highly degraded type I (retroreflectivity = 21). These signs were evaluated by the workshop attendees who drove around a course at night and gave the signs pass/fail ratings based on retroreflectivity. Both the new type III and new type I received passing ratings of 96% and 90%, respectively, but when the signs were partially degraded, their pass ratings fell to 48% and 25% for the partially and highly degraded type I signs, respectively. Without knowing the percentage of curve-warning signs that have a value less than or equal to the reduced retroreflectivity of the degraded signs used in this workshop, the fact that a sign that may already be difficult to see in a low-visibility environment could be made even less visible due to degradation over time is an issue of concern.

A study by Hagiwara, Suzuki, Tokunaga, Yorozu, and Asano (2001) compared, among other things, the detection distances of thirty-two curves in daytime and nighttime environments. The average detection distance, for all of the curves combined, was 248 meters (75.6 ft.) in the daytime, reduced to approximately 160 meters (48.8 ft.) in the nighttime, for a decrease of 35%. It could be assumed that the recognition of a curve-warning device would be similar in daytime and nighttime environments, leading to comparable notification distances from the curve regardless of visibility. Potentially, the detection of a curve-warning device could be even greater at night if a visual icon is included since the contrast ratio would increase.

The technology for a curve-warning device exists, as indicated by press reports from companies like DaimlerChrysler. Therefore, this project seeks the answer to the following important question: what is the best way to communicate to the driver that he/she needs to slow down before entering a curve? Based on the growing complexity and potential overload of current and future vehicle technologies, it must be remembered that this warning will be one of many warnings presented to the driver. Therefore, it is important that multimodal solutions be examined, incorporating the auditory, visual, and haptic channels.

1.2.5 Human Information Processing

When developing a warning system, it is important to understand how drivers will process the information received. Wogalter, Dejoy, and Laughery (1999) developed a Communication-Human Information Processing (C-HIP) Model that outlines the steps in which warnings are processed (Figure 1.1).

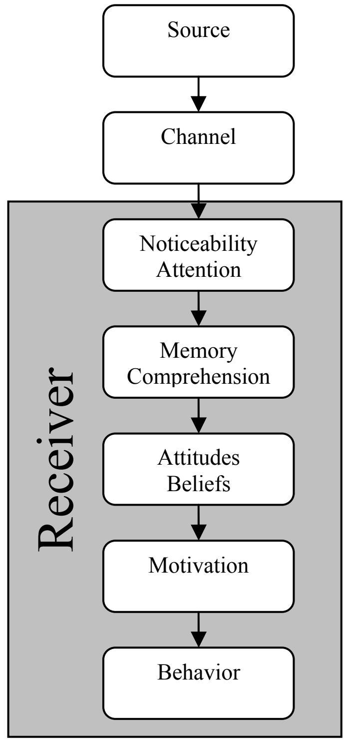

Figure 1.1 C-HIP Model

Note. From *Warnings and Risk Communication* (pg. 17), by M.S. Wogalter, D.M. Dejoy, and K.E. Laughery, 1999, London, UK: Taylor & Francis, Ltd. Copyright 1999 by Taylor & Francis. Reprinted with permission.

Once a warning is presented, the receiver (the driver), must first notice the warning (sensation), and based on memory or past experience, must be able to comprehend the warning (recognition). Once the warning is understood, appropriate behavior will result from a warning that is consistent with the driver’s mental model (i.e., attitudes, beliefs) and that has the ability to motivate the driver to react. If a warning is noticed but not understood, or if it does not match with the mental model of the receiver, inappropriate behavior may result, such as applying pressure to the wrong pedal or making incorrect steering adjustments. This further emphasizes the need to design appropriate warnings, especially for collision-avoidance types of situations in which time and action taken are critical.

In an experiment with mice, Yerkes and Dodson (1908) found that performance was greatest when stress was neither too low nor too high. When plotted, this theory results in an inverted U-shaped pattern. If this theory is applied to arousal, increasing the stress when arousal is low will increase operator performance, but only to a point. This point is the apex in the inverted U, where the optimum level of arousal occurs (Wickens and Hollands, 2000). Using a simulator, Rimini-Doering, Manstetten, Altmueller, Ladstaetter, and Mahler (2001) found that sleep episodes increased with the time spent in a foggy, stimulus-deprived stretch of road. However, the participants were rejuvenated when presented with a stretch of urban roadways with traffic.

Based on this information, an in-vehicle warning should increase arousal to a point at which performance is optimal, but it is important to be careful not to implement a warning that will place additional stress on the operator. A warning that creates additional stress becomes a distraction, potentially making a bad situation even worse. For example, warnings that are very loud may result in startle reactions, which, according to Edworthy (1994), "are not conducive to thought and planning at the very time when concentration may be necessary."

1.2.6 Effects of Age on Reaction Time

Research has shown that reaction times increase with age (Wood, 1998). In her study, Wood used three groups of participants for comparison: 1) Young (< 30 years), 2) Older (> 60 years) with normal vision, and 3) Older (> 60 years) with early visual impairment. With respect to driving performance, the peripheral reaction times for both older groups were significantly worse than those found for the younger group. For example, the average peripheral reaction time for the older group with normal vision was more than 1.5 seconds greater than the younger group. With respect to the average central reaction times, the younger group and the older group with normal vision were comparable (difference of 0.07 seconds), but the older group with early vision impairment was roughly 1 second slower.

Using a simulator, Warshawsky-Livne and Shinar (2002) compared the reaction times of three age groups defined as young (18-25, mean of 23), middle (26-49, mean of 30), and older (>50, mean of 62). Only the youngest and oldest groups were significantly different from each other ($p = 0.03$).

1.2.7 Effects of False Alarms

With a system such as a curve-warning device, false alarms are bound to occur. These false alarms may occur as a result of degradation in Global Positioning Satellite (GPS) signals, outdated road maps, and a driver exiting the road before an upcoming curve. It is important to take into account, based on previous research, how drivers react to these false alarms. Numerous false alarms can lead to a mistrust of the system and may even result in a driver ignoring the system, a potentially fatal decision if the alarm ignored is a true alarm. There are four possible responses with respect to warnings, as shown in Table 1.5:

Table 1.5 Signal Detection Theory

		Curve Present (Signal)	Curve Absent (Noise)
Curve Warning	Warning is Presented	HIT	FALSE ALARM
	Warning is NOT Presented	MISS	CORRECT REJECTION

For warning devices, the warning criteria need to be more on the conservative side, accepting the fact that false alarms will occur. In the context of signal detection, the conservative bias (β) should be as close to one as possible. In all likelihood, however, the criteria for β will be less than one, resulting in some false alarms. However, this is the sacrifice that must be made in order not to "miss" any true scenarios.

Mitta and Folds (1997) performed a study researching the effects of high false-alarm rates on operator performance. Participants were presented with three versions of an incident detection system. While monitoring twenty-four cameras, they were notified by a report and were then required to either locate the incident or to reject it (false alarm). In this scenario, the results actually suggest that the high false-alarm rate presented had no negative effect and that operator performance may have even been improved. There were two possible explanations for this finding. First, the rate of false alarms may have reduced boredom, and second, the task of rejecting false alarms was relatively easy. A second experiment was performed in which an additional incident detection system, for a total of four, was presented. This experiment had similar results to the first experiment. Because driving is a task that requires continuous awareness, it is doubtful that false alarms in a curve-warning scenario will reduce boredom. However, if the driver comprehends the warning, it may be easy to reject false alarms and, therefore, false alarms may not be of great annoyance.

One must assume that drivers are willing to reject false alarms in order to find comfort in the fact that the system will not miss a true event. However, there is the potential for drivers to begin ignoring the system due to false alarms, which could have tragic consequences. For this group of drivers, it is recommended that a curve-warning system have an on/off switch to give the consumer a choice as to whether or not to use it (Pomerleau, Jochem, Thorpe, Batavia, Pape, Hadden, McMillan, Brown, and Everson, 1999).

1.2.8 Alarm Annoyance

One of the most difficult aspects of designing appropriate warnings is setting the trigger criteria. The system should be set to a level at which the driver will be notified when necessary, but it should not be set so conservatively that the alarms are more frequent than they need to be. While using participants going about their daily routines in their own vehicles, Lerner, Dekker, Steinberg, and Huey (1996) found that when participants were presented with varying alarm frequencies (inappropriate and appropriate alarms), one inappropriate warning every four hours was rated as the most acceptable. However, the condition of one inappropriate alarm per hour was not statistically different from one per four hours and even from the one per eight-hour conditions. Interestingly, the condition of one inappropriate voice warning per hour was rated as more annoying than the one inappropriate auditory tone warning per hour condition. Because a curve-warning device has the tendency to trigger frequent warnings (i.e., on rural country road), it may be plausible to eliminate speech as a potential warning.

1.2.9 Auditory Warnings

1.2.9.1 Auditory Icons

Auditory Icons, coined by Gaver (1986), can be defined as representational and easily recognizable sounds used to convey relating messages. When used appropriately, the meanings of these sounds can be recognized and/or understood more quickly when compared to more traditional tonal warnings (Belz, Robinson, and Casali, 1999). Therefore, auditory icons have resulted in faster driver-reaction times than auditory tones and even speech (Graham, 1999; Graham, Hirst, and Carter, 1995). Examples of auditory icons used in previous research on collision avoidance include a car horn or a tire skid. When the two icons were compared, the horn auditory icon outperformed the tire-skid auditory icon (Graham, 1999).

While auditory icons have been shown to be effective, they have also been shown to result in more false positives (Graham et al., 1995). These false positives may be described as inappropriate responses, (i.e., accelerating when braking is the appropriate response). In many cases, overaggressive tendencies (more severe reaction than was necessary) were displayed by drivers as a result of the perceived urgency of the auditory icons. These overaggressive tendencies may or may not result in severe consequences. However, they should be avoided since there is a high potential for creating a second hazard as a result of avoiding the first hazard too aggressively. For example, a driver responding to a curve-warning device may believe that they must slow down immediately and may react by slamming on the brakes. A following driver, expecting a gradual deceleration, may be surprised by this overaggressive reaction, causing a rear-end collision. Therefore, it is vital that drivers understand the meaning of the auditory icon and how to react appropriately.

1.2.9.2 Auditory Tones

With respect to using more traditional tones, the main disadvantage is that users need to be trained before they understand the meaning of a tonal warning. However, once participants are aware of the meanings of the tones, they can be effective in reducing reaction times in a lane-departure scenario (Suzuki and Jansson, 2003). Auditory tones have also been used spatially by presenting the warning from different points in the car, according to the location of the lane departure, collision, etc. Bliss and Acton (2000) found that participants avoided collisions better when the warnings were presented spatially. However, the appropriateness of the participant's response was greater (but not significant) when the warning was presented from a standard location -- in this case, the console. Localization has been shown to be effective at orienting the driver to a general area from which the threat might be coming (Tan and Lerner, 1996). A spatial warning may be less appropriate for curve-warning devices, unless there was intent to signal to the driver if the upcoming curve was bending to the right versus the left.

1.2.9.3 Speech

Speech warnings can be very effective when they are used properly. However, while their meanings can be easily understood, the length of time needed to convey a meaning in a collision-avoidance situation often intrudes too much into the "Time-to-Collision" window. Because time is of the essence when alerting the driver to a potentially hazardous situation, even reaction times resulting from one-word speech warnings fall behind those of simple auditory icons (Graham et al., 1995). However, since the proposed curve-warning device will often be used to advise drivers ahead of time if they need to slow down before entering a curve, speech may be a reasonable alternative. With respect to a collision-warning device, it is also important to note that digitized voice warnings have been shown to be more favorable than synthesized voices (Tan and Lerner, 1995).

1.2.10 Visual Warnings

Visual displays have also been shown to be effective in communicating information quickly (Yoo, Hunter, and Green, 1996). However, in a driving environment where the visual senses are constantly involved, visual-warning devices are more effective when an additional stimulus is presented, creating a multi-modal display (Liu, 2001). Normally the auditory mode is used, but the haptic mode could also be potentially useful.

The main advantage in using visual icons is that they are more easily recognized by the older population. When using familiar symbols, visual icons were deemed much more appropriate for younger and older drivers then were earcons, defined as nonverbal audio messages that provide information to the user (Blattner, Sumikawa, and Greenberg, 1989), with which older participants showed an inability to learn (Kantowitz, Hanowski, and Garness, 1999). When familiar symbols are used, icons have been shown to be more effective in collision-avoidance systems when compared to text messages. Yoo et al. (1996) found that the number of collisions out of eight scenarios were seven, five, and three for the presentation of no warning, text warning, and icon warning, respectively.

1.2.10.1 HDD Icons

Even though the Heads Down Displays (HDDs) of today's vehicles are often already cluttered, the dashboard is a more feasible location for a visual icon since only a small percentage of production vehicles come equipped with a Heads Up Display (HUD). Hanowski, Dingus, Gallagher, Kieliszewski, and Neale (1999) found that when the visual icon was accompanied by an auditory tone to alert the driver that new information was being presented in the dash cluster, reaction times in collision-avoidance scenarios were almost one-third of the reaction times recorded when no warning was presented. Additionally, some participants began to trust the system, resulting in negative reaction times (i.e., responding to the warnings before seeing the object in question). These negative reaction times show the advantage in lead time that an ITS system can provide. This additional lead time can be a big advantage in advising a driver of upcoming curves, allowing for more time to react and more comfortable decelerations.

When comparing the use of an In-Vehicle Signing and Information System (ISIS) versus no ISIS, the ISIS was found to be significant in 12 out of the 15 presented events (Collins, Biever, Dingus, and Neale, 1999). These events included basic roadside information presented in the dash cluster to the right of the speedometer and were accompanied by an auditory tone when new information was presented. Because the visual information was presented five seconds before the participant would be able to see the actual road sign during the daytime, this would be an even more effective tool during poor visibility.

1.2.10.2 HUD Icons

There are many advantages to placing an icon in a HUD. Sprenger (1993) found that when comparing two identical vehicles, one equipped with a traditional speedometer and the other with a HUD, the latter was used more often to monitor vehicle speed. This research also showed that the glance time necessary to retrieve speed information was shorter when using the HUD. Displaying an icon in a HUD during a collision-avoidance scenario could be extremely beneficial since the driver is better able to keep his/her eyes focused on the roadway. However, because the HUD is located within the driver's field of view, two types of interference may occur: 1) the interference of the HUD with the detection of road events and 2) road events interfering with the detection and recognition of HUD warnings (Yoo, Tsimhoni, Watanabe, Green, and Shah, 1999). Interference can decrease the driver's efficiency at detecting both road events and warnings and should be taken into consideration when determining whether or not to use a HUD as a presentation method for warnings.

Hooey and Gore (1998) were unable to find a statistical difference between HUDs and HDDs with respect to navigational compliance, number of collisions in an emergency situation, brake response times, or deviations in velocity. Performance of the HUD was not better than the HDD; however, it was also not found to be worse, nor was it shown to be a distraction. Therefore, it was considered to be a safe alternative.

When deciding on icon placement within a HUD, the most favorable location within the screen has been determined to be at five degrees to the right of center at eye level (Tsimhoni, Watanabe, Green, and Friedman, 2000). This location has also been shown to result in the fastest detection times when compared to other points on the screen (Yoo et al., 1999).

1.2.11 Haptic Warnings

1.2.11.1 Pulsing Brake Pedal / Throttle Push-Back

A pulsing brake pedal could be very effective in a situation in which a driver is heading too quickly towards a curve. Because the warning is presented from the device that the driver must use to slow the vehicle down, the warning is easily recognizable. Tijerina (2001) found that participants brought a test vehicle equipped with a pulsing brake pedal to a complete stop more abruptly when presented with the highest brake pedal jerk rate (0.32 g/s) paired with the longest presented duration of the pedal jerk (1.0s). Tijerina also found that only the highest jerk rate (0.32 g/s) resulted in perfect detection and only when it was presented for at least 0.65s. With this type of warning, the driver may not only be able to sense the movement of the brake pedal but would also feel the deceleration of the vehicle.

In Shutko (1999), the pulsing brake pedal (0.3 g presented for one second) was shown to be more effective in reducing the number of collisions when compared to the no-warning condition and the auditory warning condition (tire skid icon), even though the tire skid icon resulted in faster response times. This finding was due to the fact that the pulsing pedal automatically began to decelerate the vehicle as a result of the pulsing. Both of the pulsing brake settings used by Tijerina and Shutko are commonly referred to as “soft braking.” However, this soft braking would be extremely difficult to recognize in a simulator study since the dynamic feeling of deceleration is non-existent.

The throttle push-back works in the same manner, communicating to the driver that he/she should be slowing down for the upcoming curve by applying a force against the driver’s foot. Janssen and Nilsson (1993) compared multiple collision-avoidance systems, including a throttle push-back that applied a force of 25 N that was sustained for as long as the set time-to-collision criteria was met. The throttle push-back condition resulted in the largest reduction in the occurrence of headways below one second. This condition also resulted in the fewest lane deviations as a result of the warning.

Participants have shown favorable reactions to the idea of a throttle push-back device as a collision-warning system. In a study conducted by Bloomfield, Grant, Levitan, Cumming, Maddhi, Brown, and Christensen (1998) that based their throttle push-back constraints on the Janssen and Nilsson (1993) study, more than 77% of the participants stated that if the throttle push-back device used in the study was on their vehicle, they would use it for collision warning scenarios. In addition to being shown to decrease stress, more than 66% of the participants also felt that this feature would greatly increase their overall safety.

1.2.12 Current ITS technologies

Modern vehicles are becoming more and more complex, with new Intelligent Transportation Systems put into production with each new model year. The following systems are acknowledged as Active Safety Warning Systems by the Society of Automotive Engineers (Gardner, personal communication, June 2, 2002).

1.2.12.1 Forward Collision Warning

Honda's Collision Mitigation Brake System (CMS), available on their home-market Inspire sedan, employs the same radar used for their Intelligent Highway Cruise Control (IHCC), and warns the driver using brake assist and seat-belt tightening if a risk of collision exists (Honda Automobile News, 2003). The system can also regulate braking, although it is against the law in Japan for the IHCC to bring the vehicle to a complete stop and, therefore, it is not equipped to do so. Adaptive Cruise Control can also be considered a type of forward collision warning when it is engaged (see section 1.2.12.4).

1.2.12.2 Lane Departure Warning

Lane Departure Warning systems have been in use since the 1990s, mostly in the trucking industry. A company by the name of Iteris produces the Autovue Lane Departure Warning System, available on Mercedes and Freightliner trucks, both of which are subsidiaries of DaimlerChrysler (Bailey, 2003). The system warns the driver through an auditory icon simulating the sound that a vehicle makes when crossing over a rumble strip (Iteris, 2002).

Honda has just recently introduced its own lane departure warning system, also available on the Inspire, which uses a camera mounted within the front window. If necessary, torque is applied to the steering wheel to help the driver maintain his/her lane position (Honda Automobile News, 2003).

1.2.12.3 Side Crash Warning

Side Crash Warning systems are similar to the Forward Collision Warnings, but in these systems, the driver is notified of potential collisions coming from the side of the vehicle. Localized warning presentation may be very applicable in this type of system, as shown by current simulator-based research in which warnings are presented to drivers from multiple locations within the vehicle (Bliss and Acton, 2000). In this particular study, auditory tones consisting of 1000 Hz sine wave pulses were presented at 90 dB(A).

1.2.12.4 Adaptive Cruise Control (ACC)

Adaptive Cruise Control is a cruise control system that allows the driver to set their cruise control and the vehicle will monitor the forward roadway for slower moving obstacles, decelerate if necessary (the amount of deceleration is limited) and will resume its preset cruising speed when the roadway is clear. Cruise control linked with sensors that monitor the forward roadway for slower moving obstacles is known as Adaptive Cruise Control. Companies such as Mercedes (DaimlerChrysler), Jaguar, Lexus (Toyota), and Honda have current production vehicles equipped with ACC. The system used in the Honda Inspire is referred to as IHCC (Intelligent Highway Cruise Control). This system uses a radar (millimeter-wave) unit built into the front grill. This is similar to the Distronic Cruise Control that has been available on select Mercedes models for a number of years, which warns the driver using a red triangle icon accompanied by an auditory tone (Memmer, 2000a). Infiniti (Intelligent Cruise Control) and Lexus (Dynamic Cruise Control), for example, use a laser sensor to measure the vehicle distances. Both systems are considered to be comparable with respect to performance.

1.2.12.5 Lane Change Support / Side Object Detection

Modern prototype lane-change support systems have been developed to help drivers safely change lanes. One notable example has been developed by Opel, a European branch of General Motors. This system uses sensors to monitor the sides and rear of the vehicle, and warns the driver with an LED bar on the outside mirror that changes colors (yellow to red) based on the level of danger (Opel, 2003).

1.2.12.6 Yaw Sensing Systems

Many production vehicles employ stability control systems. A Yaw Sensing System is based on lateral axis changes. These systems can manipulate vehicle dynamics such as braking (select wheels or all four) and throttle to help a vehicle regain its intended path (Memmer, 2001). Stability control systems have become commonplace in the automotive market and are even offered as options on the more economical models. Since this type of system makes all necessary adjustments manually, the driver is usually not alerted to the changes being made.

1.2.12.7 Roll Sensing Systems

Roll-sensing systems have been employed for a number of years now, especially in convertibles. If the characteristics of a roll are sensed, roll bars are employed to protect the passengers. For example, in the Mercedes SL model line, the system is deployed based on deceleration and lateral tilt measurements (Mercedes-Benz, 2003)

1.2.12.8 Curve Overspeed

As mentioned previously (section 1.2.4), Mercedes is currently developing a system that would warn a driver, based on digital road-map data, if it is determined that the driver is approaching a curve too rapidly. The idea behind this system is similar to the hypothetical solution that will be examined in this study. Visteon is currently involved with the University of Michigan Transportation Institute (UMTRI) in developing a lane departure system that will incorporate warnings to drivers if their speed for an upcoming curve is inappropriate (Visteon Corporation, 2003).

1.2.12.9 Back-Up Warning

There are two types of back-up warnings currently in use: those for the driver (see 1.2.12.11 Parking Aid) and those for people outside of the vehicle. These systems are generally used for large vehicles such as vans, dump trucks, tractor trailers, and other types of heavy-duty equipment. When reverse gear is engaged in an equipped vehicle, an auditory tone is presented to warn people within a close proximity that the vehicle is in motion.

1.2.12.10 Parking Aid

Mercedes unveiled the first sonar parking sensor in 1995 (Memmer, 2000b), but parking aids are no longer reserved for higher-market vehicles. Currently, this feature can be found on various models of cars, SUVs, and minivans. Most of these systems offer assistance with the rear of the vehicle only, but BMW's Park Distance Control (PDC) includes sensors on the front bumper as well.

The warnings for these systems are usually auditory only, but some systems also incorporate a video feed showing a camera view at the rear of the car. As the car inches closer to a stationary object, the presented pulsing tone will become more rapid.

Chapter 2 : Research Objectives

2.1 Rationale for the Study

Today's market is beginning to overflow with Intelligent Transportation Systems, with new systems incorporated into production vehicles with every changing model year. The technology for a curve-warning device exists, whether by use of roadside beacons (Transportation Research Board, 1998) or digital roadmaps (Mercedes Online Magazine, 2002). Curve-warning devices are currently being developed, and guidelines for such a device already exist (Pomerleau et al., 1999), as shown in Appendix B. However, there is no current research establishing guidelines or recommendations for the type of warnings that are most appropriate for this type of device. The reactions required by the driver for a curve-warning device vary greatly from those that are necessary for responding to collision-avoidance warnings. Therefore, in order to establish some basic recommendations, warnings should be researched using a curve-warning device and corresponding scenarios. The objective of this research is to determine the optimal combination of auditory, visual, and haptic modalities for alerting a driver's attention to a curve.

Basic design recommendations will be made based on performance measurements recorded during data collection, and a strong emphasis will also be placed on user acceptability. While it is important that drivers react appropriately to a given warning, emphasis should also be given to the acceptance of the warning.

2.2 Background

According to FARS, almost 26% of all vehicle fatalities in 2002 involved a curve, resulting in roughly 9,800 deaths (NHTSA, 2003). The majority of these deaths (40%) occurred on roads with a posted speed limit of 55mph. It is quite possible that many of these deaths were as a result of excessive speed, lack of familiarity, or a distracted driver.

Although advanced and traditional warning signs and posted advisory speeds are commonplace on roadsides, the percentage of the population that is able to accurately recall the signs' messages, or even their existence, is very low. Drory and Shinar (1982) found that only between 5 and 10% of drivers stopped 200m (61 ft.) after passing a warning sign could accurately recall seeing the sign or its intended message. From a cognitive perspective, this inability to recall signs can be attributed to several factors, including attentional narrowing and the degradation of the working memory due to the relatively low stress environment that driving often creates. As Yerkes and Dodson (1908) found, there is an indirect relationship between stress and performance. If the stress is too low, as may be exhibited in a driving environment in which the driver is on "autopilot" (even to the extreme of highway hypnosis), it is not surprising that roadside warning signs would go unnoticed. Therefore, in response to the aforementioned statistics, it is evident that an in-vehicle warning needs to be presented to notify a driver of an upcoming curve if the system decides that deceleration is necessary.

2.3 Experimental Goal

The goal for this study is to examine objective performance and subjective responses to warnings presented in different modalities. One outcome from examining these measures is to determine the most effective combination of auditory, visual, and haptic warnings for use in a curve-warning device. This effectiveness will be based not only on performance measurements collected, but also on subjective data provided by the participants through questionnaires.

2.4 Research Questions

This study will address questions regarding in-vehicle warnings for a curve warning device. These questions are as follows:

- How will the objective and subjective measurements vary when comparing the auditory, visual, and haptic modalities?
- How will the objective and subjective measurements vary when comparing combinations of the auditory, visual, and haptic modalities?
- How will the objective and subjective measurements of the stimulus conditions presented vary by age group?

Chapter 3 : Methods

3.1 Experimental Design

The experimental design for this study was a 4 X 3 X 2 within-subject design. The three within-subject variables were the auditory modality (four levels including a non-auditory level), visual modality (three levels including a non-visual level), and the haptic modality (two levels including a non-haptic level).

3.2 Participants

A total of 24 participants were involved in this experiment. The participants were recruited by word of mouth from the Blacksburg, Virginia area. The study lasted between two and three hours, and the participants were paid $20.00 per hour for their time.

3.3 Independent Variables

The independent variables in this study were the stimulus conditions presented. When described in accordance to the C-HIP model, discussed in Section 1.2.5, the participants acted as the Receiver, and the Source consisted of the presented conditions. The participants were controlled for age, and were recruited from two age groups: Young (18-25 years) and Older (>60 years), based on previous studies showing significant differences in reaction times between these two age groups (Warshawsky-Livne and Shinar, 2002; Wood, 2001). Each age group was also controlled for gender (6 males / 6 females).

Each participant was presented with all of the 24 stimulus conditions (Table 3.1). These conditions included a baseline, during which no stimulus was presented, and conditions in which each type of stimulus was presented, in addition to combinations of two and all three modalities. However, the combinations never included more than one stimulus of the same modality. In other words, at no time were two auditory stimuli presented simultaneously.

Table 3.1 Stimulus Conditions

No.	Type of Stimulus			Description
	Auditory	Visual	Haptic	
1	-	-	-	Baseline
2	A1	-	-	Auditory Icon
3	A1	V1	-	Auditory Icon + HDD
4	A1	V1	H1	Auditory Icon + HDD + Throttle Push-Back
5	A1	V2	-	Auditory Icon + HUD Icon
6	A1	V2	H1	Auditory Icon + HUD Icon + Throttle Push-Back
7	A1	-	H1	Auditory Icon + Throttle Push-Back
8	A2	-	-	Auditory Tone
9	A2	V1	-	Auditory Tone + HDD
10	A2	V1	H1	Auditory Tone + HDD + Throttle Push-Back
11	A2	V2	-	Auditory Tone + HUD Icon
12	A2	V2	H1	Auditory Tone + HUD Icon + Throttle Push-Back
13	A2	-	H1	Auditory Tone + Throttle Push-Back
14	A3	-	-	Speech
15	A3	V1	-	Speech + HDD
16	A3	V1	H1	Speech + HDD + Throttle Push-Back
17	A3	V2	-	Speech + HUD Icon
18	A3	V2	H1	Speech + HUD Icon + Throttle Push-Back
19	A3	-	H1	Speech + Throttle Push-Back
20	-	V1	-	HDD
21	-	V1	H1	HDD + Throttle Push-Back
22	-	V2	-	HUD Icon
23	-	V2	H1	HUD Icon + Throttle Push-Back
24	-	-	H1	Throttle Push-Back

3.3.1 Auditory Stimuli

The loudness of any auditory warning depends on the noise of the testing environment. The International Organization for Standardization (2003) recommends a Signal-to-Noise Ratio (SNR) of about 5 a-weighted decibels (dB(A)), avoiding a SNR greater than fifteen dB(A), with a range in loudness of 50 to 90 decibels. Following the guidelines of ISO 7731-1986, all auditory tones were presented at 13 dB(A) over the masked threshold in one or more of the 1/3 octave bands, respectively, based on interior noise (Berger, Royster, Royster, Driscoll, and Layne, 2000). The sound measurements used to determine the appropriate warning levels for both the auditory warnings and the informal hearing test tones can be found in Appendix C.

The Auditory Icon used in this study was the Tire Skid icon (one second in duration). Based on existing literature, this icon has been shown to be effective in producing quick response times in collision-avoidance scenarios in which braking is needed (Shutko, 1999). A 2.0 KHz and 3.0 KHz tone with a 0.2s intermittent cycle was used as the Auditory Tone and was presented for three seconds. This frequency combination and cycle were rated as conveying the highest criticality and urgency in a study by Uno, Hiramatsu, Ito, Atsumi, and Akamatsu (1999).

The Speech warning was comprised of two statements, the first of which was the phrase “Curve Ahead.” This phrase was meant to gain the driver’s attention and to advise him/her about the upcoming curve. Research indicates that auditory messages that require urgent action should be either a single-word command or a short sentence with the fewest number of syllables possible so that messages can be understood immediately upon presentation (Campbell, Carney, and Kantowitz, 1998). Therefore, in the present study, a second short phrase was presented immediately following the “Curve Ahead” message: “Reduce Speed to 20 mph,” which was used to advise the driver of the acceptable speed. Following recommended guidelines, the speech was presented at 156 words per minute (NHTSA, 1996). Both of these phrases were in the form of a digitized female voice because the digitized format has been shown to be more favorable than synthesized speech (Tan and Lerner, 1995). It is important to note that of the auditory stimuli, only the speech notified the driver of the advisory speed for the upcoming curve.

3.3.2 Visual Stimuli

The visual icon used in this study depicted the combination Horizontal Curve / Advisory Speed Sign. According to the MUTCD (FHWA, 2001), the Turn Sign (W1-1 in Appendix D) is used when the advisory speed is less than 30 miles per hour, and the Curve Sign (W1-2) is used for advisory speeds greater than or equal to 30 miles per hour. The icon used in this study mimicked Figure W1-9 in Appendix D, except that it used the curve design shown in Figure W1-2, incorporating the advisory speed plaque as well (20mph). This decision was made in order to better match the driver’s mental model of a curve, as well as to allow for the use of only one visual icon, regardless of the advisory speed. There were two versions of the icon, depending on whether the upcoming curve bent to the right or the left, as shown in Figures 3.1 and 3.2:

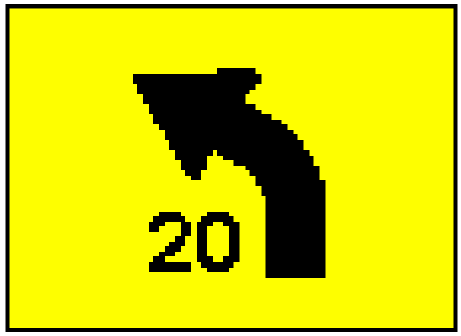

Figure 3.1 Visual Icon for Left-Handed Turn with 20mph Advisory Speed

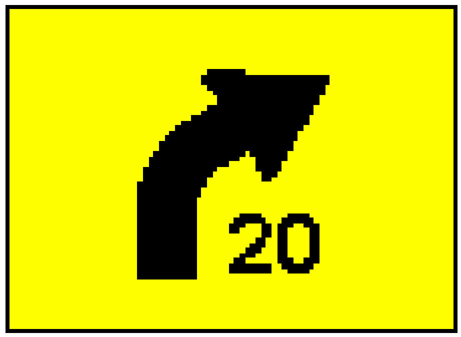

Figure 3.2 Visual Icon for Right Handed Turn with 20mph Advisory Speed

The icon and speed were originally to be presented in red for highest criticality (Uno, Hiramatsu, Ito, Atsumi, and Akamatsu, 1997), using a 0.2s blinking cycle (Uno et al., 1999), and they were to be presented as an HDD or a HUD. However, based on contrast measurements obtained during pilot testing, the HUD icon barely met the minimum symbol contrast of 3:1 (Cambell et al., 1998). Therefore, the background was changed from white to yellow. With the change to a yellow background, it was determined, based on warning guidelines, that the curve icon and advisory speed should be changed from red to black (Wogalter et al., 1999). Therefore, the final icons were presented in a black on yellow combination, as depicted in Figures 3.1 and 3.2. In the HUD, the icon was presented at approximately five degrees to the right of center at the participant's eye level (Tsimhoni, 2000; Yoo et al., 1999). The size of the icons, while confined to the limits of the Liquid Crystal Displays used to project the images, fell within the range of icon sizes defined as acceptable based on previous research. Both images were 222 x 160 pixels, which resulted in an on-screen size of approximately 1.63 inches wide by 0.94 inches high for the HUD and approximately 1.81 inches wide by 1.12 inches high for the HDD (the difference was due to the distances that were necessary between the LCDs and the screen to obtain the HUD and HDD on-screen positions; the apparatus is discussed later in this chapter). These differences in size were very small, and from the driver's position both icons appeared to be the same size. In both locations, the icon continued to flash until the participant reached the entrance to the curve. The following figures (Figures 3.3 and 3.4) show the final locations of the HDD and HUD (pictures taken during contrast measurements):

Figure 3.3 HDD Simulator Screen

Figure 3.4 HUD Simulator Screen

3.3.3 Haptic Stimulus

The haptic stimulus used in this study was presented using conditions found to be effective in past research. The throttle push-back was applied at a force of approximately

6 lbf (~25N) (Janssen and Nilsson, 1993) and was presented for three seconds. It is important to note that the haptic stimulus did not notify the driver of the advisory speed for the upcoming curve.

3.4 Dependent Variables

When comparing the different stimulus conditions, the participants' reaction times with respect to braking were expected to be critical. Any other reactions by the driver, such as steering, were accounted for, especially when looking for any responses that may have been deemed inappropriate, such as lane deviations and time out of lane. The dependent variables were defined as follows:

- Throttle Reaction time – 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.
- Brake Reaction time – the time it took for a participant to begin braking, starting from stimulus onset.
- Speed Variance – the speed variance from the point of stimulus onset to the entrance of the curve.
- Lane Deviation – the point at which the vehicle's tire came into contact with the edge or center line.
- Time Out of Lane – the time from when the tire touched the edge or center line until the tire was no longer touching the marker and the vehicle was in the correct lane.
- Vehicle State at entrance/apex/exit of curve – Vehicle characteristics such as speed and lane position calculated for the entrance, apex, and exit of the curve.

The speed limit of 55 mph that was used in this study for the main roadway was based on the fact that 40% of all fatalities involving a curve in 2002 were on roads with a speed limit of 55mph (NHTSA, 2003). Therefore, a speed of 55 mph paired with a turn advisory speed of 20 mph was used for this study since a large amount of deceleration must occur to maneuver the curve safely.

3.5 Subjective Data Collection

After each warning condition was presented, the participants rated their perceived urgency, appropriateness, acceptability, interference, and "want" (I would want this type of warning to be presented) of the stimulus condition. These ratings were presented using a Likert-type five-point scale, which did not include the open-ended question for participant suggestions. The questions included in the Post-Condition Questionnaire were as follows (the actual form presented in Appendix E):

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?

Participants were also monitored for simulator sickness using a modified version of the Simulator Sickness Questionnaire developed by Kennedy, Lane, Berbaum, and Lilienthal (1993). This questionnaire was comprised of sixteen symptoms rated on a four-point scale, as follows (the complete form seen by participants in Appendix F).

Simulator Sickness Questionnaire

1. General Discomfort	None_____Slight_____Moderate_____Severe____
2. Fatigue	None_____Slight_____Moderate_____Severe____
3. Headache	None_____Slight_____Moderate_____Severe____
4. Eyestrain	None_____Slight_____Moderate_____Severe____
5. Difficulty Focusing	None_____Slight_____Moderate_____Severe____
6. Increase Salivation	None_____Slight_____Moderate_____Severe____
7. Sweating	None_____Slight_____Moderate_____Severe____
8. Nausea	None_____Slight_____Moderate_____Severe____
9. Difficulty Concentrating	None_____Slight_____Moderate_____Severe____
10. Fullness of Head	None_____Slight_____Moderate_____Severe____
11. Blurred Vision	None_____Slight_____Moderate_____Severe____
12. Dizzy – with eyes open	None_____Slight_____Moderate_____Severe____
13. Dizzy – with eyes closed	None_____Slight_____Moderate_____Severe____
14. Vertigo	None_____Slight_____Moderate_____Severe____
15. Stomach Awareness	None_____Slight_____Moderate_____Severe____
16. Burping	None_____Slight_____Moderate_____Severe____

Finally, participants were asked to rate their acceptance of the curve-warning system as a whole after the data collection had ended, including an opportunity to rate their most and least-liked warning conditions and why. The following questions (those on a Likert-type five-point scale), developed by Van Der Laan, Heino, and De Waard (1997) were used (see Appendix G for the full form):

My judgements of the Curve Warning system are…

useful						useless
pleasant						unpleasant
bad						good
nice						annoying
effective						superfluous
irritating						likeable
assisting						worthless
undesireable						desireable
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?

3.6 Apparatus

A fixed-base STISIM *Drive*™ (registered trademark of Systems Technology, Inc.) simulator was used for data collection purposes, as pictured in Figure 3.5. This simulator featured a 135 degree field-of-view using 15-inch monitors with a variety of scenes to choose from. However, it was recommended for this research that only the center monitor be used in order to help decrease simulator sickness (Mollenhauer, Personal Communication, August 19th, 2003). Research has shown that fixed-base simulators can result in a high occurrence of simulator sickness. Lee, Yoo, and Jones (1997) conducted an experiment in which participants were asked to drive a five-minute course that consisted of twenty left and twenty right turns with straight-aways in between. They found that 9 out of the 11 participants reported simulator sickness following the course, resulting in a sickness probability of greater than 80 percent. Reducing the number of turns was suggested as a possible method for reducing the number of sickness incidences. Fortunately, in the present study, aside from a five-minute training portion that included only six curves, all 24 conditions were presented separately, with a questionnaire completed in between. This break was expected to greatly reduce the chances of simulator sickness.

Figure 3.5 STI Simulator

The controls were presented on the simulator as they would appear in an actual vehicle, with a brake and throttle pedal (Figure 3.6).   Moreover, the steering wheel had the capability of force-feedback (allowing the driver to feel steering-wheel resistance) to add to the realism. However, the STISIM was not able to incorporate any of the warnings, so an external computer was built and programmed specifically for this study to control all of the warnings, and LCDs were used to project the visual icons onto a Plexiglas screen that was placed in front of the monitor (Figure 3.7). At a given point in the driving route, the code instructed the STISIM computer to send distance data through the serial port. Once the data read matched the predetermined distance measurement for the stimulus presentation, the appropriate condition was triggered.

Figure 3.6 Throttle and Brake Pedals

Figure 3.7 External Computer, Steering Wheel, and LCD's

The software on the external computer allowed the experimenter to choose the appropriate combinations of warnings depending on the condition. Upon entering the program, a distance of 2866 feet was entered in for the stimulus onset, and 3500 feet was entered for the stimulus cut-off (these distances are described in section 3.7). The software allowed the experimenter to choose which modalities to present, as well as which stimulus to present within each modality in order to present all 24 conditions. A screen capture of the warning software can be seen in Figure 3.8).

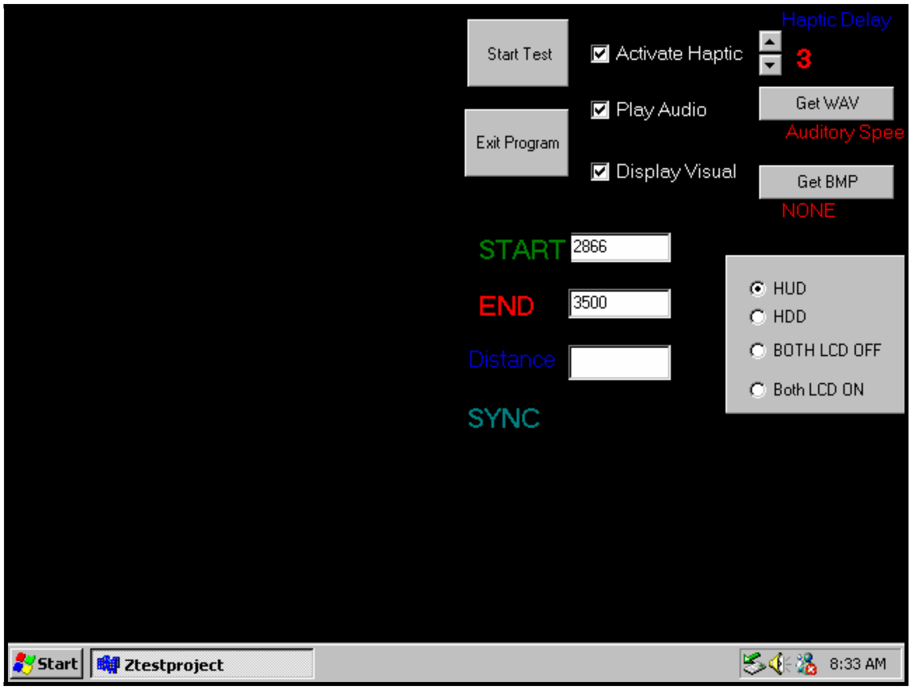

Figure 3.8 Stimulus Presentation Software

Participants were also videotaped during data collection. This was primarily done as a backup, in case the video needed to be referenced to help answer questions during data analysis, which proved to be invaluable in helping identify things that were not overtly apparent when looking at the raw data. The screen captures from the videotapes, as seen in Figure 3.9, were comprised of a view of the participant's face, the throttle and brake pedals, an over-the-shoulder view of the steering wheel and monitor, and a side view.

Figure 3.9 Screen Shot during data collection

The STISIM was also easily programmable. Creating driving scenarios, events, tasks, and setting criteria for recording performance measurements were all easily accomplished by using the Scenario Definition Language (SDL) software. Driving scenarios included roadways and curves--two features that were used in this study. Three courses were designed for use during this experiment: 1) training route, 2) right-curve route, and 3) left-curve route. Finally, the simulator was able to collect the performance measurements that were evaluated during data analysis to determine the dependent variables described in section 3.4.

3.6.1 Simulator Fidelity

To assess the realistic importance of certain variables collected using the simulator--especially speed-related variables (acceleration and deceleration), the fidelity of the simulator should be understood. Due to the fixed-base structure of the simulator used in this experiment, the lateral and longitudinal forces exhibited in real-world driving were non-existent. According to Boer, Girshick, Yamamura, and Kruge (2001), who compared the performance of a set of participants in both a simulator and real-world environment, there are three main examples of biased perception associated with the use of driving simulators:

1) The visual perception of distance, speed and acceleration are generally underestimated in driving simulators

2) Vestibular input is either not available (fixed base driving simulators) or produced via various means that differ from how the vestibular organs are stimulated in reality (e.g. tilt coordination with or without longitudinal and/or lateral sliding rails; in all cases the produced acceleration signals are scaled down from reality by a factor that is generally less then 0.5)
3) Kinesthetic stimulation is often under represented because of bandwidth constraints (plays an important role in speed perception) (35)

One of their findings, which could impact the results of this study, is that if participants have difficulty perceiving the rate of deceleration, there is the potential for too much deceleration, resulting in the driver's reaching a proper curve-entry speed too early. This was also supported by their finding that participants in the simulator environment tended to decelerate faster than in the real-world environment. On the other hand, some similarities were found concerning participant speed preference (consistent ranking across the participants).

Lateral positions have also been shown to vary between real-world and simulated environments (Blana and Golias, 2002). When comparing data collected in both environments, drivers in the naturalistic condition were found to position their vehicles at closer to the center lane than those in the simulator condition. Moreover, it was concluded that a consequence of this difference in positioning is that the vehicle trajectory with respect to the edge and center-line of the road will be considerably different between the two conditions.

With respect to both right and left curves, Godley, Triggs, and Fildes (2002) found evidence to support interactive relative validity (differences between conditions are in same direction with similar magnitudes) when comparing naturalistic and simulator data. According to Törnros (1998), a driving simulator can be a useful research tool as long as relative validity exists, but absolute validity (numerical connection) is not a necessity. It should be noted, however, that the simulator used for the comparison in Godley et al. (2001) was able to produce pitching and rolling movements to simulate acceleration, deceleration, and cornering, whereas the STI simulator used in this study was a fixed-base model.

Overall, simulator research involving curves has been shown to vary from real-world driving. Participant performance leading to the curve may also not reflect entirely what would occur in a real-world environment (differences in rate of deceleration, etc.). However, the overall relationships between the modalities, conditions, and age and gender are assumed to be reflective of those found in a naturalistic setting.

3.7 Curve Design

In order to facilitate the sizeable amount of deceleration required to obtain the advisory speed for the curve, the participants were instructed that the speed limit of the road on which they were traveling was 55 mph. Since a curve-warning system should be set to, at most, 90% of the maximum safe speed (Pomerleau et al., 1999), the actual curve was designed to have a maximum safe speed of 22.2 mph, resulting in a notification to the driver of 20 mph. The speed was calculated using the following equation (Pomerleau et al., 1999):

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

where 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. For the curve used in this study, the superelevation was set to 0%. Additionally, based on the ball-bank criteria mentioned in section 1.2.1, the side friction factor was set to 0.21. Therefore, using the equation shown above, the radius of the curve equaled approximately 157 ft to result in a maximum safe speed of 22.2 mph (see calculations in Appendix H).

The guidelines set forth by Pomerleau et al. (1999) also recommend a longitudinal deceleration threshold of 4.92 ft/s (or no more than 50% of what the vehicle is capable of). In order to determine the point at which the stimulus should be presented based on vehicle speed, the following equation was used (Pomerleau et al., 1999):

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

where a is the deceleration (4.92 ft/s), V is the current speed (55 mph, 80.67 ft/s), V_c is the maximum safe speed for the curve (22.2 mph, 32.56 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). By performing the calculations (Appendix H), it was determined that the stimulus was to be displayed at 755 ft from the apex of the curve, assuming that the participant was traveling at the set speed of 55 mph.

To create a change in direction of roughly 90 degrees, the length of the 157-ft radius curve was determined to be roughly 246.6 ft using circumference geometry. Since this curve was designed as a "perfect" curve, the apex was assumed to be in the center. Therefore, with a curve entrance set to a presentation distance of 3500 ft in the simulator scenarios, the warning was presented at the 2866 foot distance marker (~755 feet from the apex).

3.8 Experimental Procedure

3.8.1 Participant Screening

Participants were screened over the telephone using modified versions of the Participant Recruitment Script and Health Questionnaire forms used by Hankey (1996), which can be found in Appendix I. These questionnaires were developed with simulators in mind and were expected to help screen for participants who may have been susceptible to simulator sickness. Additionally, participants were asked to rate their video-game usage. In order to avoid any effects of experience, participants who played video games (not including handheld games such as those played on a cell phone, etc.) for more than 1 hour per week (or 4 hours per month) were excluded. Upon arrival at the Virginia Tech Transportation Institute (VTTI), the participants were required to produce a valid driver's license and to have a visual acuity of better than 20/40 (Department of Motor Vehicles, 2003). The Ishihara Color Vision test was also administered, as well as an informal hearing test (Appendix J). The participants were then given an Informed Consent Form (Appendix K) that informed them of any risks associated with the study and their option to withdraw freely from the study at anytime with no penalty. If any of the participants had withdrawn, they would have been compensated for their time up to that point. The complete protocol for the experimenter at the VTTI location can be seen in Appendix L.

3.8.2 Training

Following the screening, the participants were driven from VTTI to the campus of Virginia Tech, where the VTTI experimenter walked with them to Williams Hall, where the simulator was located. Upon reaching the room, the participant was introduced to a second experimenter at the Simulator location (complete protocol for second experimenter can be seen in Appendix M), whereupon the participant performed a five-minute practice run with the simulator for familiarization purposes. This practice run consisted of a rural roadway, including six equally distributed left and right turns designed with speeds of 30 mph (two), 35 mph (two), and 40mph (two). An advisory sign following MUTCD placement and appearance guidelines was presented before each curve to display the direction of the curve and the advised speed. The participants were instructed to decelerate to the speed shown on the sign by the time they reached the entrance of the curve. This instruction was expected to help participants become familiar with the feel of the simulator's brakes.

Once the training run was completed, the experimenter administered the simulator sickness questionnaire (Appendix F) for the first time. If, at this point, the participant showed any signs of simulator sickness (scoring moderate or higher on any of the symptoms), he/she was immediately offered fluids. They were then observed for ten to fifteen minutes before being allowed to continue the study. If the participant had chosen not to continue with the study, he/she would have been asked to wait until he/she was feeling better before leaving the building. Then after an extended period of time, participants would have been driven home in their own vehicle, if necessary.

3.8.3 Data Collection

Each participant was presented with all 24 stimulus conditions. The order of these conditions was counterbalanced using a balanced Latin Square Design. The driving scenario for each condition consisted of a straight stretch of roadway followed by either a left or right-handed curve (the order of which was determined using a Fractional design that resulted in two main orders, and adding the mirrored images of these two orders resulted in each order being presented for 6 participants). Both curves had the same geometric characteristics, but in reverse directions. Following each condition, the participants were asked to rate the urgency, appropriateness, acceptability, interference, and "want" of each warning using the Post Condition Questionnaire found in Appendix E. Halfway through the experiment (following the 12th presented condition), the experimenter administered the simulator sickness questionnaire (Appendix F) for the second time. The sickness questionnaire was presented one final time after the last condition was presented and data collection was completed. If a participant showed signs of simulator sickness when the SSQ was administered for the second and/or third time, the same protocol as described earlier was followed. Finally, at the end of data collection, the Acceptance Questionnaire (Appendix G), which concerned participants' overall opinions with respect to the curve-warning device, was administered. The participants were then picked up and brought back to VTTI, and then thanked and paid for their time (debriefing form can be seen in Appendix N).

3.9 Data Analysis

The data analysis consisted of reducing and analyzing subjective and objective data collected during the study.

3.9.1 Objective Data Analysis

Objective data collected during the study included measurements used to determine throttle reaction times (TRTs); brake reaction times (BRTs); speed variance; the number of lane deviations; time out of lane; and the speed and position at the entrance, apex, and exit of the curve. The mean and standard errors for the dependent measures were calculated for each of the warning conditions, as well as by age group. An analysis of variance (ANOVA) was performed to evaluate the warning conditions with respect to the dependent measures. The degrees of freedom that were used when performing the ANOVA for data analysis can be seen in the following table (Table 3.2).

Table 3.2 ANOVA Degrees of Freedom

Source	df
Between	
Subject	23
Within	
Auditory	3
Auditory x Subject	69
Visual	2
Visual x Subject	46
Visual x Auditory	6
Visual x Auditory x Subject	138
Haptic	1
Haptic x Subject	23
Haptic x Auditory	3
Haptic x Auditory x Subject	69
Haptic x Visual	2
Haptic x Visual x Subject	46
Haptic x Auditory x Visual	6
Haptic x Auditory x Visual x Subject	138
Total	**575**

The objective data analysis was performed to determine, based on an $\alpha = 0.05$, any significant differences among the modalities. A *post-hoc* analysis was performed using the Student Newman-Keuls Sequential Range Test to evaluate any differences between the four auditory levels. Exploratory techniques were also used to determine differences between age, gender, and stimulus condition.

3.9.2 Subjective Data Analysis

The subjective data analysis consisted of evaluating the responses from the Post Condition Questionnaire (Appendix E) and the Curve-Warning Acceptance Questionnaire (Appendix G). An ANOVA was performed for the results of the Post Condition Questionnaire to determine any significant differences between the stimulus conditions, as well as between groups, in addition to determining the mean and standard deviation for each condition. A content analysis was also performed for the open-ended question at the end of the Post Condition Questionnaire. An ANOVA was also performed for the Curve-Warning Acceptance Questionnaire to determine any significant differences with respect to age and gender. Finally, since there were no instances of simulator sickness, no analysis was performed with respect to the Simulator Sickness Questionnaire.

3.10 Expected Results

With respect to the research questions posed in Chapter 2, the following results were expected:

- *How will the objective and subjective measurements vary when comparing the auditory, visual, and haptic modalities?*

Based on previous research cited in the Literature, objective measurements were expected to show that the Tire Skid auditory icon would result in the quickest response times. With respect to the auditory stimuli, the tone was expected to outperform the speech warning, although both would most likely fall behind the auditory icon. Although the majority of participants would have little to no experience with an HUD, the visual icon was expected to perform better when presented in the HUD versus the HDD. However, without an auditory or haptic element, the visual conditions by themselves were not expected to perform well with respect to reaction times.

It is important to note that only the visual icons and the speech warning actually notified the driver of the advised speed for the upcoming curve. Therefore, it was expected that although some of these warnings may have elicited quick reaction times, participants' velocity variance and speed at the entrance of the curve may have been off since they had not been notified of the advised speed.

Subjectively, it was expected that the participants would prefer the speech warning over the tone warning and the auditory icon (because of the inclusion of the advisory speed), and the HUD over the HDD.

- *How will the objective and subjective measurements vary when comparing combinations of the auditory, visual, and haptic modalities?*

Objectively, it was expected that the optimal combination would include a visual display (HUD) because it notifies the driver of the advised speed, accompanied by an auditory (tone) and/or the haptic modality. The subjective measurements were expected to correspond with the optimal multi-modality performer.

- *How will the objective and subjective measurements of the warning conditions presented vary by age group?*

It was expected that reaction times would differ between the age groups (Owens and Lehman, 2001; Warshawsky-Livne et al., 2002; Wood, 1998). However, the preferred warning conditions were expected to be similar based on objective and subjective measurements.

Chapter 4 : Results & Discussion

4.1 Objective Measurements

An ANOVA was performed for the objective data obtained during data collection, as described in Chapter 3. The model used for the analysis was a 4 (Auditory stimulus) X 3 (Visual stimulus) X 2 (Haptic stimulus) mixed-factorial design. Of the 576 stimulus conditions (i.e., 4*3*2 = 24 conditions, multiplied by 24 participants) presented during the study, two were removed before analysis: one was falsely overwritten during file transfer and the second was removed due to the presentation of a visual icon depicting a right curve for an upcoming left-handed curve.

Before the ANOVA was conducted, the data was merged and checked for normality, primarily through Univariate analysis and box plots. Potential outliers were noted and the determination to keep or remove the data was made after looking through the raw data and/or by watching the video-recorded condition in question. The data were treated as missing if the participant crashed during the condition, mainly due to that fact that the participant showed essentially no reaction in terms of deceleration, and therefore most of the other dependent variables were affected. In the end, there were seven crashes (approximately 1.2%) that were not included in the data analysis; however, these crashes are addressed separately in the report. Another condition was also removed for lack of reaction. In this condition, while the driving behavior was extreme, the participant did not crash, which resulted in wide variations in most of the dependent variables for that given condition. Based on the presentation order, this condition in question was the first one presented for this participant. After watching the video, it was clear that the participant noticed the warning but was very confused as to what to do; therefore, the condition was not included in the final data set for analysis. Because of the missing data, a PROC GLM (as opposed to a PROC ANOVA) was used in SAS®, the statistical software used to analyze data for this study.

4.1.1 Performance Measurements

A summary of significant ANOVA findings for the continuous objective dependent variables is presented in Table 4.1. All dependent variables were analyzed by an ANOVA except for the number of lane deviations. Since the number of lane deviations is a frequency count, a chi-squared analysis was performed to determine significance, and the results are included in the summary table. All results for the significant main effects and interactions are presented by dependent variable, which will be grouped by similarity as follows:

1. Throttle reaction time (TRT) and brake reaction time (BRT)
2. Speed and lane position at the entrance, apex, and exit of the curve
3. Speed variance
4. Time out of lane and the number of lane deviations

All graphs presented depict the means and standard errors. The ANOVA output tables and chi-squared analysis for all significant findings can be found in Appendix O.

Table 4.1 Summary of Significant Findings for Performance Measurements

Source	Throttle Reaction	Brake Reaction	Entrance Velocity	Entrance Lane Position	Apex Velocity	Apex Lane Position	Exit Velocity	Exit Lane Position	Speed Variance	Time out of Lane	No. of Lane Deviations
Between											
Subject											
Within											
Auditory	x	x	x		x				x	x	x
Auditory X Subject											
Visual	x	x	x	x	x		x		x		
Visual X Subject											
Haptic	x	x	x								
Haptic X Subject											
Auditory X Visual	x	x	x						x		
Auditory X Visual X Subject											
Auditory X Haptic								x			
Auditory X Haptic X Subject											
Visual X Haptic	x										
Visual X Haptic X Subject											
Auditory X Visual X Haptic			x						x		
Auditory X Visual X Haptic X Subject											

x = $p < 0.05$ (significant)

4.1.1.1 Throttle and Brake Reactions

Before the throttle and brake reaction times were calculated, certain parameters had to be defined with respect to foot placement. The data was marked regarding the participant's foot placement at the time of stimulus onset, resulting in three possible scenarios: foot on the throttle only, foot on the brake pedal (with or without the right foot on the throttle), and feet on neither pedal. If the participant's foot was on the throttle at the stimulus onset, both throttle and brake reaction times were calculated based on the constraints defined in the methods section. If the participant's foot was on the brake pedal at the time of stimulus onset, both the throttle and brake reaction times were treated as missing. For example, Participant 20, an older female, rode the brakes often using her left foot and was found to be pressing on the brake pedal during 18 of 24 stimulus conditions presented. Calculating a brake reaction time based on an increase in brake pressure was attempted and compared to data for the same age and gender (older female) for the conditions in question, but there was an obvious reaction time advantage in having one's foot already on the pedal. Table 4.2 compares the stimulus conditions in which Participant 20's left foot was "riding" the brake at stimulus onset, with the averages for each condition across the remaining older female participants (all differences greater than or equal to 1 second are shown in bold). Finally, if the participant's foot was on neither pedal at the time of stimulus onset, only the BRT was calculated. Additionally, throttle and brake reaction times that occurred after curve entry were also treated as missing data. It was determined that approximately 96% of the warnings were presented when the participant's foot was only on the throttle, 3.2% when the participant's foot was on the brake, and less than 1% when the participant's foot was on neither pedal.

Table 4.2 Comparison TRTs with respect to foot position

Stimulus Condition	Foot = 2	Foot = 1 Average	Difference
1	6.4	5.7	0.6
2	**1.1**	**4.8**	**-3.7**
3	**0.8**	**2.2**	**-1.5**
5	**0.6**	**2.1**	**-1.4**
6	1.4	2.2	-0.8
7	**3.7**	**1.8**	**1.9**
8	2.6	2.4	0.2
9	1.3	1.8	-0.5
10	1.3	1.3	0.0
13	**4.6**	**2.7**	**1.9**
14	2.0	2.3	-0.2
15	1.1	1.7	-0.6
16	1.7	2.0	-0.3
17	**0.9**	**2.9**	**-2.0**
19	**2.1**	**3.0**	**-1.0**
21	2.0	2.2	-0.2
22	**1.5**	**5.6**	**-4.1**
23	**3.1**	**4.1**	**-1.0**

Based on the ANOVA results, several main effects and interactions were found to be significant (Table 4.1). The degrees of freedom are less than the original model due to the missing data described previously, as well as the fact that not every condition had both a throttle and/or a brake reaction. In summary, out of the 566 conditions analyzed, there were 541 recorded throttle reactions and 536 recorded brake reactions.

All main effects were found to be significant ($p < 0.05$), as was the interaction between visual and auditory modalities for both reaction times. The interaction between the haptic and visual modalities was also found to be significant for the throttle reaction time. A *post-hoc* analysis was performed for each dependent variable for the auditory and visual significant main effects using the Student Newman Keuls (SNK) method. When viewing the *post*-hoc analysis, means with the same letter are not considered significantly different.

The interaction between the auditory and visual modalities (Figure 4.1) illustrates the patterns of the individual auditory and visual stimuli, as well as their effect on each other. When paired together, the order for the auditory stimuli from quickest to slowest was the auditory icon, tone, and speech. There appears to be a slight advantage when the auditory stimuli are paired with the HDD versus the HUD, but the addition of the visual stimuli regardless of its location greatly improves the reaction times. This statement can also be made when comparing the "None (no stimulus) and HDD" and "None and HUD" conditions to those with an auditory stimulus. The auditory and visual combinations resulting in the quickest throttle and brake reaction times were the Icon and HUD combination (1.2 seconds) and the Icon and HDD combination (2.1 seconds), respectively. Encouragingly, the slowest combination of auditory and visual stimuli (Speech and HUD) outperformed the conditions where no auditory or visual stimulus was presented (denoted by 'none and none') by a magnitude greater than 2.6 seconds for the TRT.

The visual and haptic interaction illustrates the faster reaction time elicited by the HDD in comparison to those same conditions presented with the HUD. This difference in reaction time was found to be significant for the throttle reaction time (Figure 4.2). However, when the visual icons were paired with the throttle push-back, this difference was not large (0.27 seconds). Importantly, however, those conditions with a visual and haptic stimulus outperformed the conditions with neither stimulus, as well as conditions with only one of the modalities.

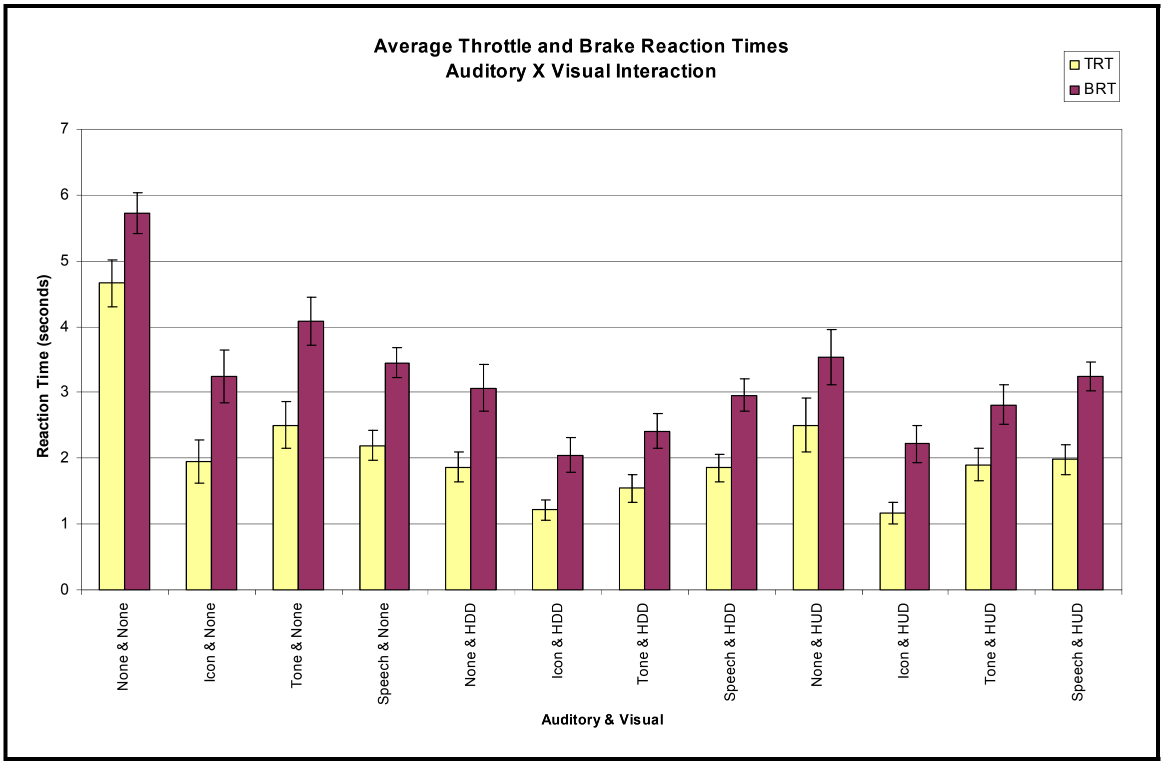

Figure 4.1 Reaction Time Comparison of Auditory X Visual Interaction

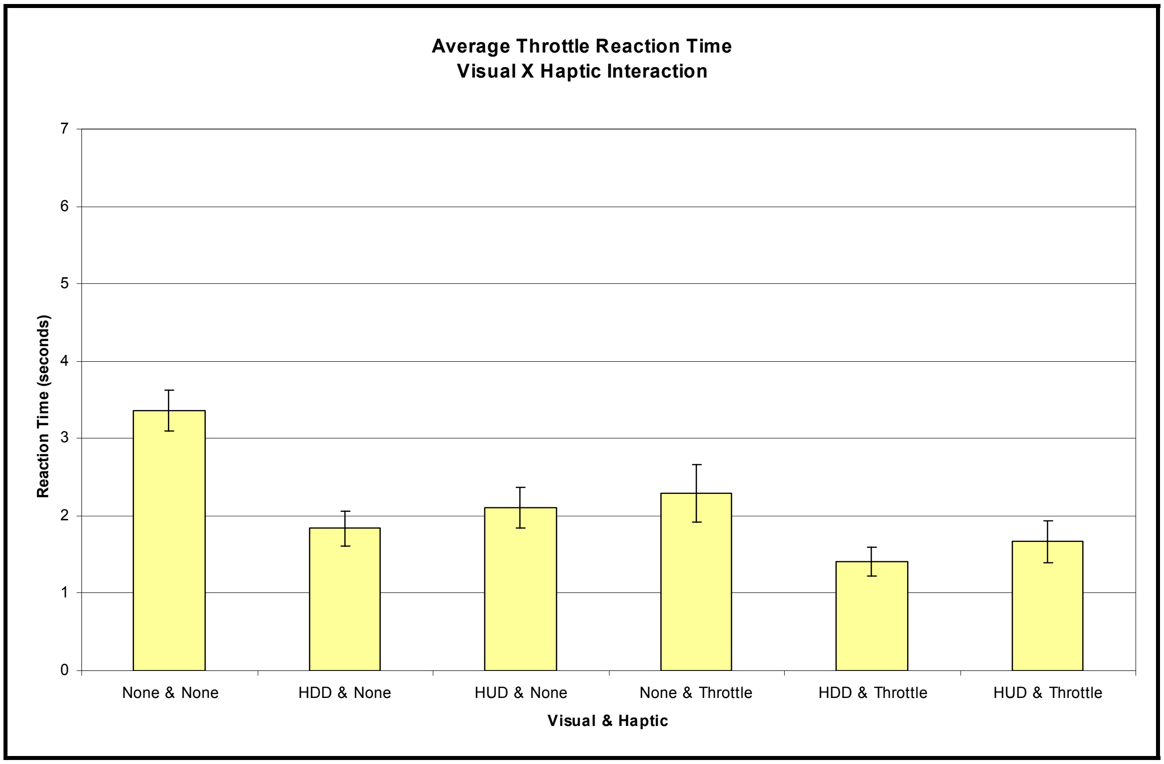

Figure 4.2 Reaction Time Comparison of Visual X Haptic Interaction

Conditions in which an auditory stimulus was presented resulted in significantly faster reaction times than those conditions in which no auditory stimulus was presented (Figure 4.3). As was expected, the throttle and brake reaction times for the auditory icon (1.57 seconds and 2.73 seconds, respectively) were significantly shorter than those for the two other auditory stimuli. Based on comments and experimenter observations made throughout data collection, it was not uncommon for the auditory icon to startle the participant, and due to its alarming nature, participants tended to apply the brakes quickly once presentation occurred. The throttle and brake reaction times for the speech stimulus (2.08 seconds and 3.34 seconds, respectively) were not considered different from the reaction times for the tone (2.15 seconds and 3.33 seconds respectively) based on the *post-hoc* analysis.

Similarly, conditions with visual stimuli resulted in significantly shorter reaction times as compared to those conditions for which no visual icon was included (Figure 4.4). However, the throttle and brake reaction times for conditions that included a visual icon in the HDD (1.70 seconds and 2.81 seconds respectively) had significantly shorter reaction times than those that included an icon in the HUD (2.01 seconds and 3.17

seconds respectively), which conflicted with the expected performance gain of the HUD over the HDD. The conditions for which the throttle-push-back was presented resulted in significantly shorter reaction times than those conditions with no haptic stimulus (Figure 4.5).

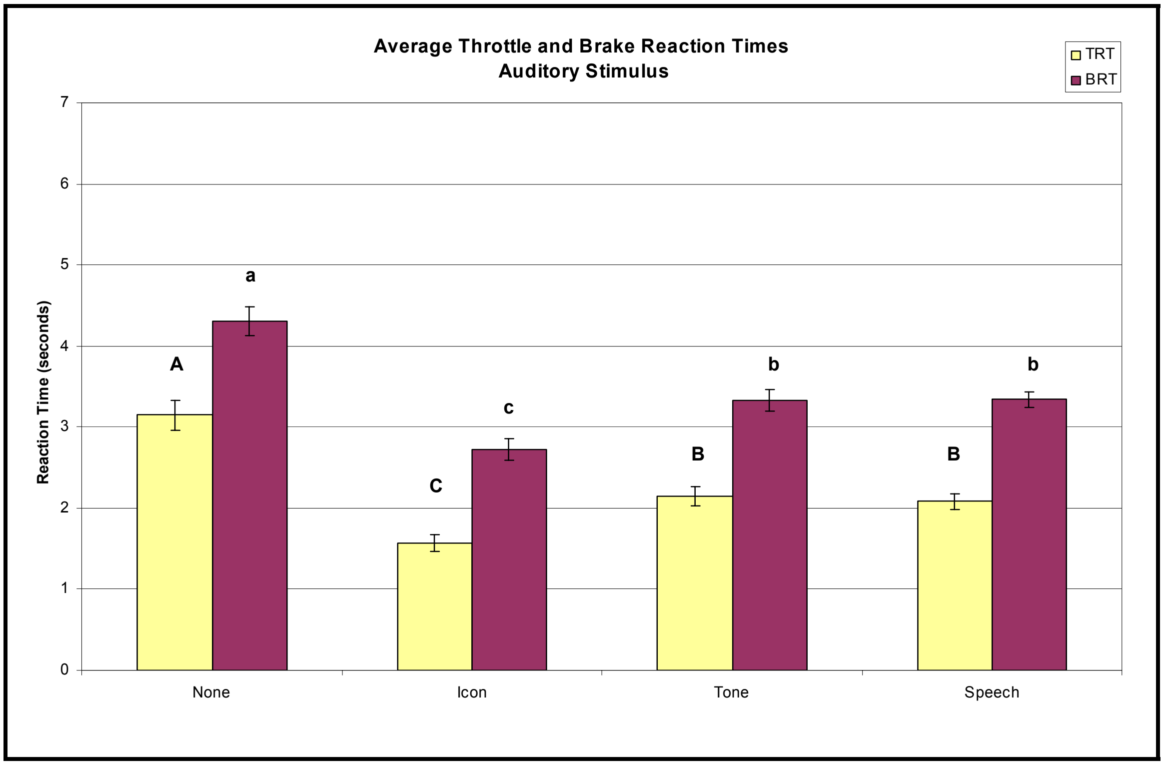

Figure 4.3 Reaction Time Comparison of Auditory Main Effect

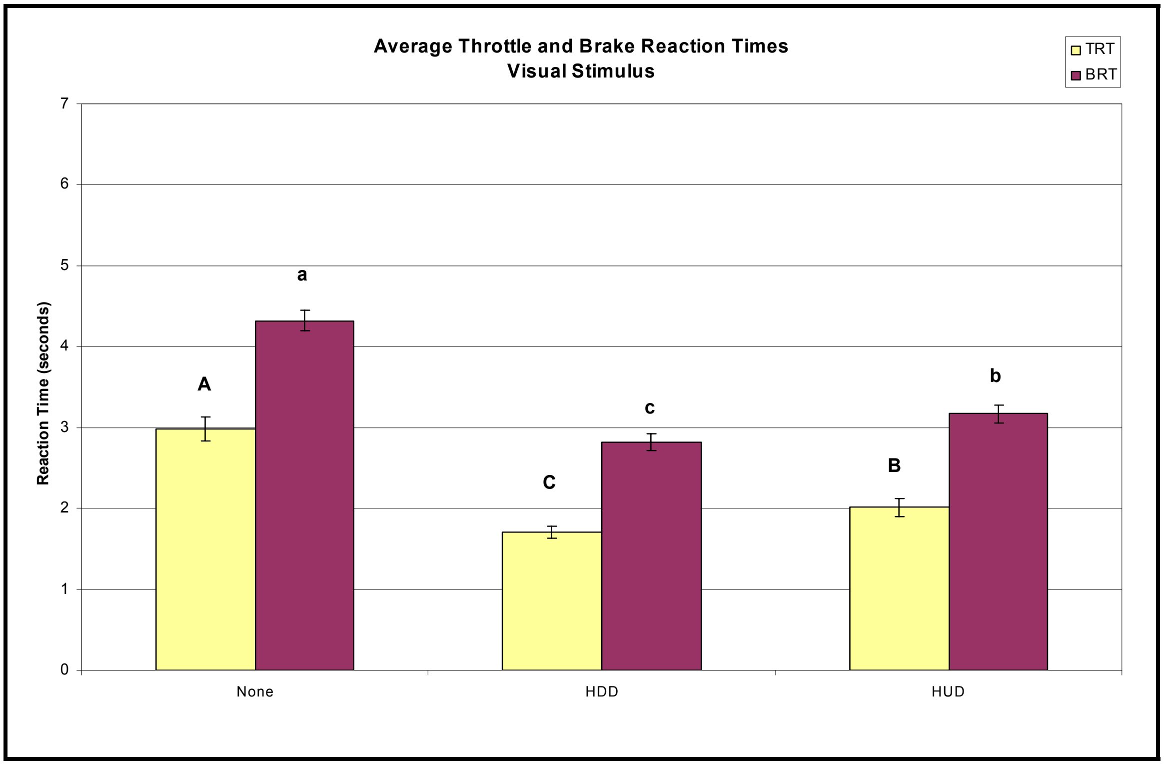

Figure 4.4 Reaction Time Comparison of Visual Main Effect

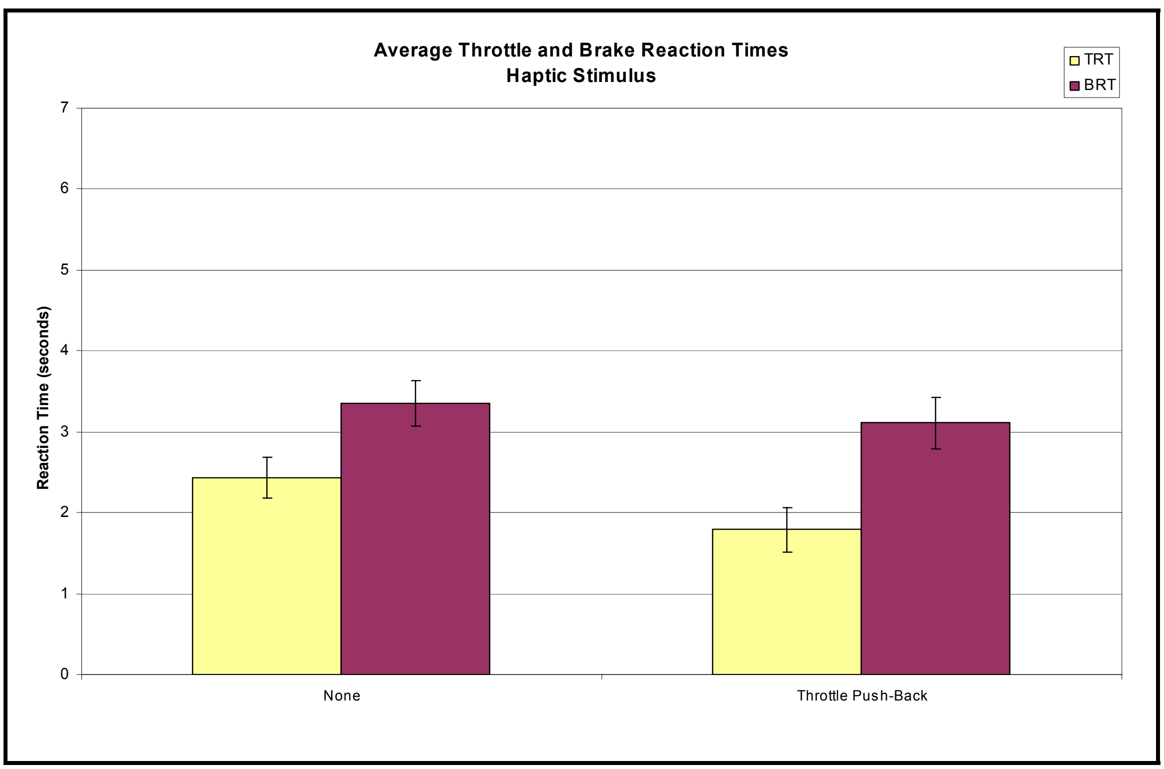

Figure 4.5 Reaction Time Comparison of Haptic Main Effect

4.1.1.2 Vehicle Speed and Position at the Curve

A snapshot of vehicle velocity and position was captured from the raw data for the entrance, apex, and exit of the curve. Based on the curve design described in Chapter 3, the entrance of the curve was set at a distance of 3500 feet from the starting point of the condition. Given the radius, also described in Chapter 3, circumference calculations were performed to determine the length of the curve, resulting in a perfect half arc, with the exit of the curve placed at approximately foot marker 3746. Therefore, the apex was assumed to be at the center of the curve, at roughly 3623 feet. Several main effects and interactions were found to be significant (Table 4.1).

The three-way interaction between the modalities was found to be significant for their curve-entrance velocities (Figure 4.6). The two conditions with curve-entry speeds closest to the 20 mph target (marked by the red line), at approximately 21 mph, were the conditions that included the Tone and HDD, and the Speech and HDD, both with the haptic stimulus. This is an interesting finding, considering that two conditions with different auditory and visual warnings would effectively tie for the lowest curve-entrance speed when combined with the throttle push-back. Seventy-five percent of the conditions were able to achieve an average entry speed of less than 25 mph, and aside from the baseline and haptic-only conditions, all were below 30 mph.

The auditory and visual interaction (Figure 4.7) demonstrates the effectiveness of the Speech stimulus with regard to advisory speed compliance. Since the speech stimulus and both of the visual icons communicated the 20 mph advisory speed, it is not surprising that conditions with one or both of these stimuli came closest to the target (shown by the red line). The Speech and HDD condition resulted in the slowest average entrance speed, at approximately 21 mph, and all conditions for which an auditory and/or visual stimulus was presented had an entrance speed of less than 28 mph, a great improvement over the 35 mph entrance speed for conditions without either the auditory or visual stimuli.

The interaction between the auditory and haptic modalities was also found to be significant for their lane position at the exit of the curve. Interestingly, the average lane position for drivers during all of the auditory and haptic conditions fell within the lane deviation criteria, likely as a result of a limiting attribute of the simulator used in the study. All conditions resulted in the participant's vehicle being positioned approximately four feet from the center of the lane, meaning that at least half of the vehicle was across the center line.

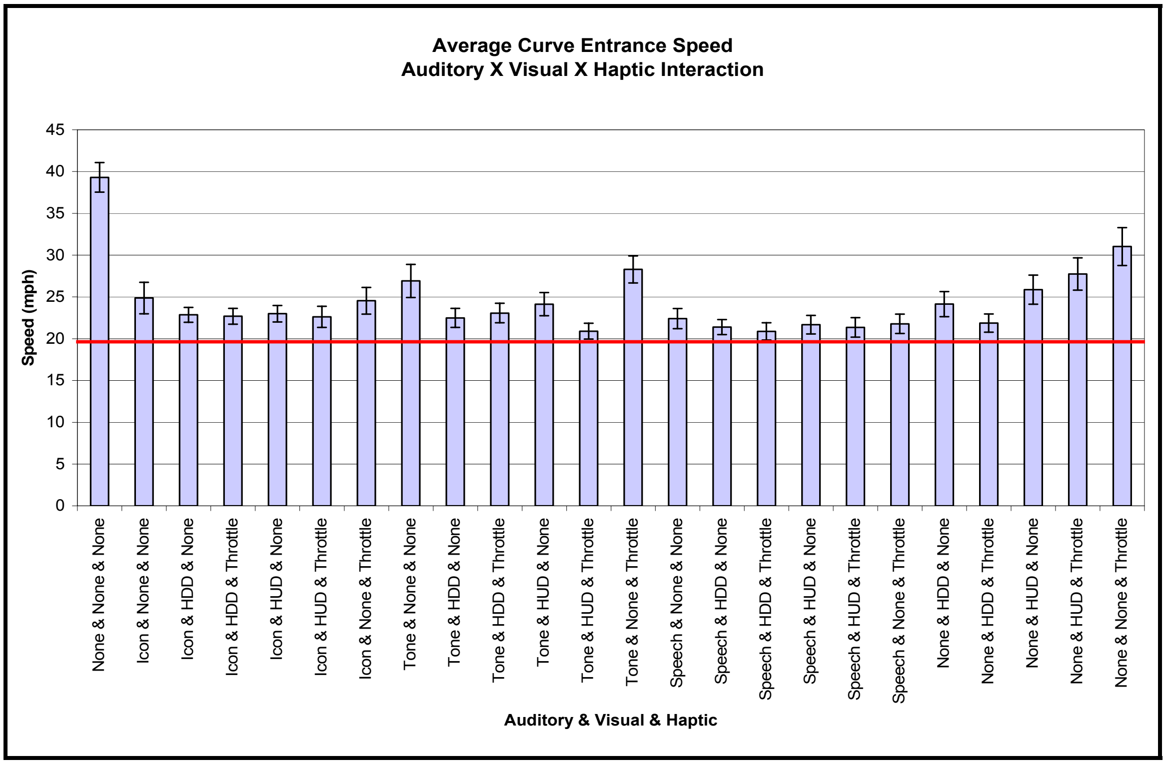

Figure 4.6 Curve Entrance Speed Comparison of Auditory X Visual X Haptic Interaction (Red line marks target speed of 20mph)

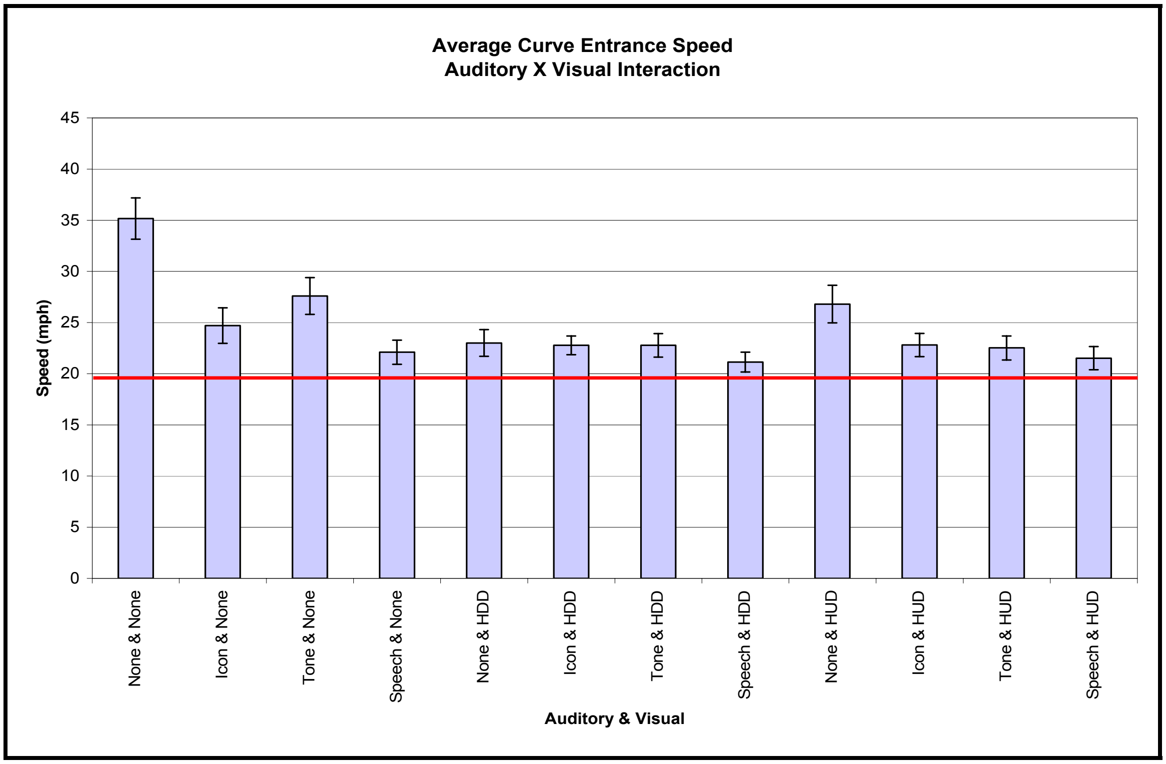

Figure 4.7 Curve Entrance Speed Comparison of Auditory X Visual Interaction (Red line marks target speed of 20mph)

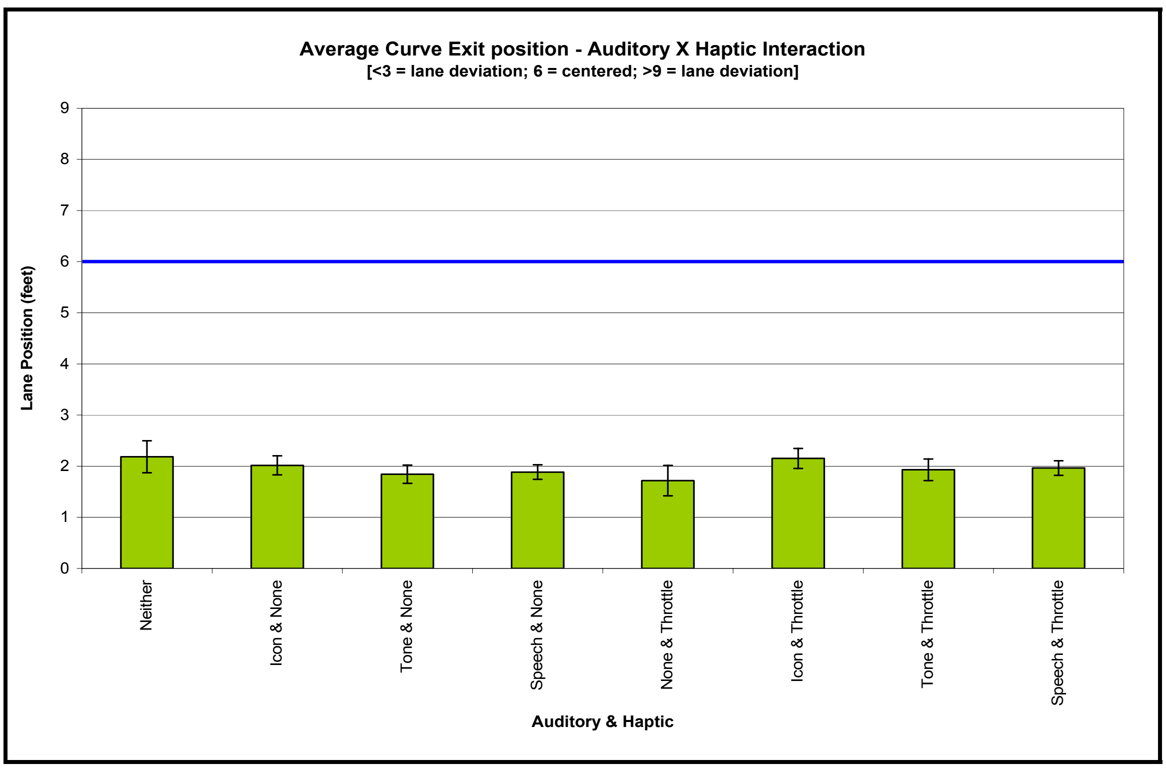

Figure 4.8 Curve Exit Lane Position Comparison of Auditory X Haptic Interaction (Blue line marks lane center)

The *post-hoc* results for the auditory main effect with respect to velocities at the curve entrance and apex are shown in Figure 4.9. As expected, the stimulus conditions that included a speech stimulus resulted in an entry speed closer to the advised 20 mph for the designed curve (marked by the red line). The entry speed for the speech stimulus was significantly different from the other auditory stimuli. The auditory tone and icon were not shown to be different from each other, but both had entry speeds significantly slower than those conditions for which no auditory stimulus was presented. Similarly, the speech stimulus resulted in significantly slower apex speeds compared to the auditory icon and no-auditory conditions. This finding was likely a result of the reduced entry speeds elicited by the speech stimulus. There was no significant difference between the tone and the other auditory stimuli with respect to apex speed.

The curve-entry and apex speeds for conditions in which a visual icon was presented were significantly lower than those speeds for conditions with no visual icons (Figure 4.10). With respect to speed compliance, there was no difference between the HUD and HDD. Only HUD conditions were significantly different from the conditions without any visual stimulus, but the HDD was not significantly different from the other two conditions with respect to exit velocities. The lane position at the curve entrance was also found to be significant for the visual modality (Figure 4.11). However, all three levels had a mean lane position that was close to the center of the lane (marked by the blue line). When measuring vehicle speed at the curve entrance, a difference of just over one mile per hour was enough to show a significant difference between conditions with the throttle push-back and those without (Figure 4.12).

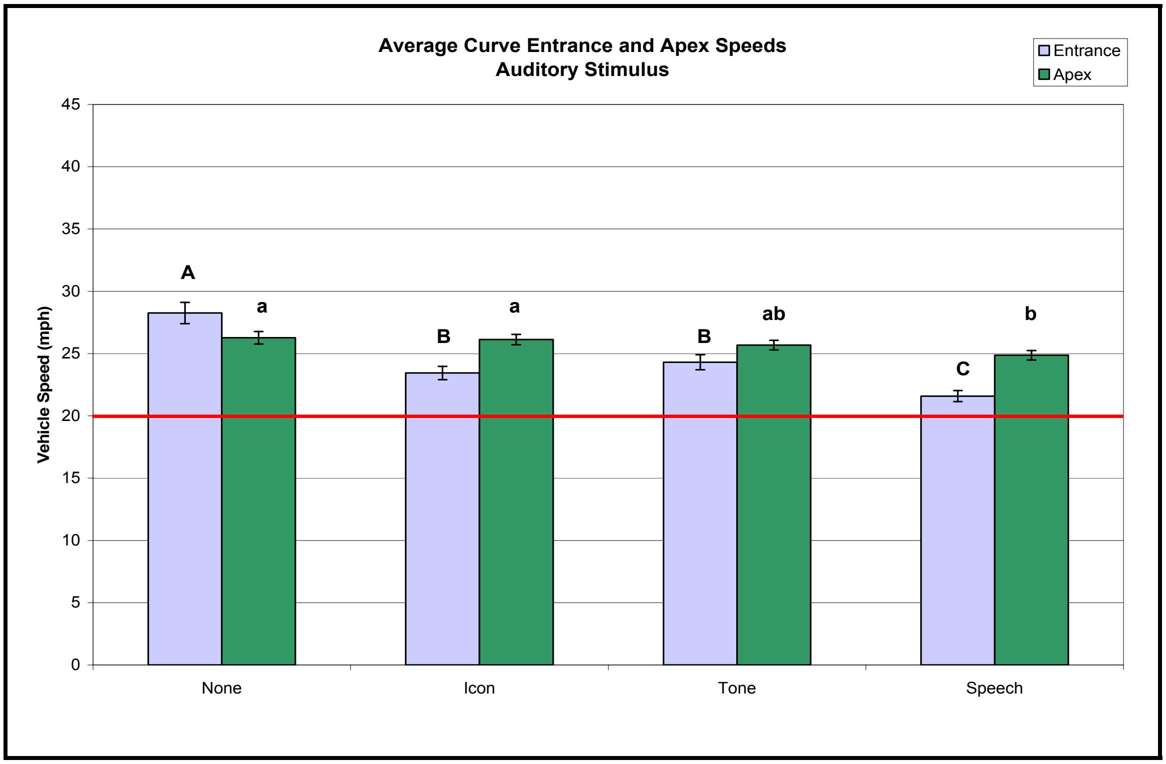

Figure 4.9 Curve Speed Comparison of Auditory Main Effect
(Red line marks target speed of 20mph)

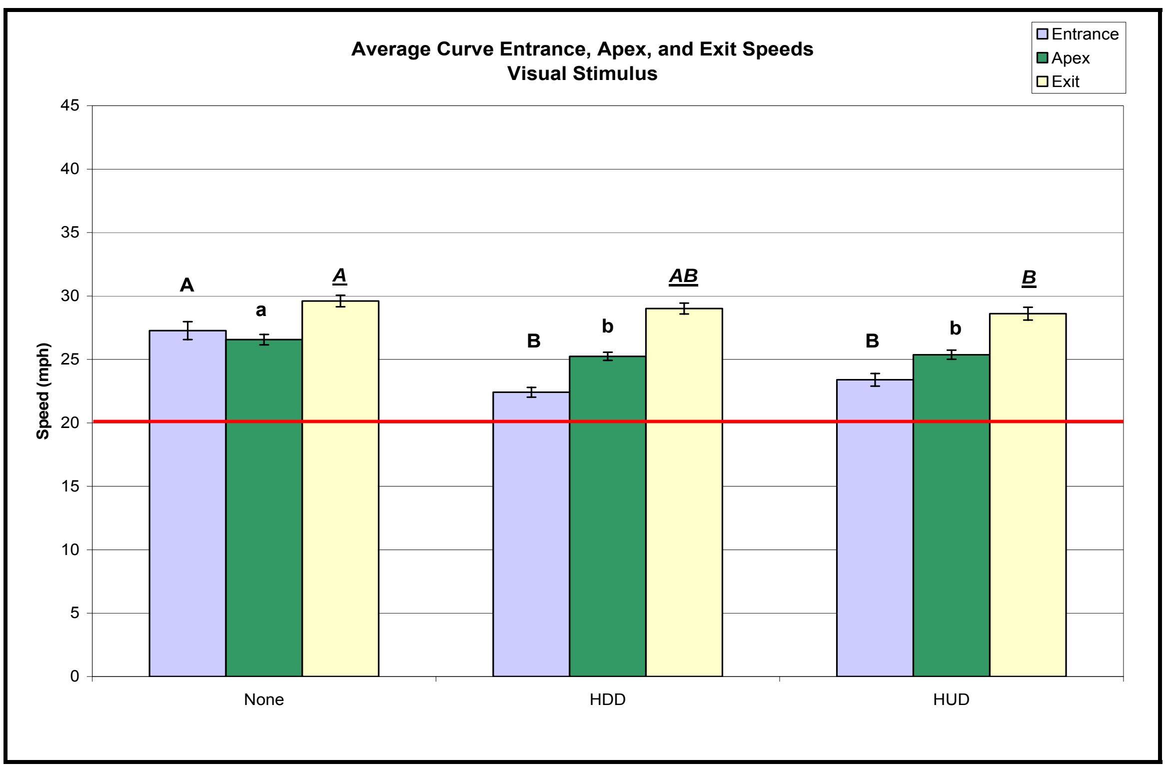

Figure 4.10 Curve Speed Comparison of Visual Main Effect
(Red line marks target speed of 20mph)

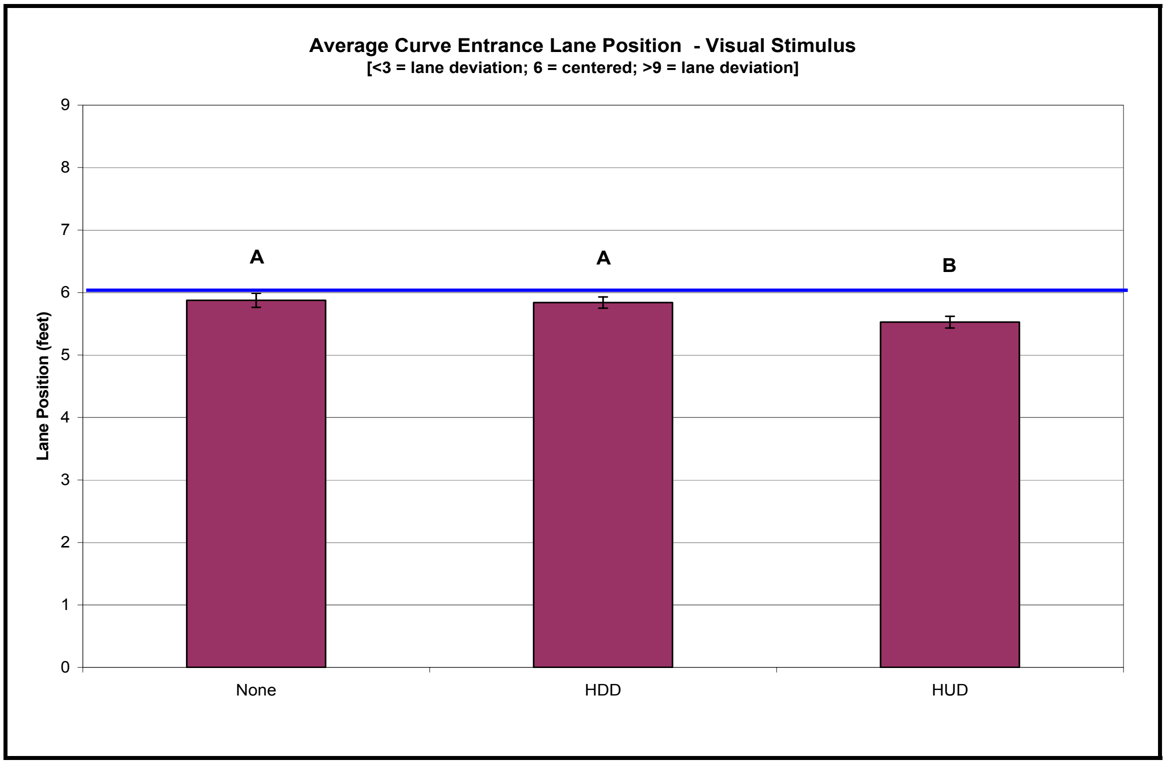

Figure 4.11 Curve Entry Lane Position Comparison of Visual Main Effect (Blue line marks lane center)

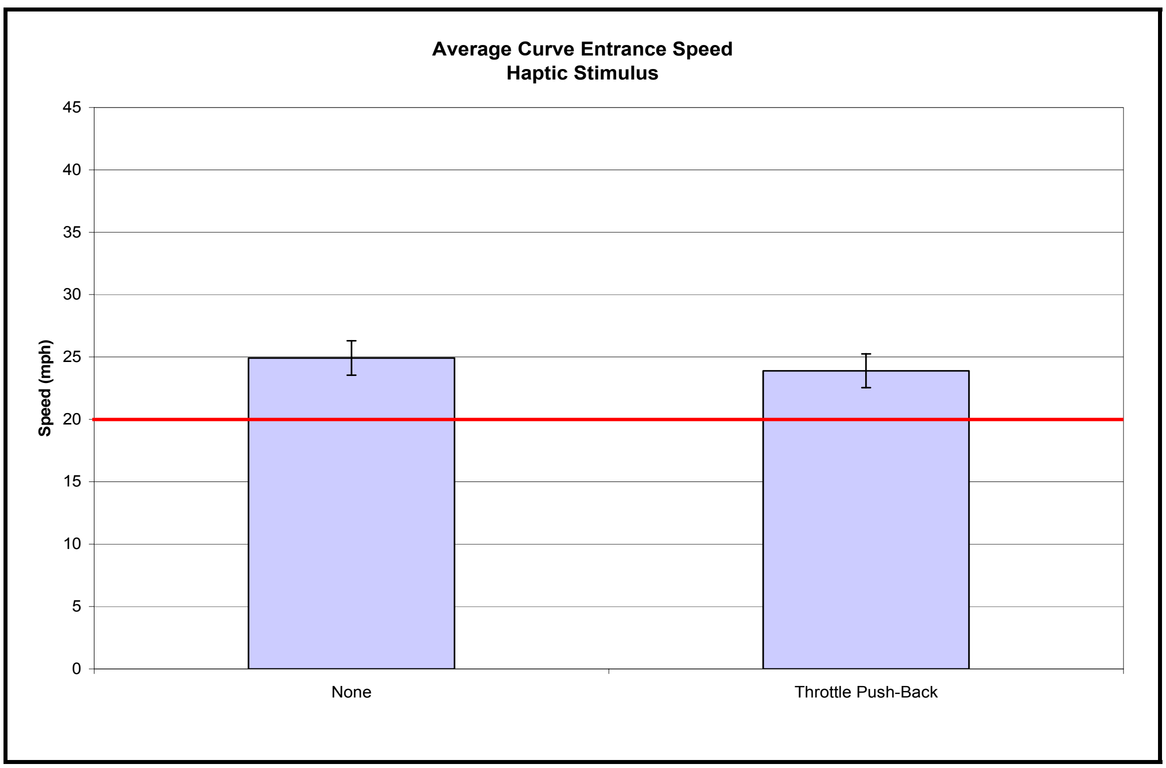

Figure 4.12 Curve Entry Speed Comparison of Haptic Main Effect (Red line marks target speed of 20mph)

4.1.1.3 Speed Variance

The speed variance was calculated over the period of time from when the stimulus was presented until the participant reached the entrance of the curve, for a total distance of approximately 634 feet. Unlike the other measures, where conditions that obtained either the highest or lowest values were considered optimal depending on the measure, a speed variance for one condition that is significantly higher or lower than its counterparts can signify confusion or lack of effectiveness. A warning that is not noticed or obtains a delayed reaction may result in only a small amount of deceleration and, in turn, a relatively small velocity variance. On the other hand, a stimulus condition could also result in an immediate reaction, with the participant decelerating quickly-- perhaps even to below the advised speed--then having to re-accelerate before reaching the curve, resulting in a high speed variance. Two values will be used to help guide the reader through the results: the expected speed variance and the overall average across all conditions.

To help explain the speed-variance results, the variance was calculated for an "optimal scenario," which represented the expected variance. To "replicate" this scenario, a spreadsheet was created that depicted data collected at a rate of 30Hz to mimic the raw data. Under the assumption of 2.5 second reaction time, the speed for the first 2.5 seconds was held at a constant 80.67 ft/s (55 mph). Based on the design of the stimulus (see Curve Design Calculations, Appendix H), the speed was evenly decreased at a rate of 4.92 ft/s^2 until it reached 29.33 ft/s (20 mph). The velocity variance for this "optimal scenario" was calculated, resulting in a variance of roughly 281.2 mph^2. In comparison, the average velocity variance, across all 24 conditions, was 142.1 mph^2. Both of these values will be the basis of comparison for the explanation of results.

The three-way interaction (Figure 4.13) shows that conditions that included the speech stimuli had relatively the same speed variance regardless of what other modalities were present. The condition with the highest speed variance was the speech alone, at approximately 177 mph^2, and the remaining five speech conditions fell within the next six highest conditions. Except for the baseline condition (with a variance of 26.0 mph^2), the throttle push-back by itself (84.6 mph^2), and the Tone and Throttle with no visual condition (91.6 mph^2), all conditions had a speed variance of at least 120 mph^2.

The interaction between the auditory and visual stimuli was found to be significant, and is shown in Figure 4.14. The speed variances for conditions with the speech stimuli were all approximately the same (average of approximately 172 mph^2), regardless of the presence of a visual warning, or the lack thereof. However, the two other auditory stimuli did benefit from the addition of the visual warning, most likely as a result of the inclusion of the advisory speed. Importantly, all visual and auditory combinations had significantly higher variances than the conditions that included neither.

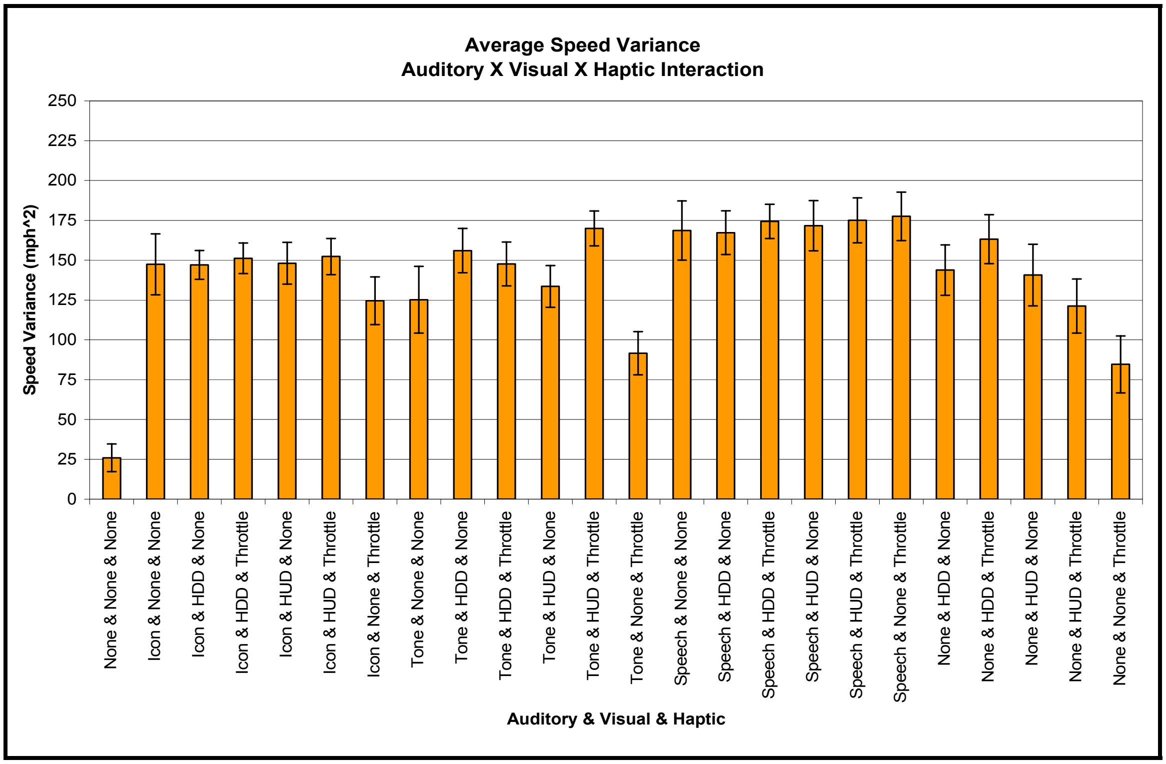

Figure 4.13 Speed Variance Comparison of Auditory X Visual X Haptic Interaction

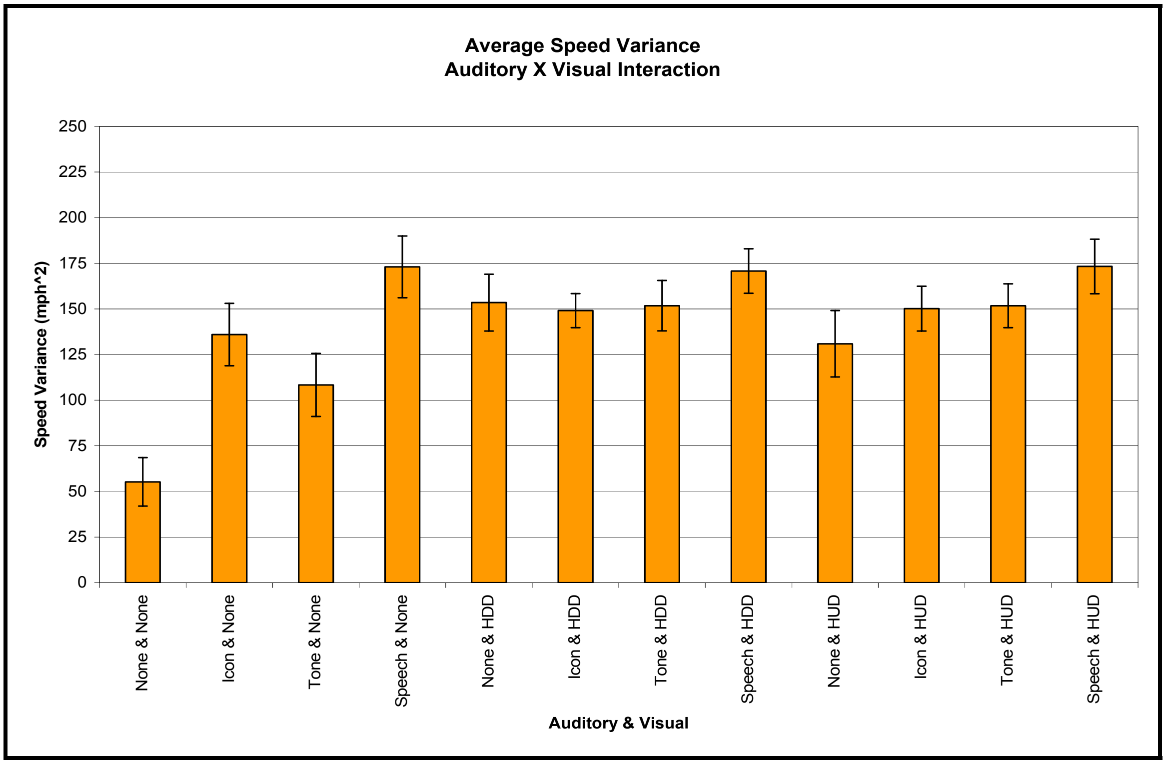

Figure 4.14 Speed Variance Comparison of Auditory X Visual Interaction

The speed variance was also found to be significant for both the auditory and visual main effects (Figure 4.15 and Figure 4.16). The speech stimulus had the highest variance, at roughly 172 mph^2, and was significantly different from the other two warnings and the no-auditory conditions. It appears that the higher the speed variance, without exceeding the "optimal" value of 281 mph^2, the smoother the transition was between reacting to the stimulus along with holding a steady rate of deceleration leading to the curve. The auditory icon and tones were not significantly different from each other, although both had significantly higher variances than the conditions with no auditory stimulus. This order of auditory stimuli, not unexpectedly, is reversed from the curve-entrance velocity relationship between the four levels. Therefore, for this particular study, the argument can again be made that the lower the speed variance, the higher the speed at the entrance of the curve. With respect to the visual modality, both the HDD and HUD, with variances in speed of roughly 156 and 151 mph^2, respectively, were significantly higher than the no-visual conditions (119 mph^2) but were not different from each other.

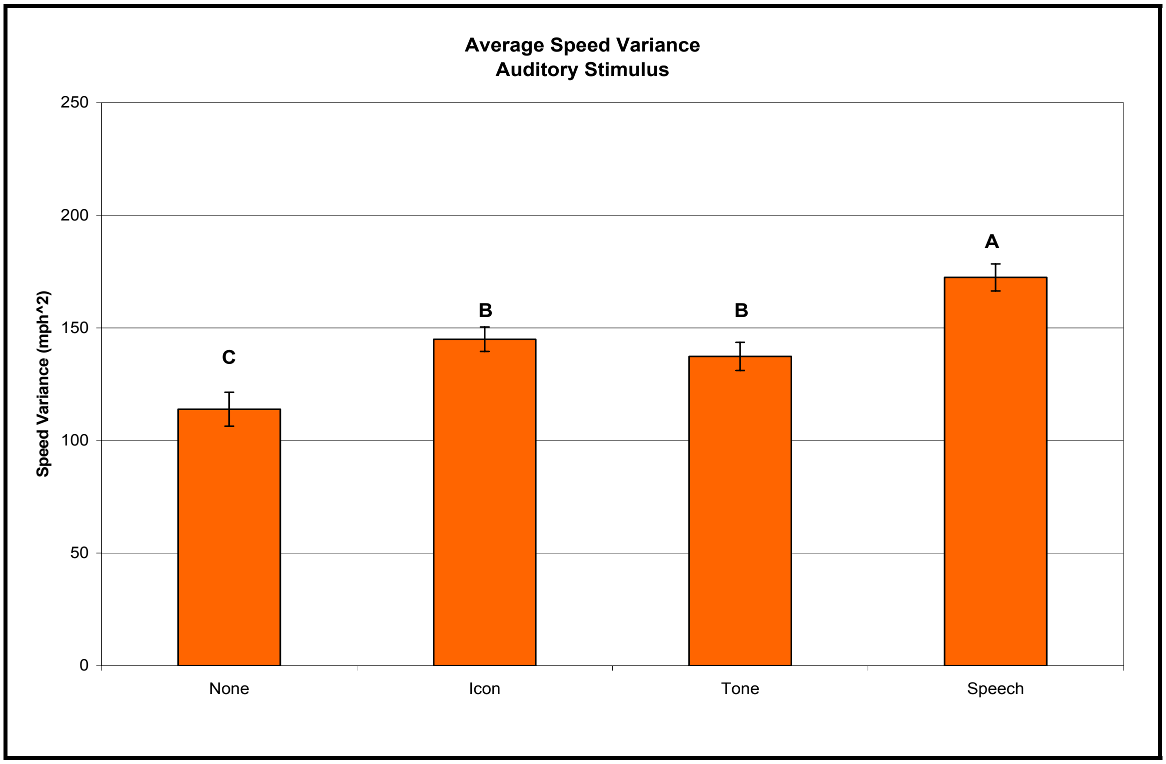

Figure 4.15 Speed Variance Comparison of Auditory Main Effect

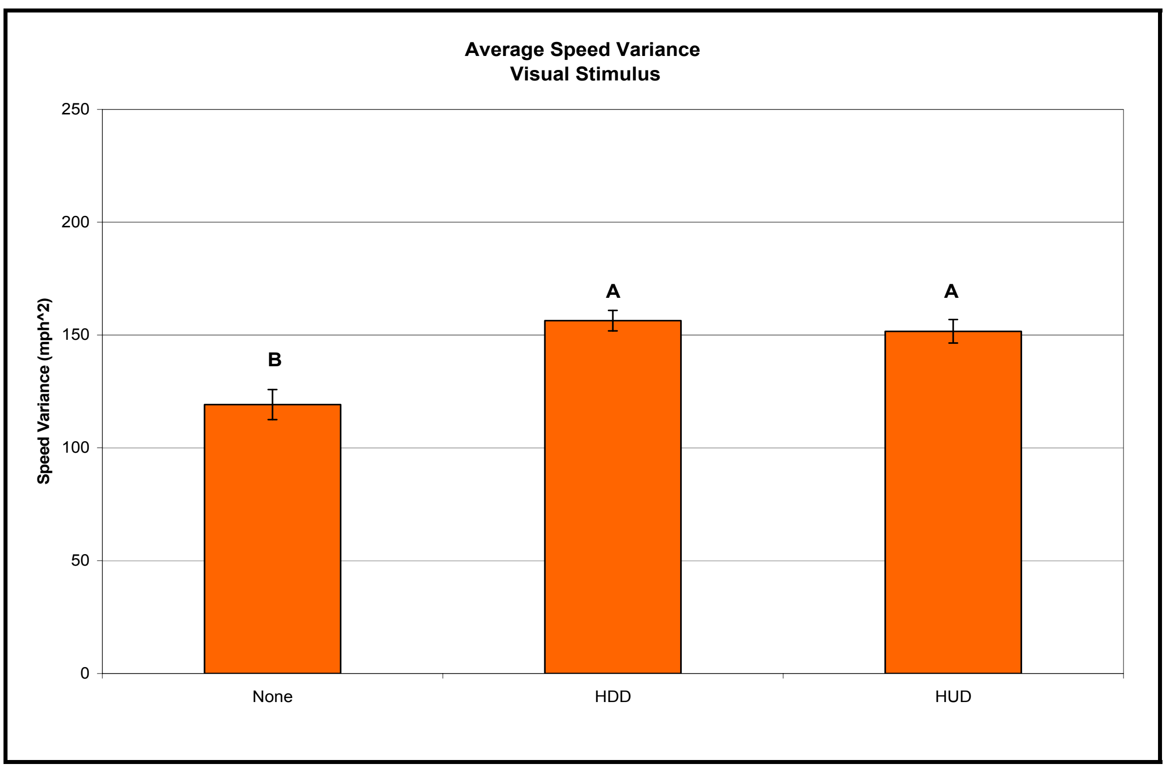

Figure 4.16 Speed Variance Comparison of Visual Main Effect

4.1.1.4 Time out of Lane and Lane Deviations

The time out of lane dependent variable was defined as the time from the point at which the vehicle came into contact with the center or edge line until the vehicle was back in the correct lane and no longer touching the center or edge line. The total time out of lane or the summation of all deviations within a condition was used for the analysis. Only the auditory main effect was found to be significant (Figure 4.17). The conditions that included the speech stimulus had significantly less time out of lane when compared to the auditory icon, tone, and conditions with no auditory stimulus. The auditory tone was found to result in significantly less time out of lane when compared to the conditions without an auditory stimulus, but it was not significantly different from the auditory icon. The time out of lane during conditions that included the auditory icon was not different from the non-auditory conditions.

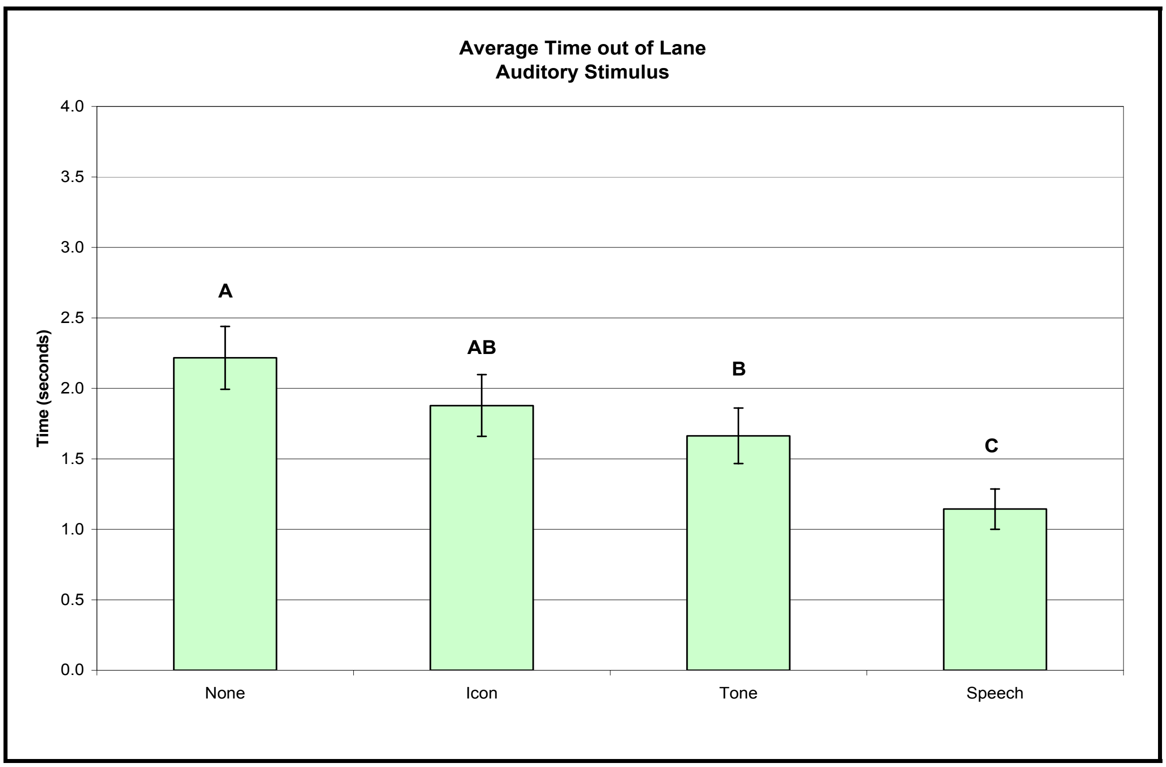

Figure 4.17 Time out of Lane Comparison of Auditory Main Effect

A chi-squared analysis was performed to determine significance with respect to the number of lane deviations (all non-significant chi-squared tables can be seen in Appendix P). Again, the only significance found was for the auditory main effect (Table

4.3). The speech stimulus resulted in the lowest total number of lane deviations, with 85 (Figure 4.18). This measure combined all conditions that included the speech stimulus. The auditory icon and tones had 99 and 101 total lane deviations, respectively, compared to 136 combined from all six conditions without an auditory stimulus. Primarily, these lane deviations occurred during the curve, often as a result of excessive speed. Therefore, the number of lane deviations can also be considered to be an indication of warning comprehension and compliance.

Table 4.3 Lane Deviation Analysis of Auditory Main Effect

	Auditory				
	None	Icon	Tone	Speech	Total
Lane Deviations	136	99	101	85	**421**

DF	Value	p-value
3	13.4228	0.0004

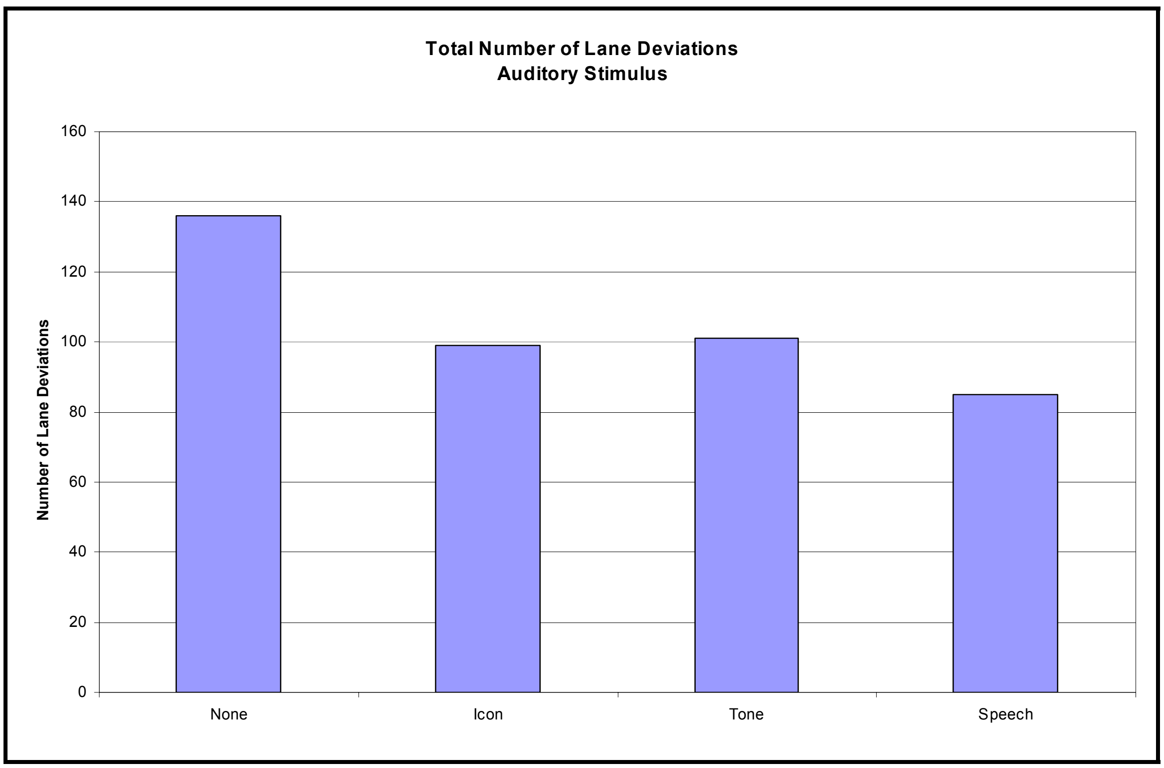

Figure 4.18 Lane Deviation Analysis for Auditory Main Effect

4.1.2 Performance Measurements by Age and Stimulus Condition

Exploratory techniques were used to determine significance between age and stimulus condition by developing a mixed-factors design. The model and respective degrees of freedom can be seen in Table 4.4

Table 4.4 ANOVA Model for Age and Condition

Source	**df**
Between	
Age	1
Subject(Age)	22
Within	
Condition	23
Age X Condition	23
Condition X Subject(Age)	506
Total	**575**

All of the dependent variables were analyzed using the PROC GLM command in SAS®, except for the number of lane deviations, which was analyzed using a chi-squared analysis. A summary of significant findings can be found in Table 4.5. All significant main effects and interactions are presented by dependent variable, which are grouped again by similarity (i.e., throttle and brake reaction time). All of the ANOVA summary tables can be seen in Appendix Q.

Table 4.5 Summary of Significant Findings for Age and Condition

Source	Throttle Reaction	Brake Reaction	Entrance Velocity	Entrance Lane Position	Apex Velocity	Apex Lane Position	Exit Velocity	Exit Lane Position	Speed Variance	Time out of Lane	No. of Lane Deviations
Between											
Age			**x**		**x**	**x**	**x**		**x**		
Subject(Age)											
Within											
Condition	**x**	**x**	**x**		**x**				**x**	**x**	
Age X Condition	**x**	**x**	**x**				**x**		**x**		
Condition X Subject(Age)											

x = p < 0.05 (significant)

4.1.2.1 Throttle and Brake Reaction

Significance was found for both the throttle and brake reaction times for the condition main effect and the interaction between condition and age ($p < 0.0001$). A *post-hoc* analysis using the SNK method was performed for the condition main effect.

The interaction between age and condition was found to be significant with respect to TRTs, and there were some considerable differences between younger and older participants for a number of the conditions (Figure 4.19). The TRT values by age, as well as the numerical and percentile differences can be found in Table 4.6. The top-five TRTs for each age group are shown in bold. The results show some overlap between the top five for each age group, with both groups sharing the same configuration at the top spot – the Icon and HUD and Throttle combination. The younger participants greatly outperformed the older participants on all conditions without an auditory modality, with reaction time differences ranging from 0.65 to 2.06 seconds.

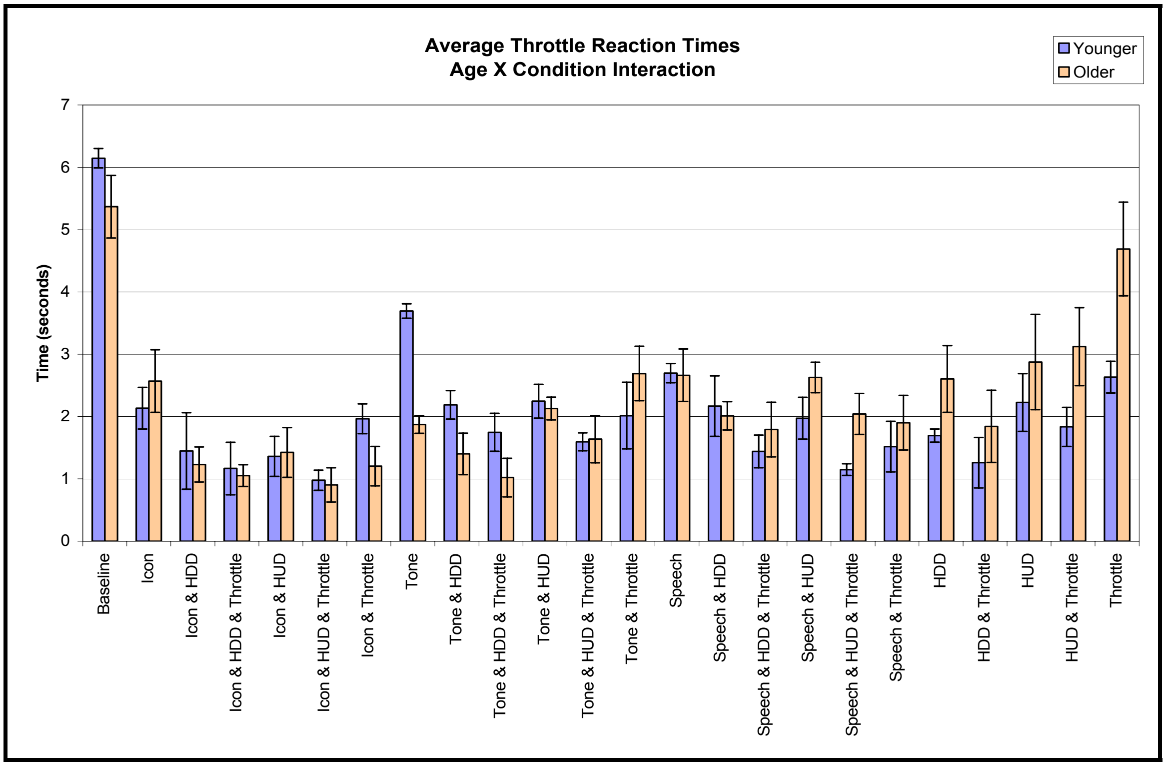

Figure 4.19 Throttle Reaction Time Comparison of Age X Condition Interaction

Table 4.6 TRT Comparison of Age X Condition Interaction

Condition	Younger	Older	TRT Difference
Baseline	6.1	5.4	0.8
Icon	2.1	2.6	-0.4
Icon & HDD	1.4	**1.2**	0.2
Icon & HDD & Throttle	**1.2**	**1.1**	0.1
Icon & HUD	**1.4**	1.4	-0.1
Icon & HUD & Throttle	**1.0**	**0.9**	0.1
Icon & Throttle	2.0	**1.2**	0.8
Tone	3.7	1.9	1.8
Tone & HDD	2.2	1.4	0.8
Tone & HDD & Throttle	1.7	**1.0**	0.7
Tone & HUD	2.2	2.1	0.1
Tone & HUD & Throttle	1.6	1.6	0.0
Tone & Throttle	2.0	2.7	-0.7
Speech	2.7	2.7	0.0
Speech & HDD	2.2	2.0	0.2
Speech & HDD & Throttle	1.4	1.8	-0.4
Speech & HUD	2.0	2.6	-0.7
Speech & HUD & Throttle	**1.1**	2.0	-0.9
Speech & Throttle	1.5	1.9	-0.4
HDD	1.7	2.6	-0.9
HDD & Throttle	**1.3**	1.8	-0.6
HUD	2.2	2.9	-0.6
HUD & Throttle	1.8	3.1	-1.3
Throttle	2.6	4.7	-2.1

The comparison of throttle reaction times across the conditions can be seen in Figure 4.20. Initially, the *post-hoc* results show that the baseline and throttle push-back-only conditions performed significantly worse than all other conditions with respect to throttle reaction times. The average throttle reaction time for the haptic-only condition was roughly 3.9 seconds, one second longer than the presentation of the haptic stimulus. On the other hand, the throttle push-back was included in nine of the twelve conditions with the lowest throttle reaction times, which shows its effectiveness when paired with the visual and auditory modalities. For example, the auditory icon by itself averaged approximately 2.6 seconds, but this decreased to roughly 1.7 seconds with the addition of the haptic modality.

The auditory trends are still exhibited when broken down by condition, with the auditory icon performing better than the tone and speech. There also does not appear to be a drastic difference between visual icons when paired with the auditory modality. The combination with haptic alone resulted in significantly faster reaction times for the HDD and throttle versus the HUD and throttle condition. Interestingly, of the twelve conditions with TRT's below two seconds, 92% of them included an auditory warning; 83% included a visual icon; and as mentioned earlier, 75% included the throttle push-back. Six out of the twelve conditions performing better than two seconds included all three modalities.

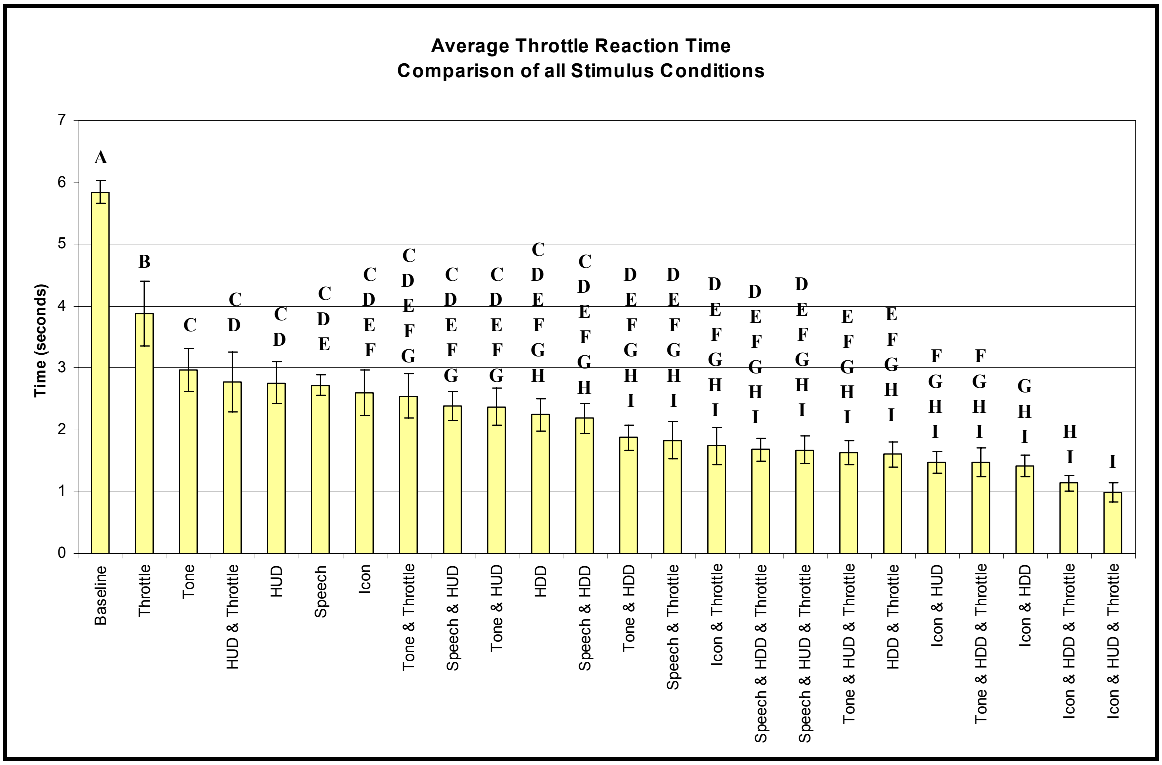

Figure 4.20 Throttle Reaction Time Comparison of Condition Main Effect

As with the TRT, there are some notable BRT differences with some of the stimulus conditions when broken down by age group (Figure 4.21). Some of the same conditions that showed a large difference for the TRT continued to show the same result for the BRT. Table 4.7 breaks down the numerical data by age group as well as the differences between the two groups. Interestingly, if the differences are averaged out, the older participants outperform the younger participants by 0.41 seconds, a reversal from the 0.14 seconds advantage the younger participants had for TRTs. Four stimulus conditions had spots in the top-five quickest BRTs for both age groups, which is more overlap than the two conditions that were shared with respect to TRTs.

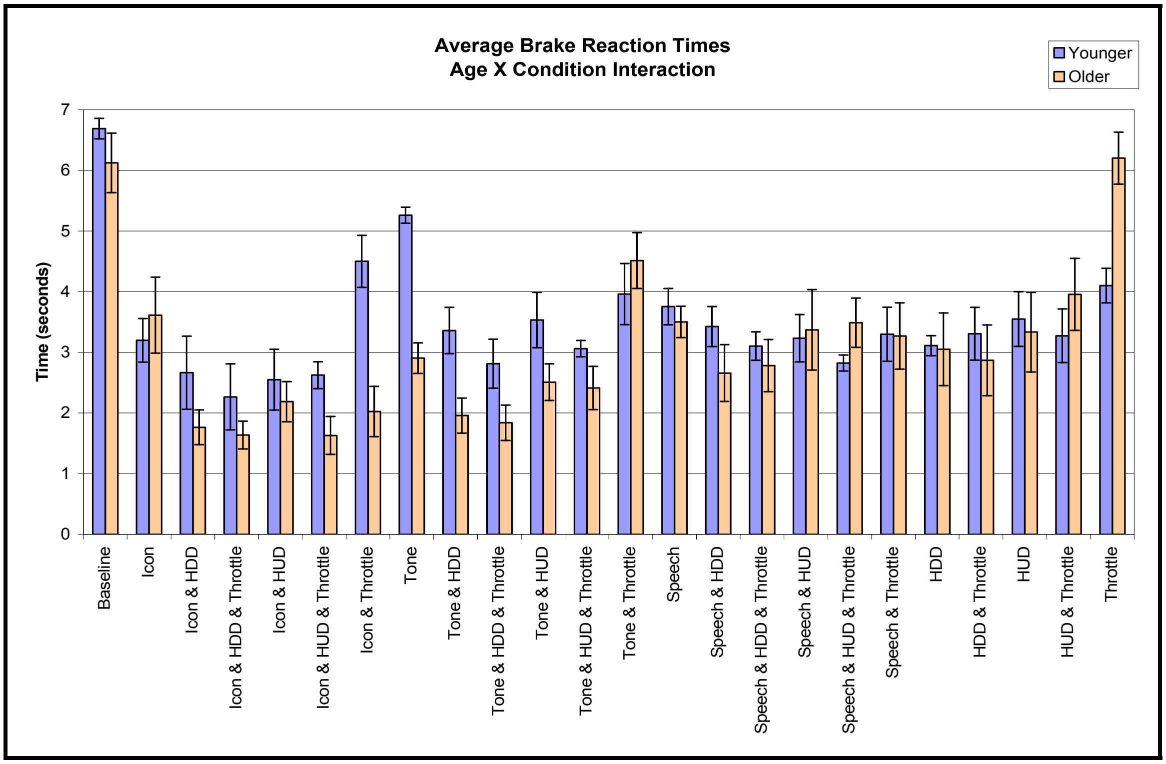

Figure 4.21 Brake Reaction Time Comparison of Age X Condition Interaction

Table 4.7 BRT Comparison of Age X Condition Comparison

Condition	Younger	Older	BRT Difference
Baseline	6.7	6.1	0.6
Icon	3.2	3.6	-0.4
Icon & HDD	**2.7**	**1.8**	0.9
Icon & HDD & Throttle	**2.3**	**1.6**	0.6
Icon & HUD	**2.5**	2.2	0.4
Icon & HUD & Throttle	**2.6**	**1.6**	1.0
Icon & Throttle	4.5	2.0	2.5
Tone	5.3	2.9	2.4
Tone & HDD	3.4	**2.0**	1.4
Tone & HDD & Throttle	**2.8**	**1.8**	1.0
Tone & HUD	3.5	2.5	1.0
Tone & HUD & Throttle	3.1	2.4	0.6
Tone & Throttle	4.0	4.5	-0.6
Speech	3.8	3.5	0.3
Speech & HDD	3.4	2.7	0.8
Speech & HDD & Throttle	3.1	2.8	0.3
Speech & HUD	3.2	3.4	-0.1
Speech & HUD & Throttle	2.8	3.5	-0.7
Speech & Throttle	3.3	3.3	0.0
HDD	3.1	3.1	0.1
HDD & Throttle	3.3	2.9	0.4
HUD	3.5	3.3	0.2
HUD & Throttle	3.3	4.0	-0.7
Throttle	4.1	6.2	-2.1

Since the time to react by pressing the brake pedal was often affected by the participants' throttle reaction time, the overall order of performance for the BRTs is fairly similar (Figure 4.22); however, some exceptions do apply. Although the HDD and throttle push-back combination was ranked sixth in TRT, with a reaction of 1.6 seconds, its BRT was almost 3.4 seconds on average, dropping it to 13th overall. What seemed to be effective in alerting the driver to remove his/her foot from the throttle was not necessarily enough to get him/her to begin braking. The stimulus make-up has changed somewhat, resulting in the top-12 BRT conditions comprised of 92% auditory, 100% visual, and a drop to 50% for the haptic stimulus.

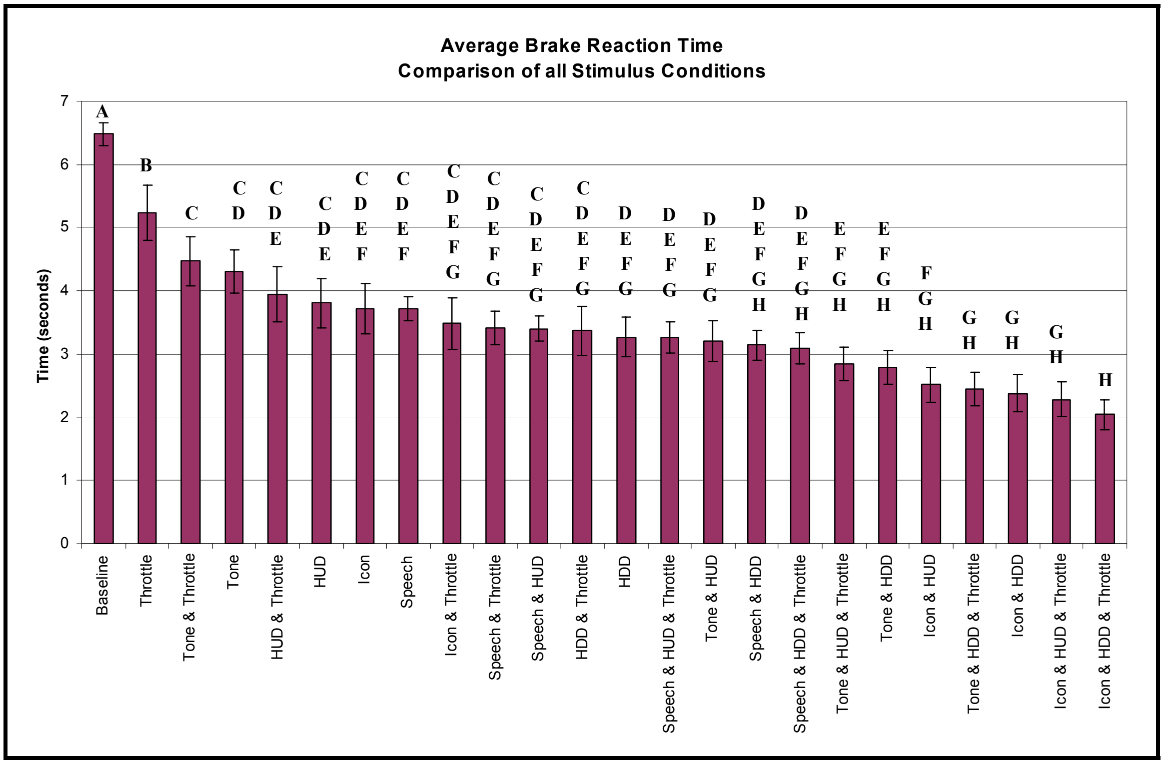

Figure 4.22 Brake Reaction Time Comparison of Condition Main Effect

<u>*4.1.2.2. Curve speeds and lane positions*</u>

A compliance trend between the older and younger participants can be seen in the Age X Condition interaction (Figure 4.23). Table 4.8 presents the numerical data and differences, ranging from less than 0.15 mph (HUD and Throttle) to as high as 14 mph (tone only). Aside from the Tone and Throttle condition, the speed at the curve entrance was lower for the older participants. The older participants arrived at the advised speed of 20 mph in fourteen (58%) of the stimulus conditions, compared to none for the younger participants. The closest the younger participants came to the advised speed was approximately 23 mph, obtained for the Tone and HUD and Throttle, and the Speech and HUD and Throttle conditions.

The Age X Condition interaction was also found to be significant for curve exit speeds (Figure 4.24). The younger participants exited the curve in each of the conditions at a higher rate of speed, with differences ranging from approximately 4 mph to 12 mph. This significant interaction illustrates that in addition to higher curve entry speeds, the younger participants were less likely to continue braking once entering the curve, and accelerated more than the older participants during the curve.

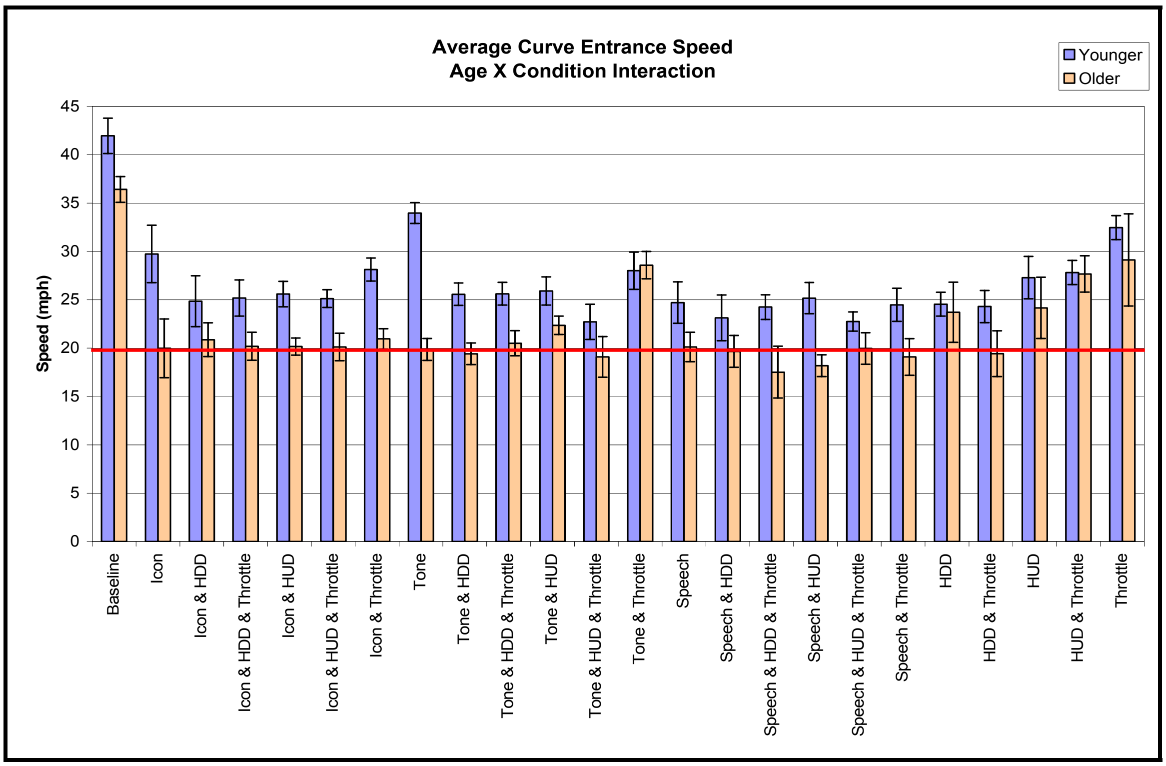

Figure 4.23 Curve Entry Speed Comparison of Age X Condition Interaction (Red line marks target speed of 20mph)

Table 4.8 Curve Entry Speed Comparison of Age X Condition Interaction

Condition	Younger	Older	Entry Speed Difference
Baseline	42.0	36.4	5.5
Icon	29.7	20.0	9.8
Icon & HDD	24.9	20.9	4.0
Icon & HDD & Throttle	25.2	20.2	5.0
Icon & HUD	25.6	20.2	5.4
Icon & HUD & Throttle	25.1	20.1	5.0
Icon & Throttle	28.1	21.0	7.2
Tone	34.0	19.9	14.1
Tone & HDD	25.6	**19.4**	6.2
Tone & HDD & Throttle	25.6	20.5	5.1
Tone & HUD	25.9	22.4	3.5
Tone & HUD & Throttle	**22.7**	**19.1**	3.6
Tone & Throttle	28.0	28.6	-0.6
Speech	24.7	20.1	4.6
Speech & HDD	**23.1**	19.7	3.5
Speech & HDD & Throttle	**24.2**	**17.5**	6.7
Speech & HUD	25.2	**18.2**	7.0
Speech & HUD & Throttle	**22.7**	20.0	2.8
Speech & Throttle	24.5	**19.1**	5.4
HDD	24.5	23.7	0.8
HDD & Throttle	**24.3**	19.4	4.9
HUD	27.3	24.2	3.1
HUD & Throttle	27.8	27.7	0.2
Throttle	32.5	29.1	3.3

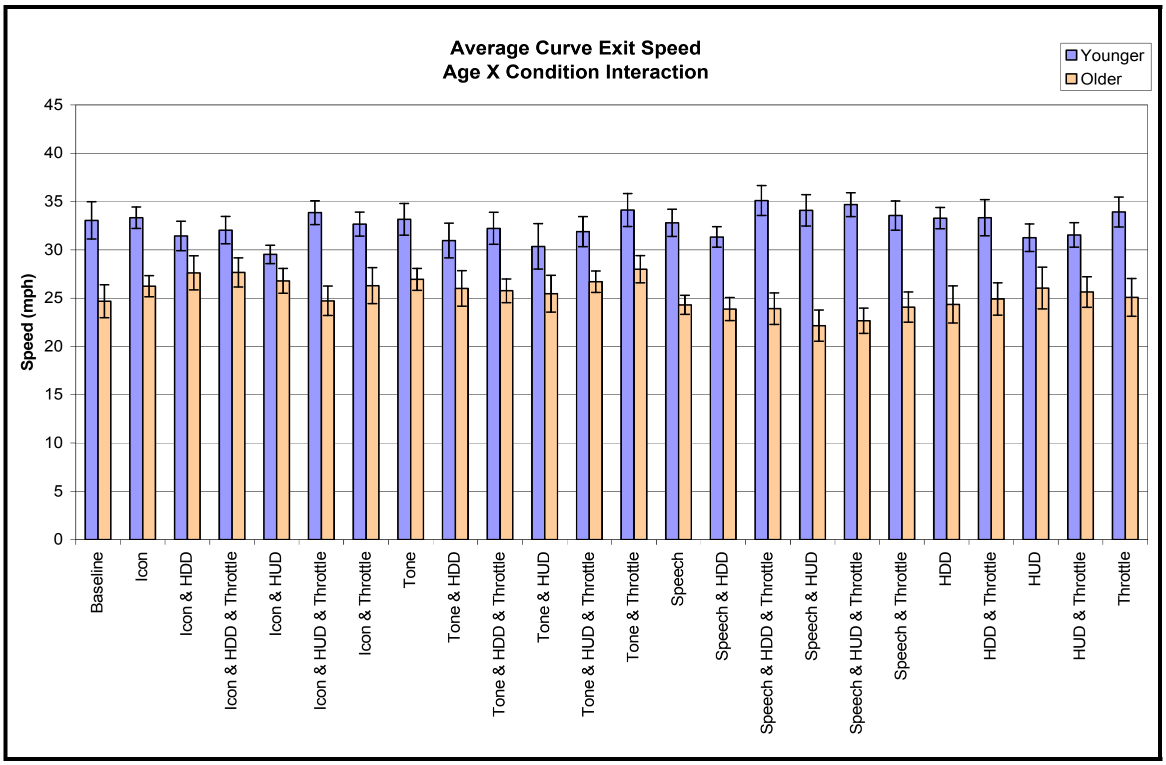

Figure 4.24 Curve Exit Speed Comparison for Age X Condition Interaction

Table 4.9 Curve Exit Speed Comparison of Age X Condition Interaction

Condition	Younger	Older	Exit Speed Difference
Baseline	33.0	24.7	8.4
Icon	33.3	26.2	7.1
Icon & HDD	31.4	27.6	3.8
Icon & HDD & Throttle	32.0	27.7	4.4
Icon & HUD	**29.5**	26.8	2.7
Icon & HUD & Throttle	33.8	24.7	9.1
Icon & Throttle	32.7	26.3	6.4
Tone	33.2	26.9	6.2
Tone & HDD	**31.0**	26.0	5.0
Tone & HDD & Throttle	32.2	25.8	6.5
Tone & HUD	**30.4**	25.5	4.9
Tone & HUD & Throttle	31.9	26.7	5.2
Tone & Throttle	34.1	28.0	6.1
Speech	32.8	24.3	8.5
Speech & HDD	**31.3**	**23.9**	7.5
Speech & HDD & Throttle	35.1	**23.9**	11.2
Speech & HUD	34.1	**22.2**	11.9
Speech & HUD & Throttle	34.7	**22.7**	12.0
Speech & Throttle	33.5	**24.1**	9.5
HDD	33.3	24.3	8.9
HDD & Throttle	33.3	24.9	8.4
HUD	**31.3**	26.0	5.2
HUD & Throttle	31.5	25.6	5.9
Throttle	33.9	25.1	8.8

Age was found to be significant for speed at the curve entrance, apex, and exit, as seen in Figure 4.25. The older participants were more compliant, or perhaps more cautious, with respect to the advised speed of 20 mph (marked by the red line)—slowing, on average, to roughly 22 mph, compared to the 27 mph average entry speed for the younger participants (note that 75% of the conditions conveyed the 20 mph advisory speed through auditory and/or visual stimuli). As mentioned before, the speeds at the apex and exit of the curve seem to be largely dependent on the entry speed; therefore, it is no surprise to see the trend of younger-versus-older continued for those two dependent variables.

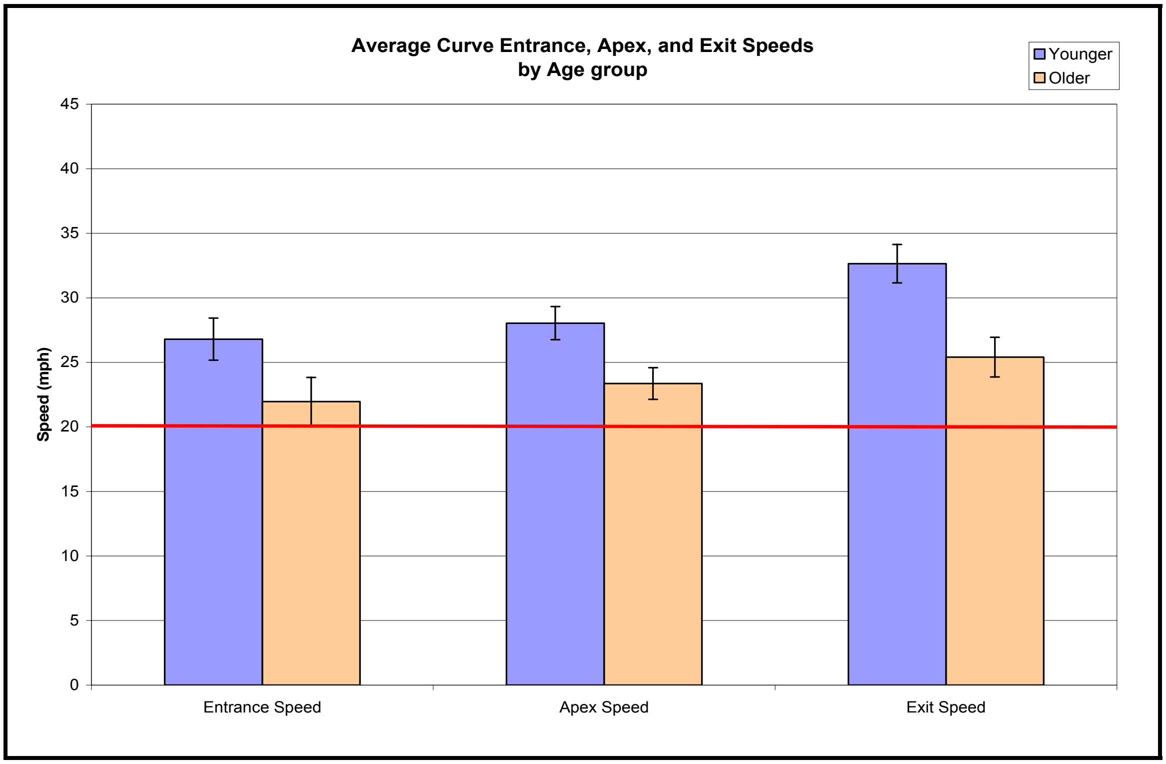

Figure 4.25 Curve Speed Comparison of Age Main Effect
(Red line marks target speed of 20mph)

The differences between stimulus conditions are not quite as clear, however, based on the *post-hoc* analysis shown in Figure 4.26. The baseline had a significantly higher curve-entry speed compared to conditions for which a stimulus was presented, with participants, on average, entering the 20 mph advised curve at a speed greater than 39 mph. Not surprisingly, all six conditions containing the speech stimulus fell within the top-8 lowest curve-entry speeds conditions. Additionally, the top-16 conditions presented the advised speed of 20 mph by visual stimulus and/or speech, which shows the importance of conveying the actual recommended speed as opposed to just warning the driver of an upcoming curve.

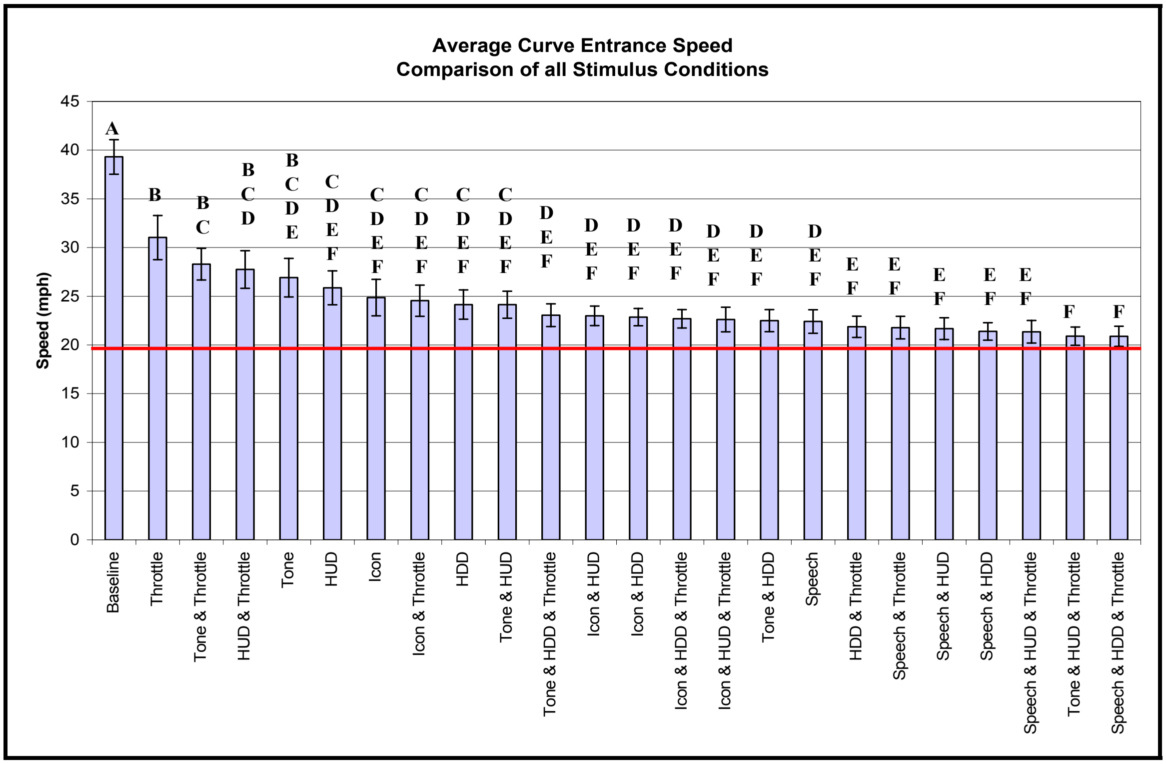

Figure 4.26 Curve Entry Velocity Comparison of Condition Main Effect
(Red line marks target speed of 20mph)

Significance was also found for the Age main effect with respect to lane position at the curve apex (Figure 4.27), and by Condition for the curve apex speed (Figure 4.28). The difference in apex lane position was approximately 0.5 feet, but both age groups were within the lane and near the center of the lane, marked by the blue line. The speeds at the curve apex all fell between approximately 24 mph and 28 mph. Therefore, it is not surprising to only find a significant difference between the conditions with the slowest and highest speeds: the Speech and HDD and the Baseline conditions, respectively.

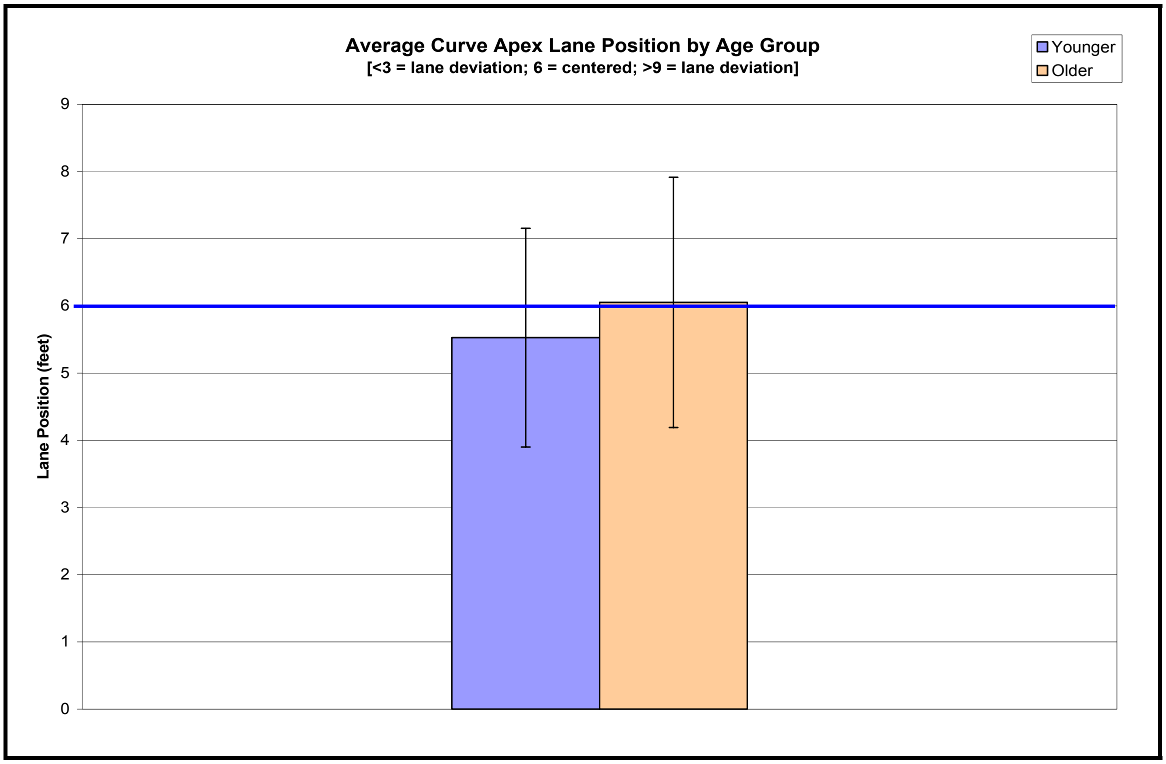

Figure 4.27 Curve Apex Lane Position Comparison of Age Main Effect (Blue line marks lane center)

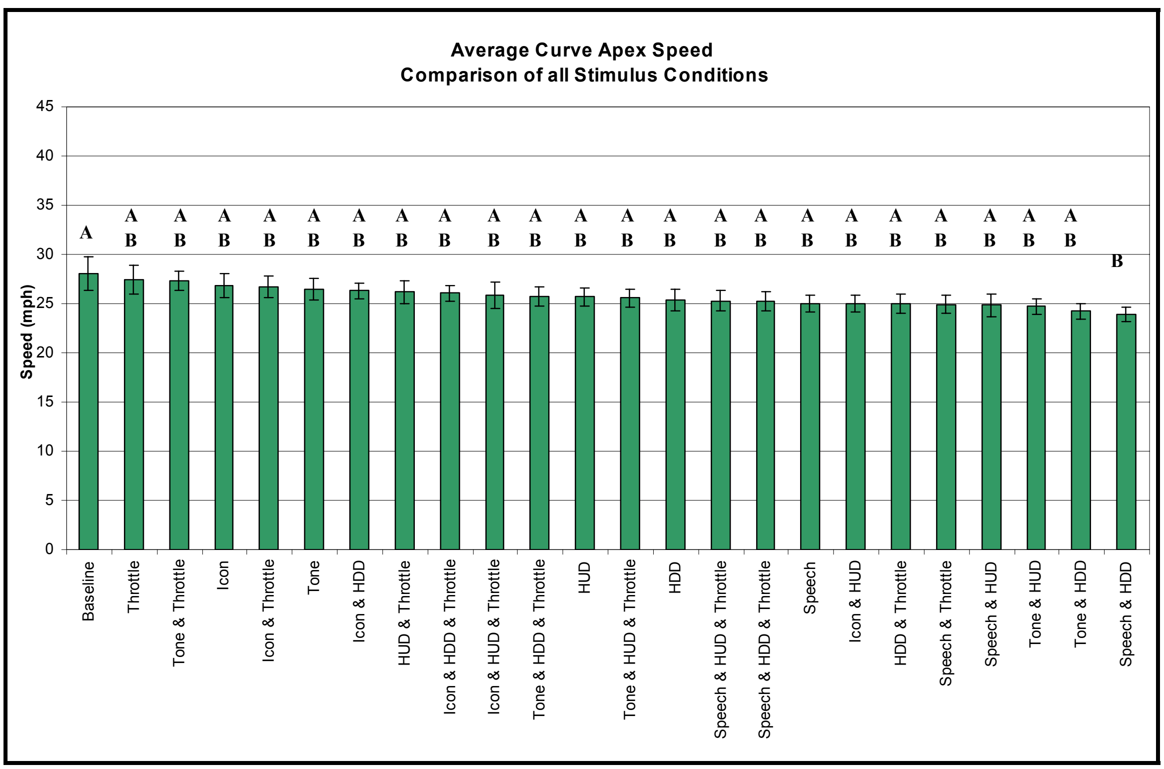

Figure 4.28 Curve Apex Speed Comparison of Condition Main Effect

4.1.2.3 Speed Variance

As expected, based on the results of the speeds at the curve entrance, the speed variance was found to be significant for age and condition main effects, as well as the interaction between the two. The differences between the age groups by condition are shown in Figure 4.29. Table 4.10 shows the numerical differences by stimulus condition; the five conditions with the highest speed variances are shown in bold by age group. The speech and throttle push-back, and the same combination with the addition of the HDD resulted in shared top spots for both age groups. Differences between the younger and older participants ranged from approximately 15 to 147 mph^2, for the HUD and Throttle and the Tone conditions, respectively.

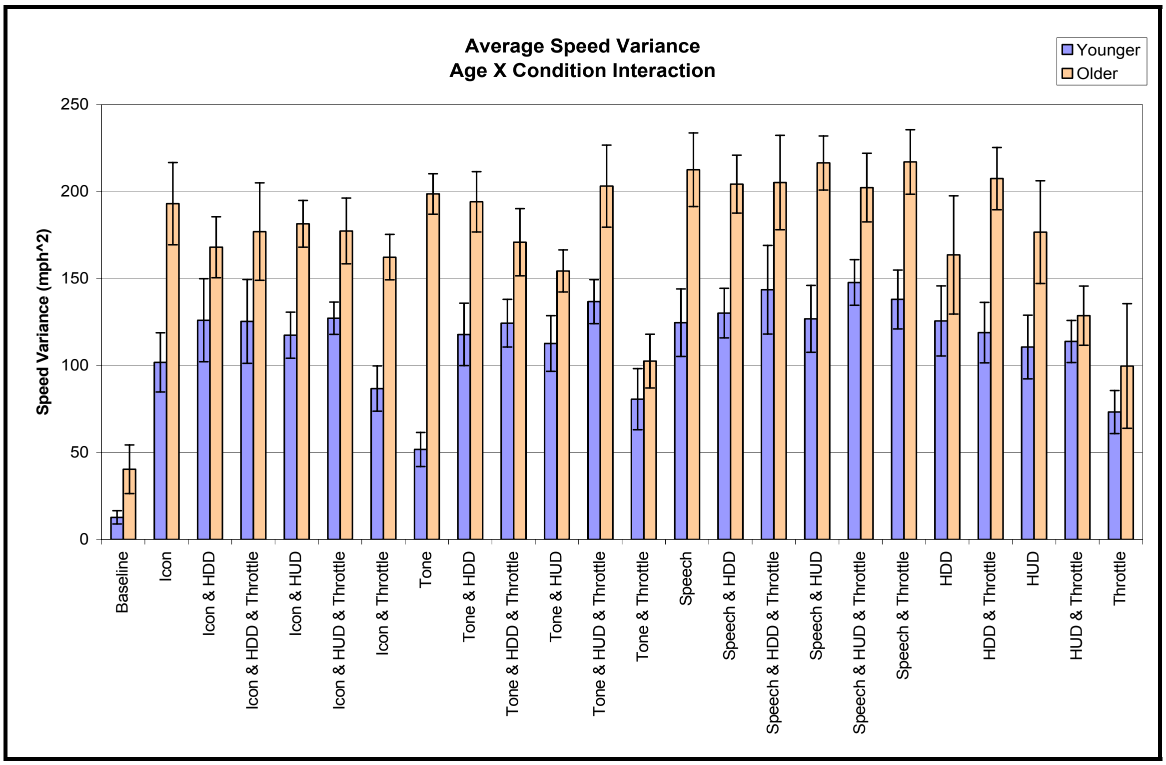

Figure 4.29 Speed Variance Comparison of Age X Condition Interaction

Table 4.10 Speed Variance Comparison of Age X Condition Interaction

Condition	Younger	Older	Speed Varaince Difference
Baseline	12.7	40.4	-27.7
Icon	101.8	193.0	-91.2
Icon & HDD	126.0	168.0	-42.0
Icon & HDD & Throttle	125.3	177.0	-51.6
Icon & HUD	117.5	181.5	-64.0
Icon & HUD & Throttle	127.2	177.3	-50.1
Icon & Throttle	86.8	162.3	-75.5
Tone	51.7	198.6	-146.9
Tone & HDD	117.9	194.1	-76.3
Tone & HDD & Throttle	124.3	170.9	-46.6
Tone & HUD	112.7	154.4	-41.7
Tone & HUD & Throttle	**136.7**	203.1	-66.4
Tone & Throttle	80.6	102.5	-21.9
Speech	124.6	**212.6**	-87.9
Speech & HDD	**130.1**	204.3	-74.2
Speech & HDD & Throttle	**143.5**	**205.2**	-61.7
Speech & HUD	126.8	**216.5**	-89.6
Speech & HUD & Throttle	**147.7**	202.3	-54.5
Speech & Throttle	**138.0**	**217.0**	-79.0
HDD	125.6	163.6	-38.0
HDD & Throttle	118.9	**207.5**	-88.5
HUD	110.6	176.7	-66.0
HUD & Throttle	113.8	128.6	-14.8
Throttle	73.3	99.7	-26.4

The younger and older participants had large differences in their speed variance, with results of approximately thirty mph on either side of the 142 mph^2 average. Only the baseline condition, with a speed variance of 26 mph^2, was significantly less from all other conditions. The Tone & Throttle and the throttle push-back by itself also had significantly lower speed variances than all of the other conditions outside of the baseline. All conditions with speed variances greater than 120 mph^2 (21 out of 24) were not found to be significantly different.

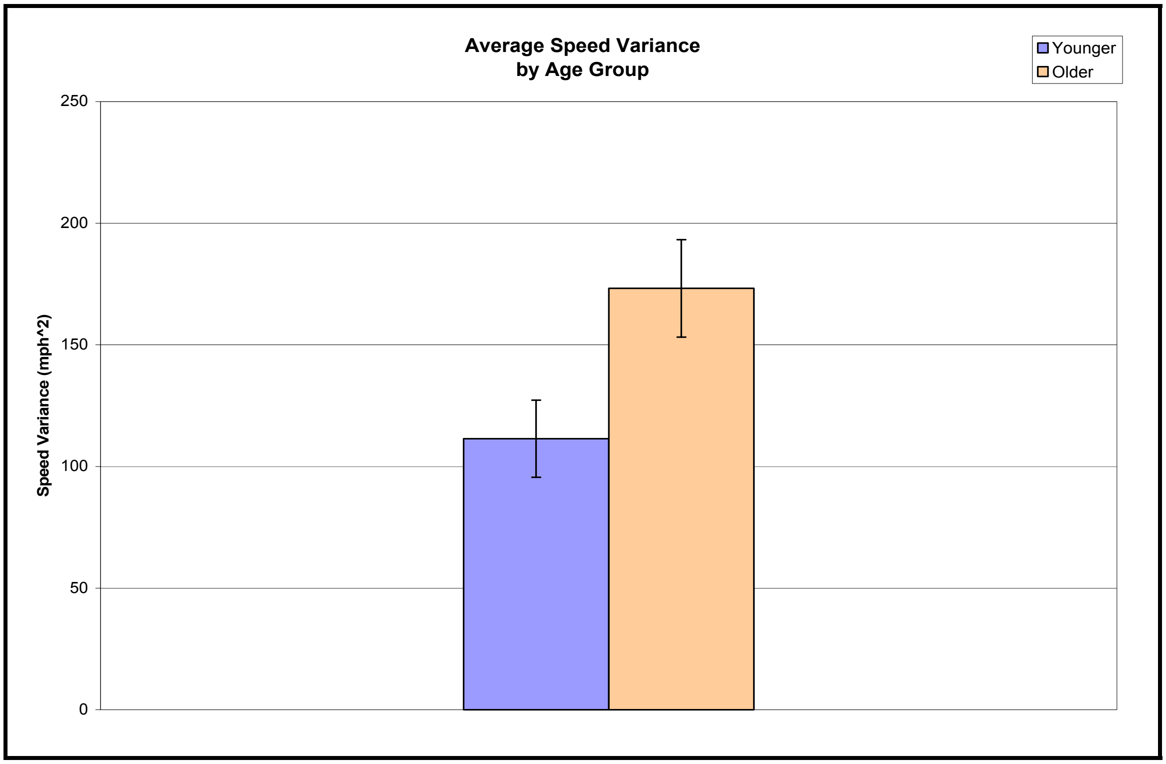

Figure 4.30 Speed Variance Comparison of Age Main Effect

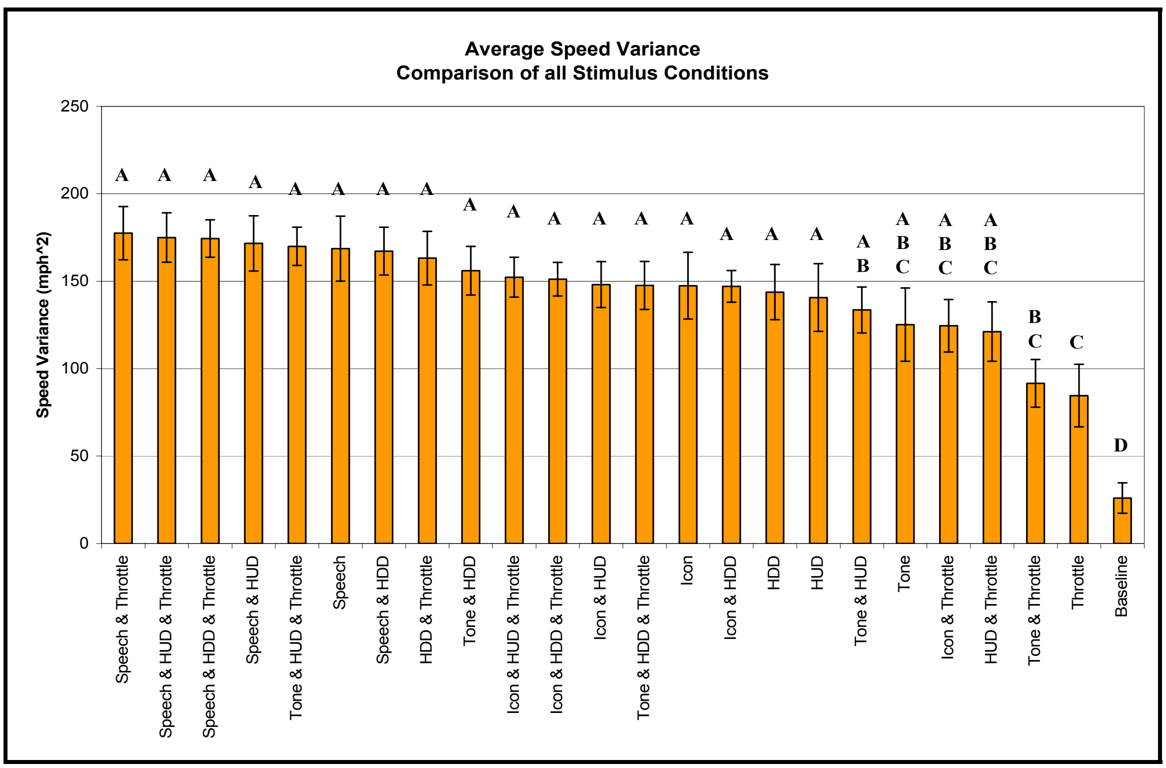

Figure 4.31 Speed Variance Comparison of Condition Main Effect

4.1.2.4 Time out of Lane and Number of Lane Deviations

The total time out of lane was found to be significant only for the condition main effect. The *post-hoc* results, however, show no significant difference between any of the stimulus conditions (Figure 4.32), as all of the means share the same letter. Besides the missing values described earlier, the inability to find significance from the *post-hoc* analysis may also be due to the large standard errors shown for each condition. To verify these findings, the measurements were analyzed using a more conservative *post-hoc* analysis (Bonferroni) but the same no-significance results were obtained. Some trends do exist, however. The 12 conditions that spent the least time out of lane included a makeup of 100% auditory, 75% visual, and 42% haptic modalities. All six conditions that included the speech stimulus fell within this top 12, as did four tone conditions and two auditory icon conditions. There were no significant findings for Age or Condition with respect to the number of lane deviations, but the chi-squared tables can be seen in Appendix R.

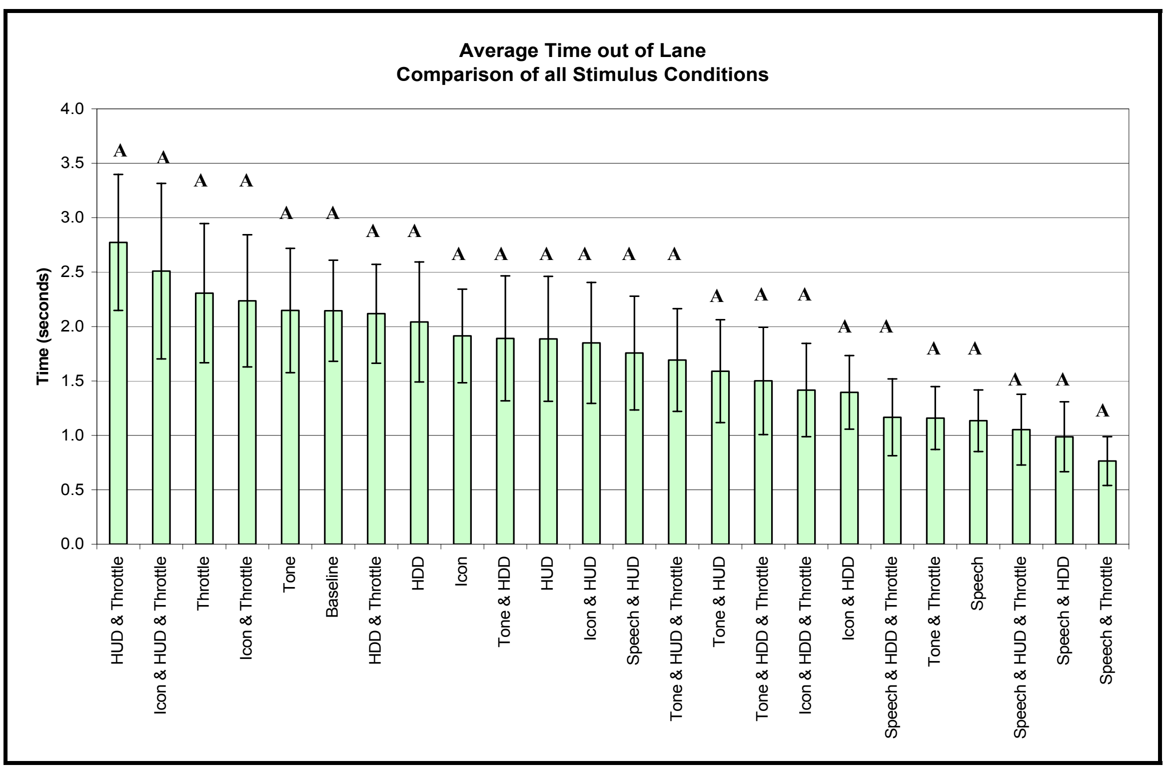

Figure 4.32 Time Out of Lane Comparison of Condition Main Effect

4.1.3 Performance Measurements by Gender and Stimulus Condition

As with the analysis by Age and Condition, exploratory techniques where used to find significance with respect to Gender and Warning. The mixed-factors design developed to test for significance can be seen in Table 4.11. Table 4.12 summarizes the significant findings. No significance was found for the Gender main effect for any of the dependent variables, but the Gender X Condition interaction was found to be significant for the curve apex and exit speeds. Significance found for the condition main effect is repeated from the age and condition model and has already been discussed in section 4.1.2. All ANOVAs and chi-squared tables can be seen in Appendices S and T respectively.

Table 4.11 ANOVA Model for Gender and Condition

Source	**df**
Between	
Gender	1
Subject(Gender)	22
Within	
Condition	23
Gender X Condition	23
Condition X Subject(Gender)	506
Total	**575**

Table 4.12 Summary of Significant Findings for Gender and Condition

Source	Throttle Reaction	Brake Reaction	Entrance Velocity	Entrance Lane Position	Apex Velocity	Apex Lane Position	Exit Velocity	Exit Lane Position	Speed Variance	Time out of Lane	No. of Lane Deviations
Between											
Gender											
Subject(Gender)											
Within											
Condition	x	x	x		x				x	x	
Gender X Condition					x		x				
Condition X Subject(Gender)											

x = p < 0.05 (significant)

4.1.3.1 Curve Speeds and lane positions

The Gender X Condition interaction (Figure 4.33) indicates that male participants had a higher apex speed compared to female participants for approximately 70% of the conditions. Table 4.13 shows the numerical differences between the genders, with differences ranging from none to greater than 5 mph. The five conditions resulting in the lowest apex speeds are shown in bold for each gender. Interestingly, the top-five conditions for the female participants all included the speech stimulus. Not unexpectedly, the Gender X Condition interaction for the exit speed (Figure 4.33 and Table 4.14) shows a similar pattern across the genders.

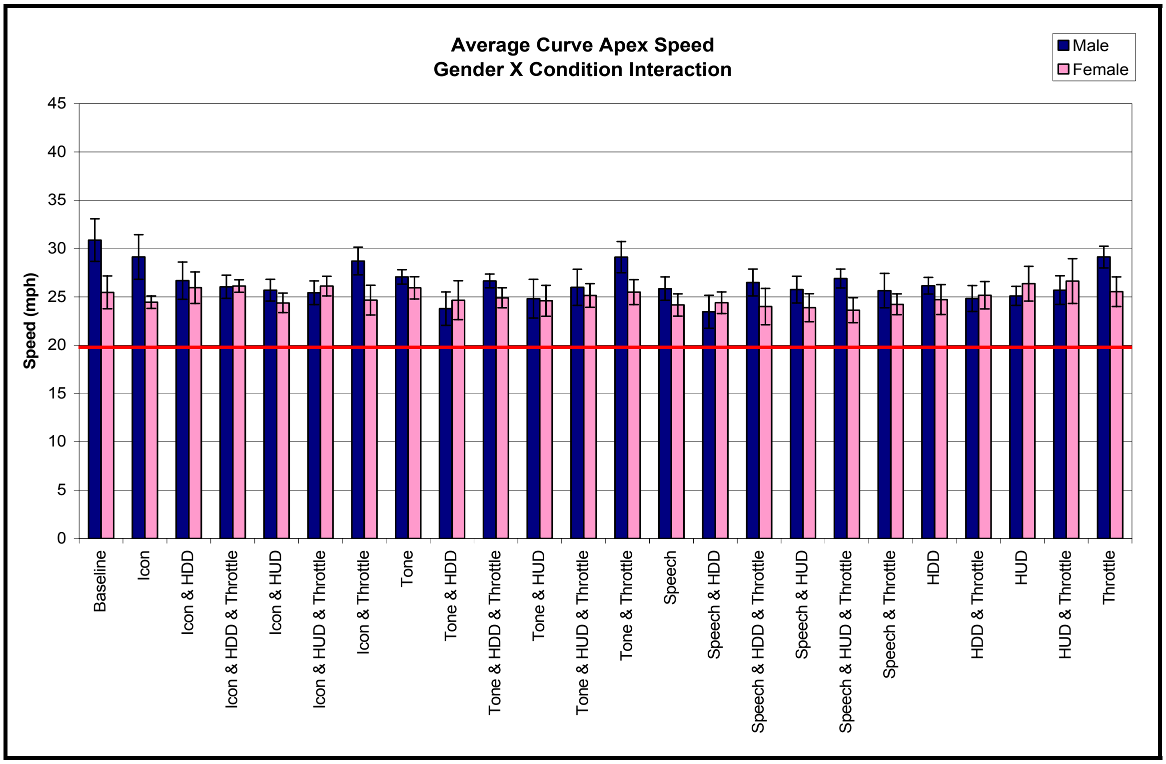

Figure 4.33 Curve Apex Speed Comparison of Gender X Condition Interaction (Red line marks target speed of 20mph)

Table 4.13 Curve Apex Speed Comparison of Gender X Condition Interaction

Condition	Male	Female	Apex Speed Difference
Baseline	30.9	25.5	5.4
Icon	29.1	24.5	4.7
Icon & HDD	26.7	26.0	0.7
Icon & HDD & Throttle	26.0	26.1	-0.1
Icon & HUD	25.7	24.4	1.3
Icon & HUD & Throttle	25.4	26.1	-0.7
Icon & Throttle	28.7	24.7	4.1
Tone	27.1	25.9	1.1
Tone & HDD	**23.8**	24.7	-0.9
Tone & HDD & Throttle	26.6	24.9	1.7
Tone & HUD	**24.8**	24.6	0.2
Tone & HUD & Throttle	26.0	25.1	0.8
Tone & Throttle	29.1	25.5	3.6
Speech	25.9	**24.2**	1.7
Speech & HDD	**23.5**	24.4	-0.9
Speech & HDD & Throttle	26.5	**24.0**	2.5
Speech & HUD	25.8	**23.9**	1.9
Speech & HUD & Throttle	26.9	**23.6**	3.3
Speech & Throttle	25.7	**24.2**	1.4
HDD	26.2	24.7	1.4
HDD & Throttle	**24.8**	25.2	-0.3
HUD	**25.1**	26.4	-1.3
HUD & Throttle	25.7	26.6	-0.9
Throttle	29.1	25.5	3.6

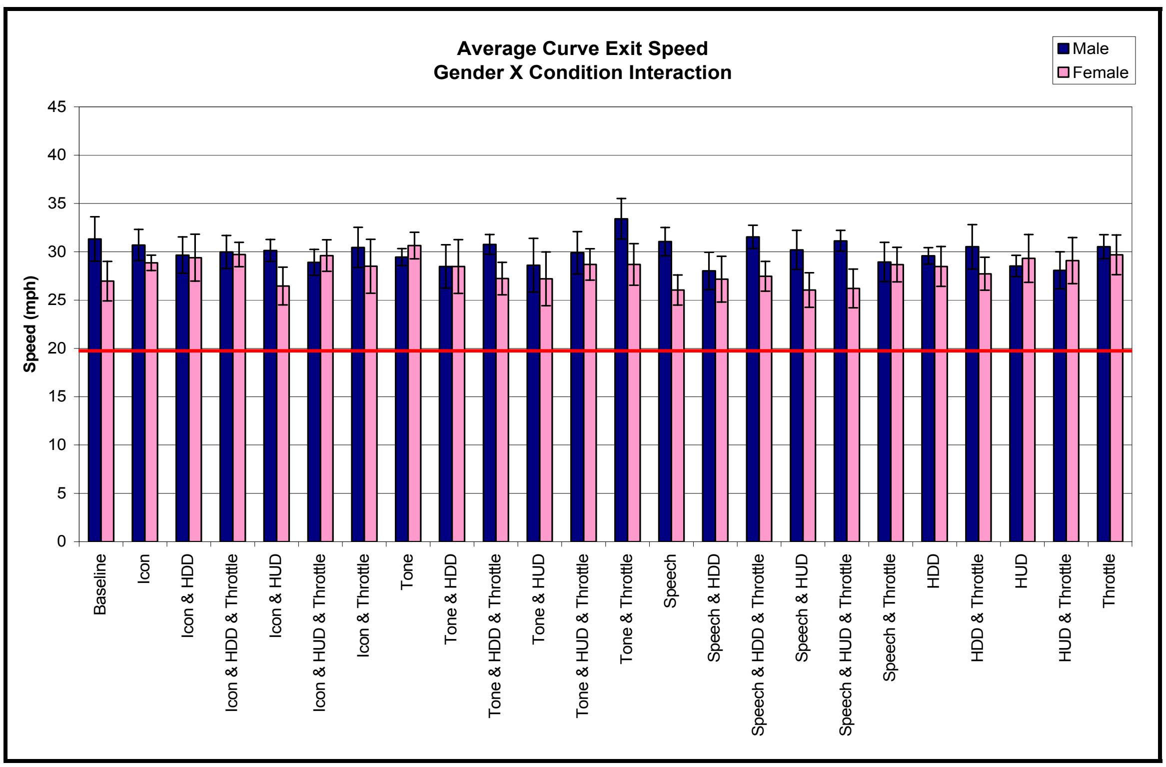

Figure 4.34 Curve Exit Speed Comparison of Gender X Condition Interaction (Red line marks target speed of 20mph)

Table 4.14 Curve Exit Speed Comparison of Gender X Condition Interaction

Condition	Male	Female	Exit Speed Difference
Baseline	31.3	**27.0**	4.4
Icon	30.7	28.9	1.9
Icon & HDD	29.7	29.4	0.3
Icon & HDD & Throttle	30.0	29.7	0.3
Icon & HUD	30.1	**26.5**	3.7
Icon & HUD & Throttle	28.9	29.6	-0.7
Icon & Throttle	30.5	28.5	1.9
Tone	29.5	30.6	-1.2
Tone & HDD	**28.5**	28.5	0.0
Tone & HDD & Throttle	30.8	27.2	3.5
Tone & HUD	**28.6**	27.2	1.4
Tone & HUD & Throttle	29.9	28.7	1.2
Tone & Throttle	33.4	28.7	4.7
Speech	31.1	**26.0**	5.0
Speech & HDD	**28.0**	27.2	0.9
Speech & HDD & Throttle	31.5	27.5	4.1
Speech & HUD	30.2	**26.0**	4.2
Speech & HUD & Throttle	31.1	**26.2**	4.9
Speech & Throttle	28.9	28.7	0.3
HDD	29.6	28.5	1.1
HDD & Throttle	30.5	27.7	2.8
HUD	**28.5**	29.3	-0.8
HUD & Throttle	**28.1**	29.1	-1.0
Throttle	30.5	29.7	0.8

4.2 Subjective Results

The conditions that were removed prior to performing the objective data analysis, aside from the condition that was falsely overwritten during file transfer, were also removed for consistency purposes before any subjective data were analyzed. Therefore, a PROC GLM was used in SAS® due to the missing data. Like the results of the objective data, the subjective results will consist of multiple sections but will follow the following general order:

- Post-Condition Questionnaire results (separated by question)
- Post-Condition Questionnaire results by Age and Stimulus Conditions (separated by question)
- Post-Condition Questionnaire results by Gender and Stimulus Conditions (separated by question)
- Content Analysis based on open ended question in Post-Condition Questionnaire, by Age and Gender
- Curve-Acceptance Questionnaire by Age and Gender
- General results on open ended questions in Curve-Acceptance Questionnaire

4.2.1 Post Condition Questionnaire

As mentioned previously, the Post-Condition Questionnaire was administered after each condition, resulting in a total of 576 questionnaires from data collection (567 used for analysis). The Post-Condition Questionnaire (Appendix E) consisted of five questions to be rated on a Likert-type 5-point scale, from 1 (strongly disagree) to 5 (strongly agree).

4.2.1.1 Post Condition Questionnaire results

There were a total of 21 significant findings (out of a possible 35) revealed through the analyses by stimulus (Table 4.15). Several main effects and interactions were found to be significant for the Urgency, Appropriateness, and Want statements, and two main effects were found to be significant for the Annoying and Interference statements. All of the ANOVA summary tables can be seen in Appendix U.

Table 4.15 Summary of Significant Findings for Post Condition Questionnaire

Source	Urgency	Annoying	Appropriate	Interference	Want
Between					
Subject					
Within					
Auditory	**x**	**x**	**x**	**x**	**x**
Auditory X Subject					
Visual	**x**		**x**		**x**
Visual X Subject					
Haptic	**x**	**x**		**x**	**x**
Haptic X Subject					
Auditory X Visual	**x**		**x**		**x**
Auditory X Visual X Subject					
Auditory X Haptic	**x**				
Auditory X Haptic X Subject					
Visual X Haptic			**x**		**x**
Visual X Haptic X Subject					
Auditory X Visual X Haptic	**x**		**x**		**x**
Auditory X Visual X Haptic X Subject					

x = $p < 0.05$ (significant)

4.2.1.1.1 Urgency

The first question presented on the Post-Condition Questionnaire was as follows: "This type of warning conveyed a sense of urgency (requiring immediate attention)." When analyzed by stimulus, this statement was found to be significant for all three main effects, as well as for the interactions between auditory and visual, auditory and haptic, and the interaction between all three modalities. An SNK *post-hoc* analysis was performed for both the auditory and visual main effects.

The significant three-way interaction, shown in Figure 4.35, found that roughly 92% of the conditions received an average rating above "Undecided," and even 25% were rated above the "Agree" ranking. The conditions rated above the "Agree" ranking all had auditory and visual stimuli, and four out of the six included the haptic stimulus as well. The probable cause for the significance, however, is the drastic decline in urgency ratings for the baseline (expected) and haptic-only conditions. The haptic-only condition fell just above the "Disagree" ranking, with a 2.1 average.

The benefit of combining auditory and visual stimuli to increase urgency can be seen in Figure 4.36. The trend that appears to exist for this interaction is the highest rated auditory stimulus and HDD pairings (average rating of 4.1), followed closely by the auditory stimulus and HUD pairings (3.9 average), followed then by the auditory stimulus with no visual icon pairings (3.6 average). All conditions that included an auditory stimulus also greatly outranked the conditions with none, which fell closer to the "Undecided" ranking, with an average of 3.2.

Unexpectedly, the throttle push-back did little to increase the perceived urgency (Figure 4.37). The auditory warnings with no haptic stimulus received an average rating of 3.8, and this rating increased to roughly 3.9 when the haptic stimulus was included. The throttle push-back with no auditory stimulus fell just under the "Undecided" ranking, which explains its lack of effect on the auditory and haptic conditions.

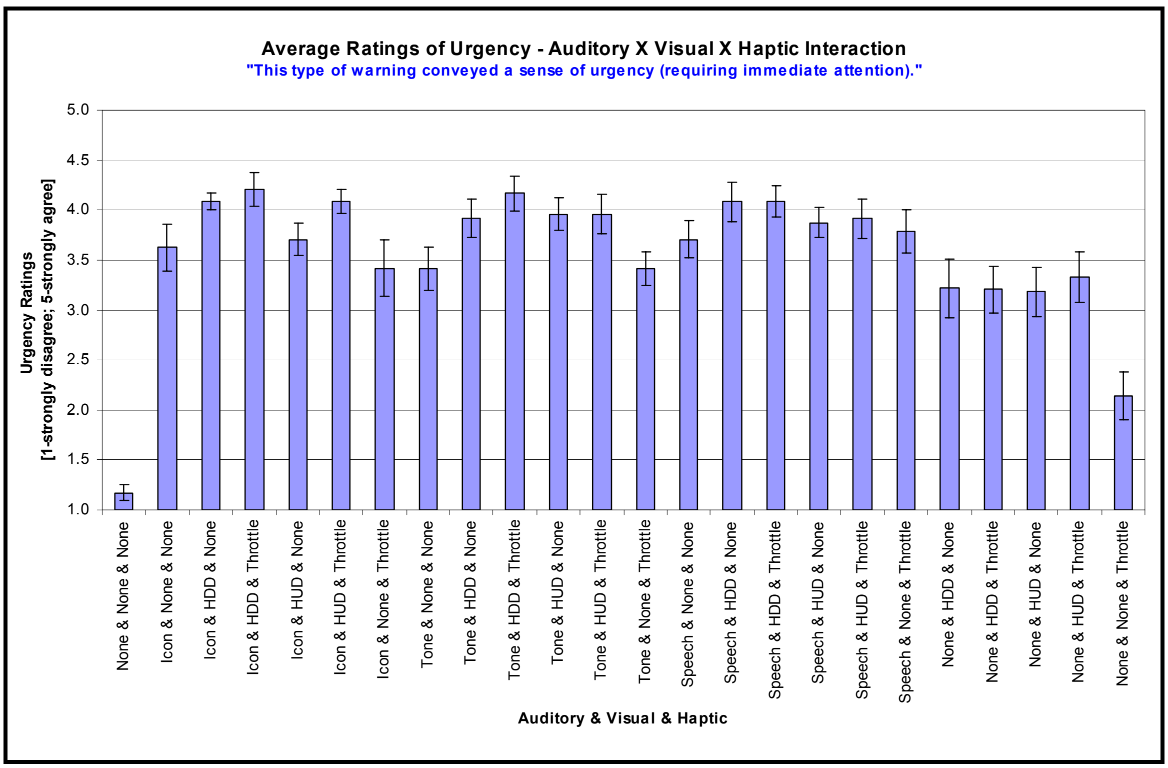

Figure 4.35 Urgency Ratings Comparison of Auditory X Visual X Haptic Interaction

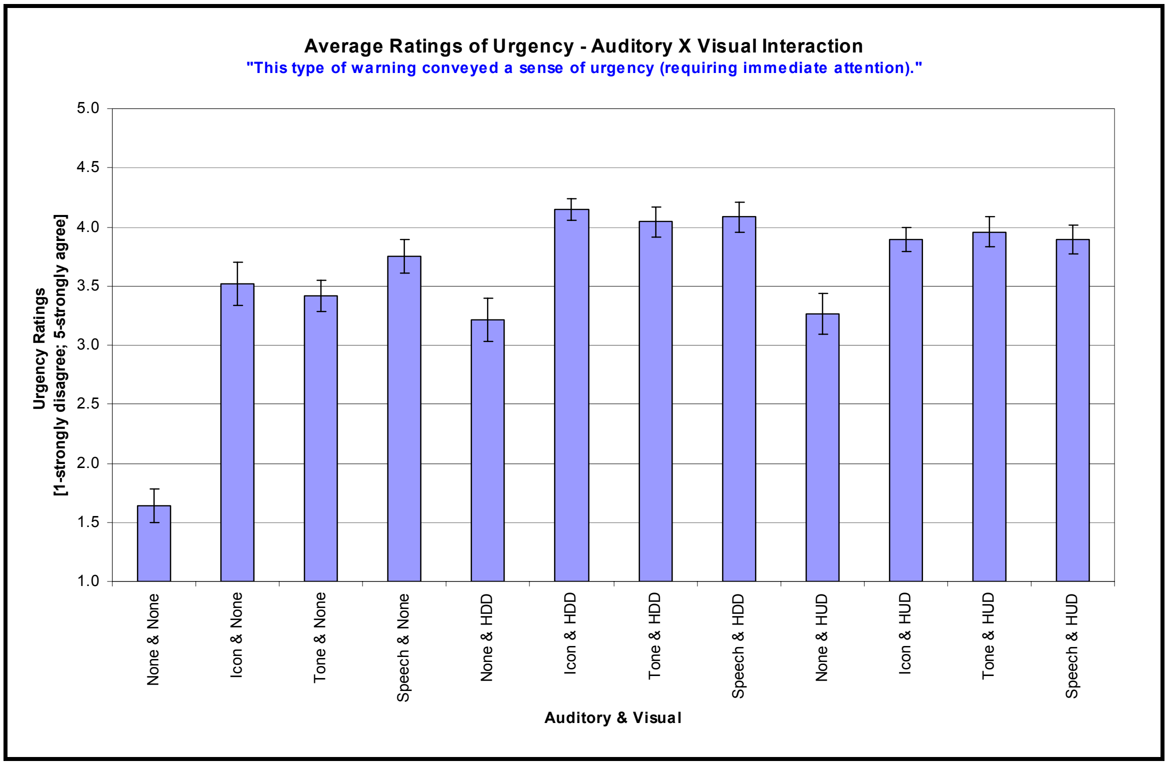

Figure 4.36 Urgency Ratings Comparison of Auditory X Visual Interaction

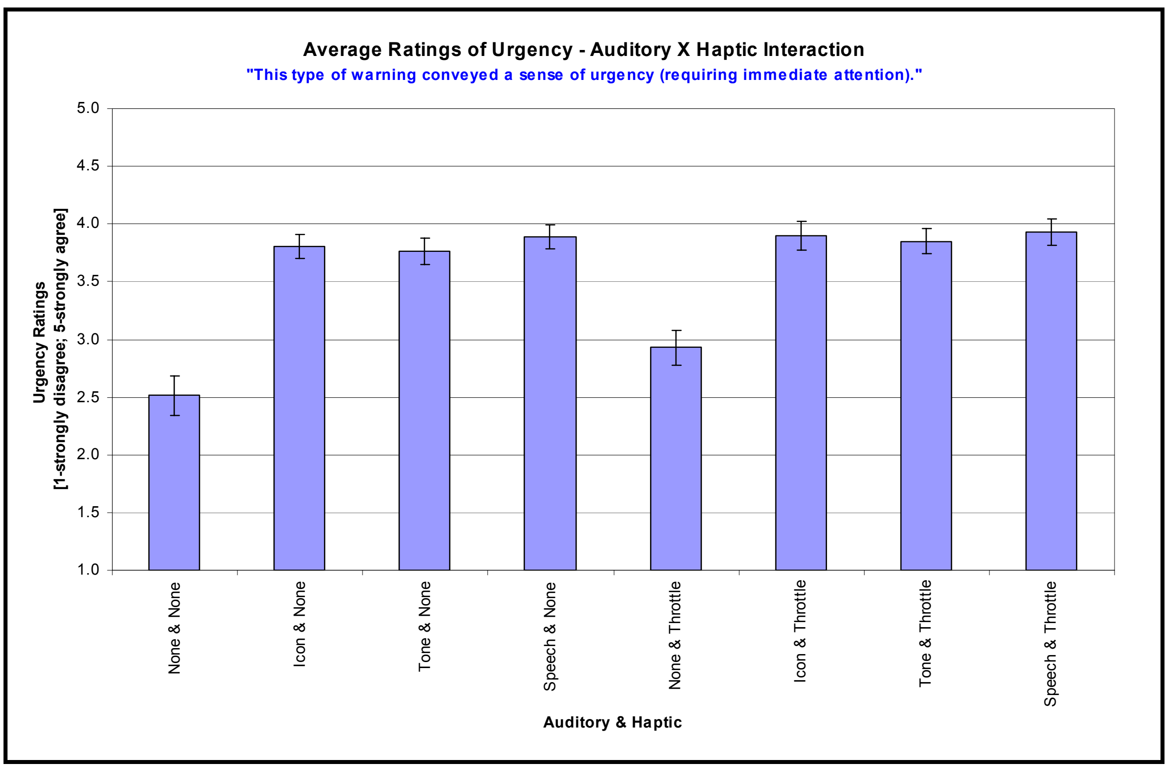

Figure 4.37 Urgency Ratings Comparison of Auditory X Haptic Interaction

All three auditory stimuli fell just under the “Agree” rating for conveying a sense of urgency, and based on the *post-hoc* analysis, they were not significantly different from each other (Figure 4.38). The three auditory stimuli were, however, significantly different from conditions in which no auditory stimulus was presented, with a rating of approximately 2.7, falling just below the “Undecided” ranking. These findings are another indication of the need for an auditory stimulus of some kind in a curve-warning device. Regardless of the stimulus type, all three auditory stimuli conveyed enough of a sense of urgency that participants, on average, felt that they needed to respond immediately.

Similar to the auditory results, both visual icons were not found to be significantly different from each other, but both were significant from conditions in which no visual icon was presented (Figure 4.39). The HDD and HUD also fell near the “Agree” ranking, with urgency ratings of 3.9 and 3.8, respectively. Those conditions without a visual icon were again closer to the “Undecided” rating, with an average urgency rating of 3.1.

The throttle push-back was shown to be significantly more urgent than conditions with no haptic element, although the difference was small (Figure 4.40). The haptic stimulus had an average urgency rating of roughly 3.7, close to the “Agree” rating, whereas the conditions with no haptic stimulus had an average rating of 3.5, directly between the “Undecided” and “Agree” ratings.

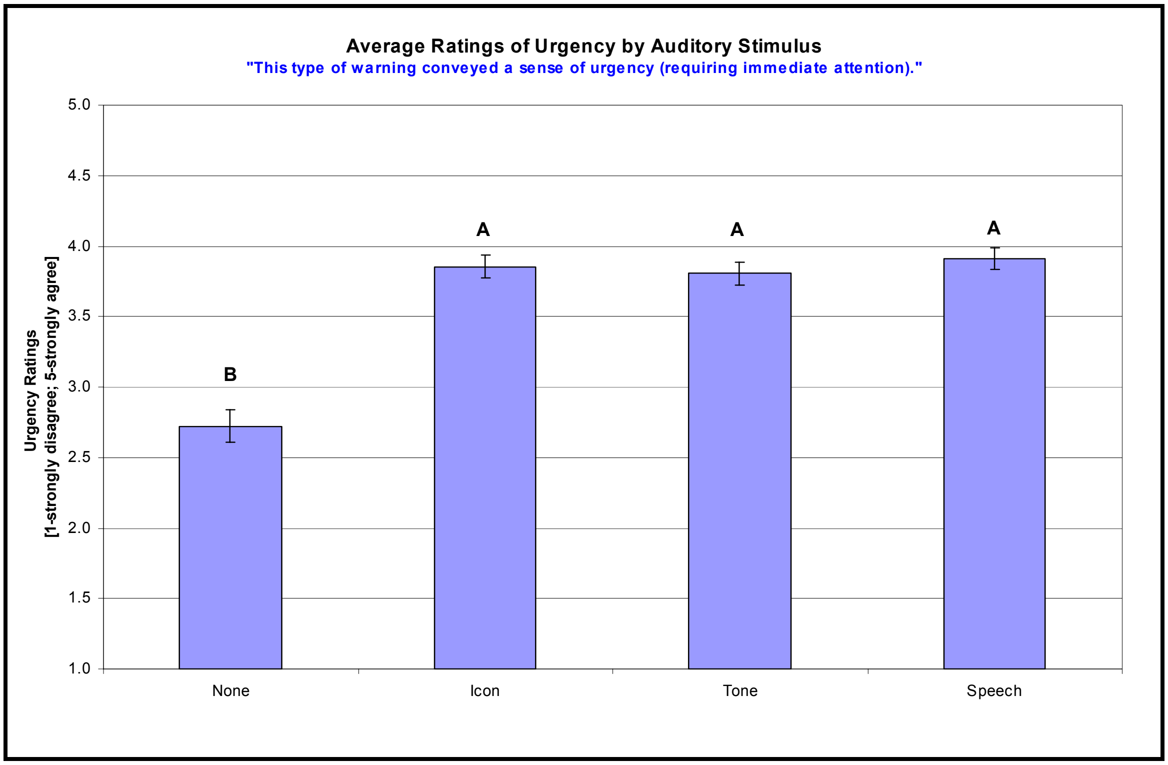

Figure 4.38 Urgency Ratings Comparison of Auditory Main Effect

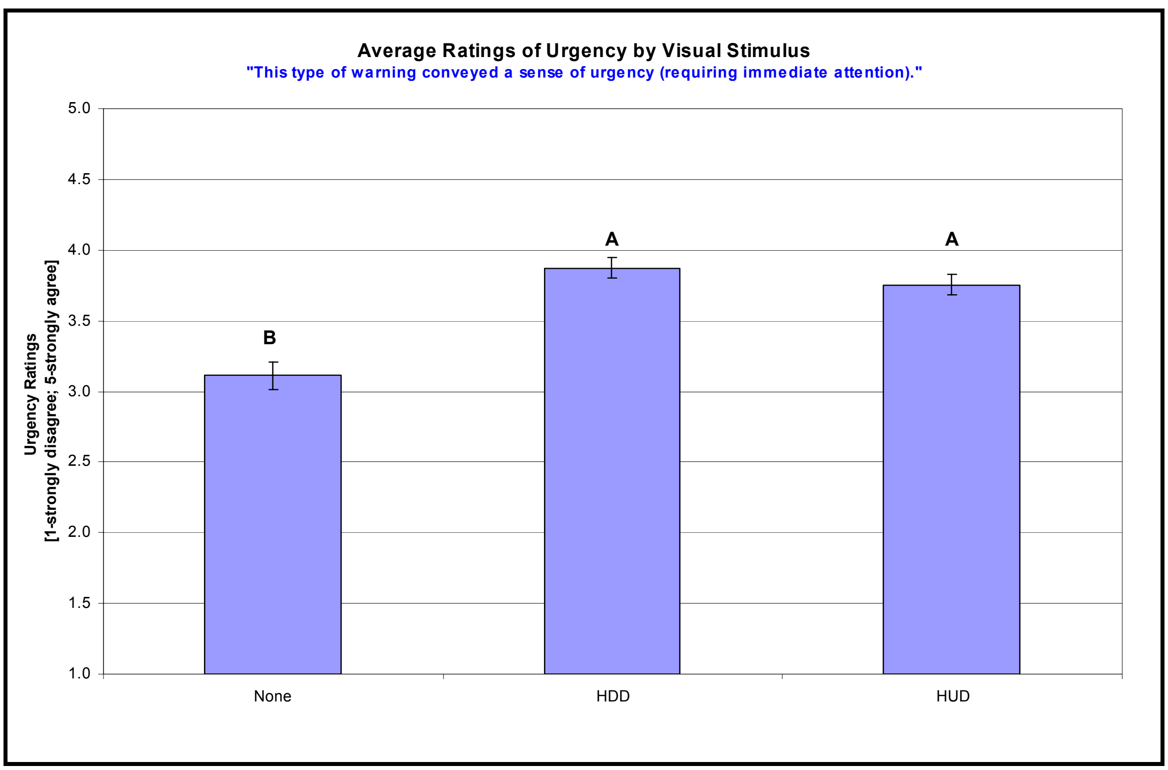

Figure 4.39 Urgency Ratings Comparison of Visual Main Effect

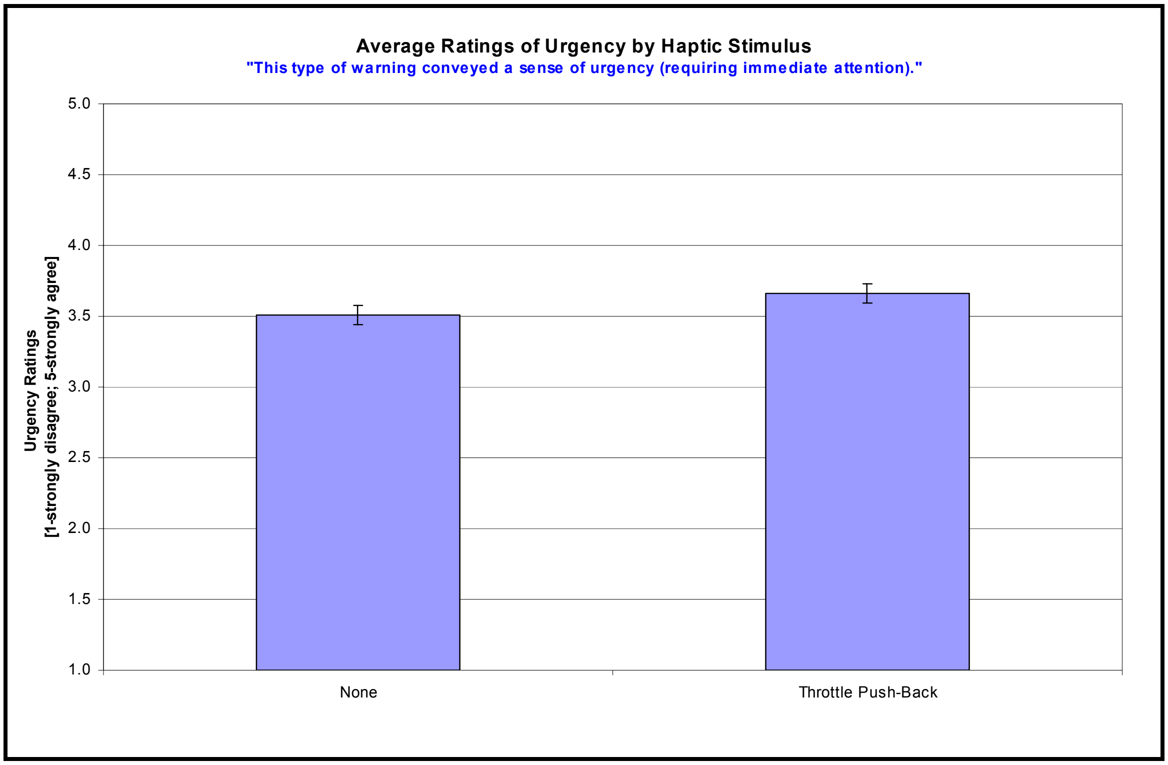

Figure 4.40 Urgency Ratings Comparison of Haptic Main Effect

4.2.1.1.2 Annoyance

The second question presented on the Post-Condition Questionnaire was as follows: "This type of warning was annoying." When analyzed by modality, this statement was found to be significant for the auditory and haptic main effects. An SNK *post-hoc* analysis was performed for the auditory main effect (Figure 4.41).

As expected, based on participant reactions during data collection, the auditory icon was significantly different from the two other auditory stimuli, as well as the non-auditory conditions, with an annoyance rating of 3.7, nearing the agreement value of 4. The speech stimulus, with a rating of 2.3, was closest to the "Disagree" ranking and was significantly different from the "Undecided" ranking of 2.8 for the tone. Both the speech and tone were not, however, significantly different from the conditions without the auditory stimulus, which had an average rating of 2.6.

Also not surprisingly, the throttle push-back was found to be significantly more annoying than conditions with no haptic element, with an average rating of 3 versus 2.7 respectively (Figure 4.42). As with the auditory icon, it appears that its subjective dismissal may outweigh any objective benefit the throttle push-back offers.

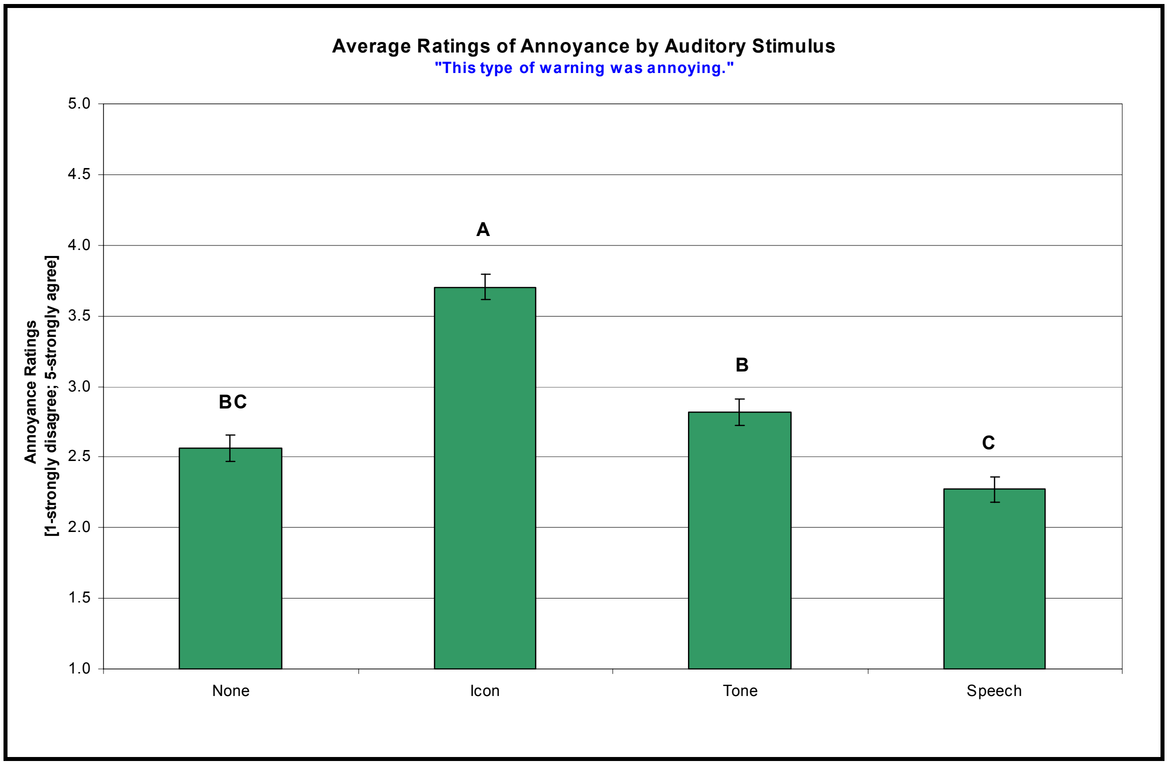

Figure 4.41 Annoyance Ratings Comparison of Auditory Main Effect

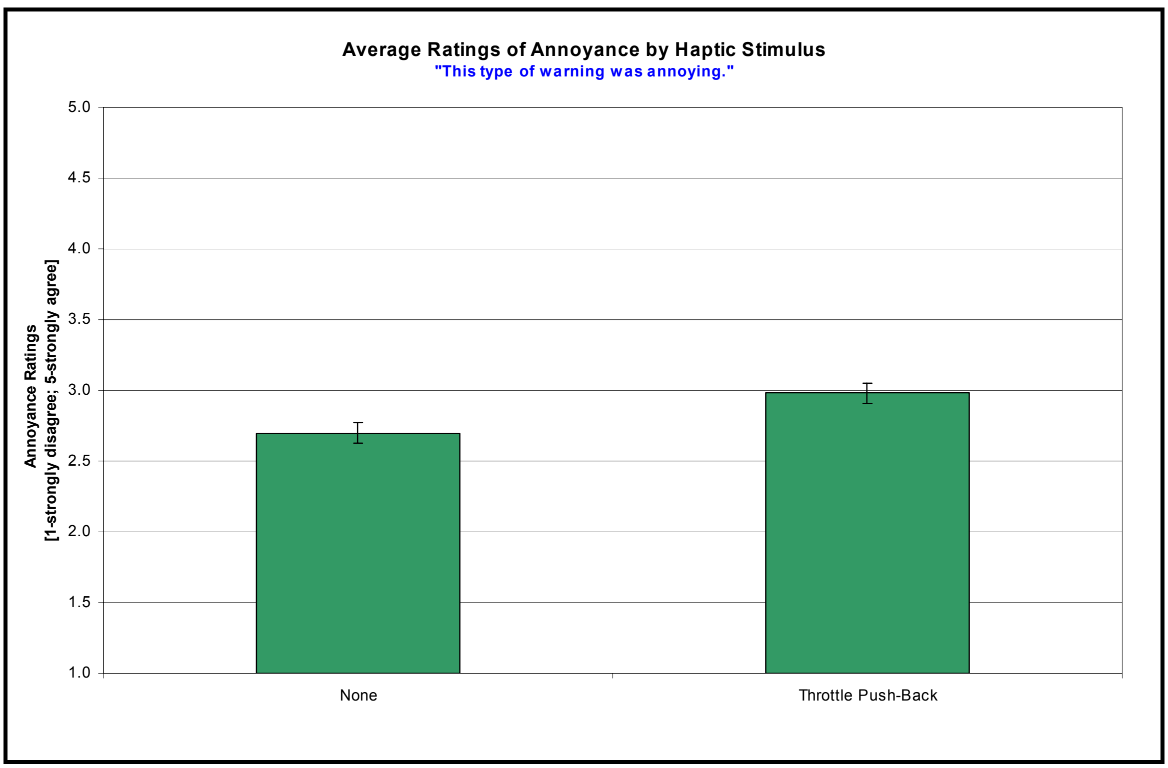

Figure 4.42 Annoyance Ratings Comparison of Haptic Main Effect

4.2.1.1.3 Appropriateness

The third statement presented on the Post-Condition Questionnaire was as follows: “This type of warning was appropriate for a curve warning device.” When analyzed by modality, this statement was found to be significant for the auditory and visual main effects, as well as for the interactions between the auditory and visual, haptic and visual, and all three modalities. An SNK *post-hoc* analysis was performed for the auditory and visual main effects.

As for the significant three-way interaction (Figure 4.43), the rankings were more scattered than they were for the urgency rating. Just over 50% of the conditions fell above the “Undecided” rating, and only the Speech and HDD condition averaged above the “Agree” rating. Four conditions also fell right at or below the “Disagree” rating, including the baseline, the auditory icon alone, the throttle push-back alone, and the combination of the two. Otherwise, the majority of the remaining conditions fell within the 2.5 to 4.0 range.

The Auditory X Visual interaction (Figure 4.44) demonstrates the preference of the speech as the most appropriate auditory stimulus and HDD as the top visual. All combinations with the HDD outperformed the combinations with the HUD, as well as combinations with no visual icon. Speech was rated higher than all of the conditions that included the auditory tone, and both stimuli were rated far more appropriate than any of the auditory icon conditions. The highest and lowest ranking Auditory and Visual combinations were the Speech and HDD and the None and None conditions, with ratings of approximately 3.9 and 1.6, respectively.

The throttle push-back again failed to have a major impact on ratings of appropriateness when paired with the visual modality (Figure 4.45). The difference between the pairings of the HDD and Throttle and the HDD and None was roughly 0.3 (3.6 and 3.3, respectively). This difference was almost nonexistent when the HUD was substituted into the same pairings. Importantly, all visual and haptic combinations that included a visual icon fell above the “Undecided” rating, whereas the two combinations with no visual stimulus were closer to the “Disagree” ranking, with average ratings of 2.3 and 2.5 (the None and None and the None and Throttle conditions, respectively).

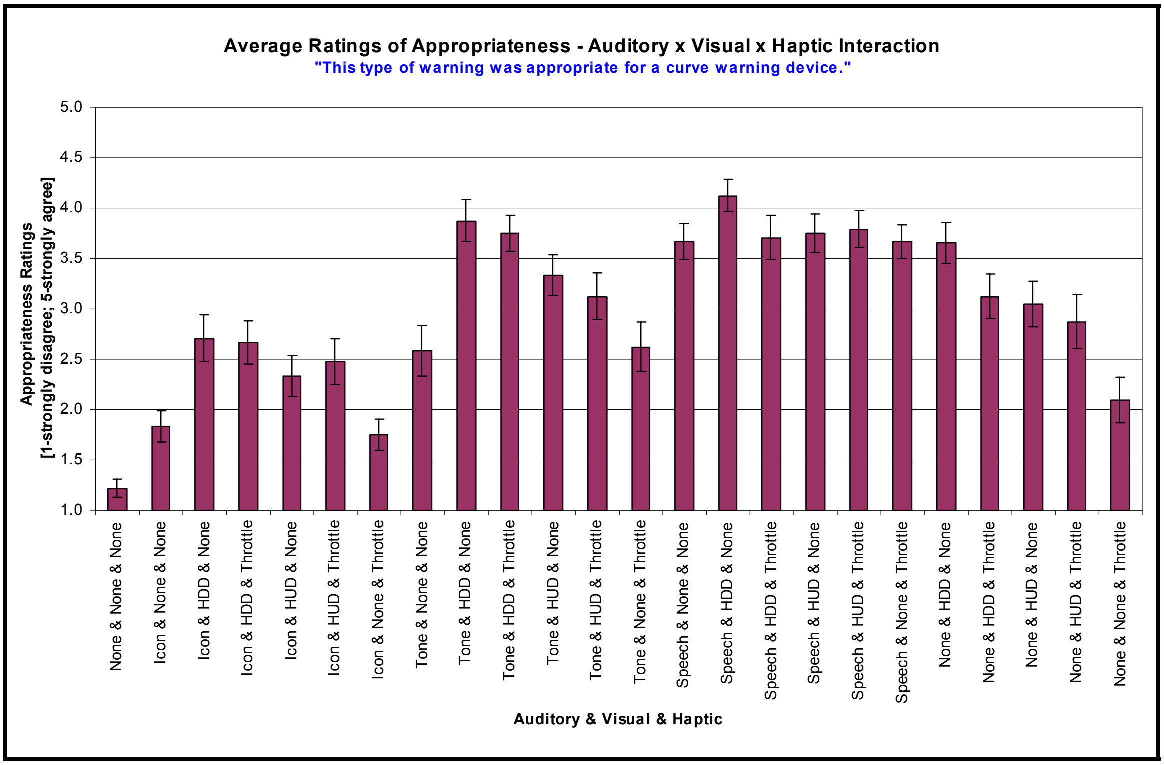

Figure 4.43 Appropriateness Ratings Comparison of Auditory X Visual X Haptic Interaction

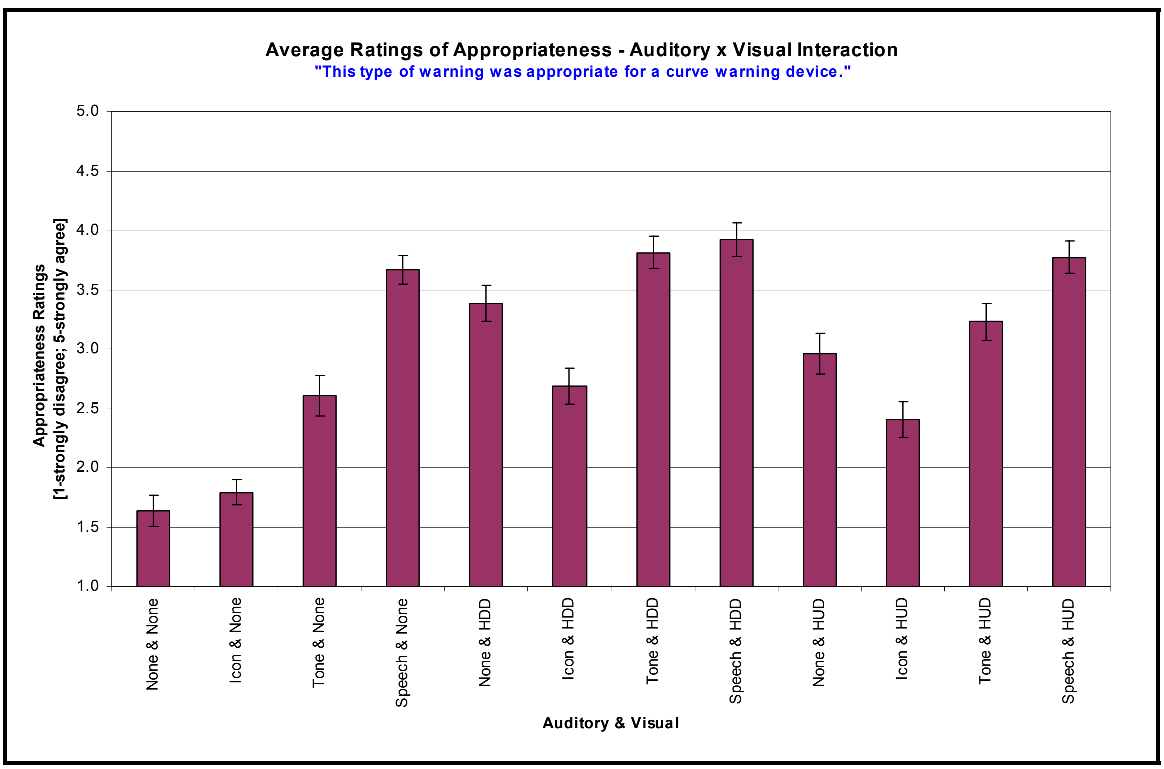

Figure 4.44 Appropriateness Ratings Comparison of Auditory X Visual Interaction

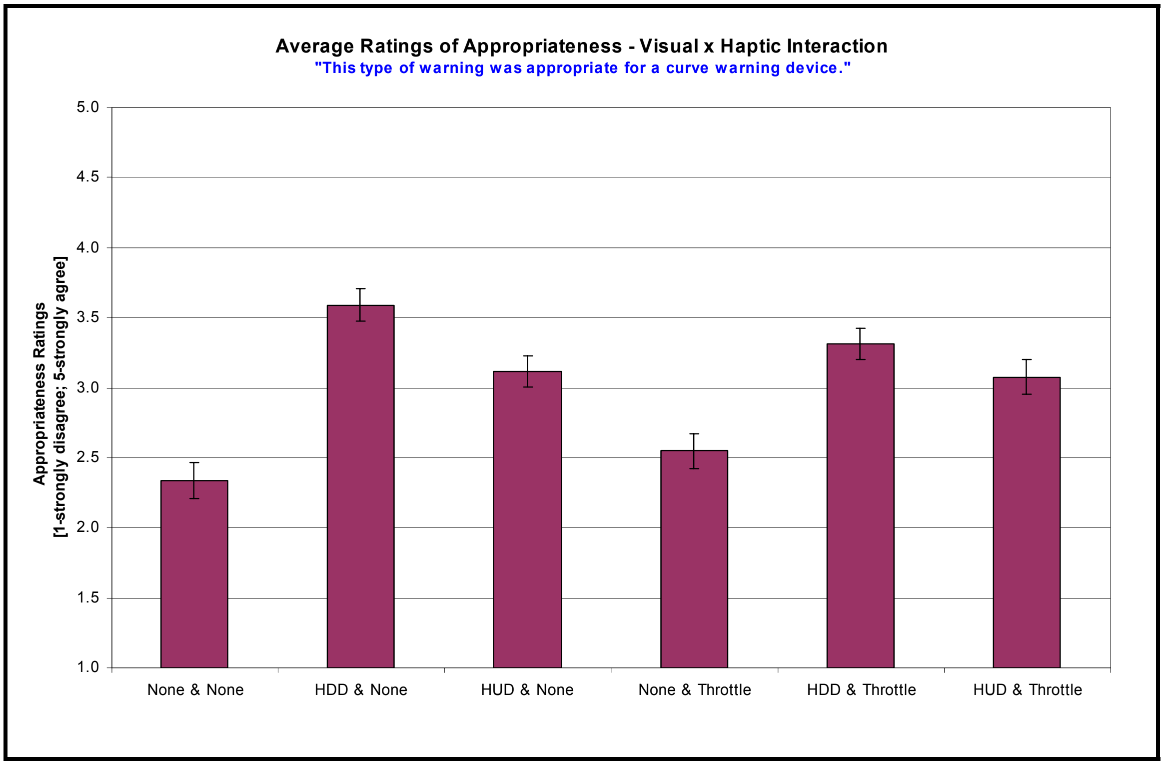

Figure 4.45 Appropriateness Ratings Comparison of Visual X Haptic Interaction

All four levels of the auditory modality were found to be significantly different from each other (Figure 4.46), in the following order of appropriateness: Speech, Tone, None, and Icon. With respect to the auditory icon, even conditions with no auditory stimulus were given a significantly higher appropriateness rating (2.3 versus 2.7, respectively). The auditory icon has so far been rated the highest for annoyance, and is now also the lowest for appropriateness.

As with the auditory main effect, all three levels of the visual stimulus were found to be significantly different from each other (Figure 4.47), although in this scenario both icons were rated as more appropriate than no icon. The HDD and HUD had average ratings of 3.5 and 3.1, respectively.

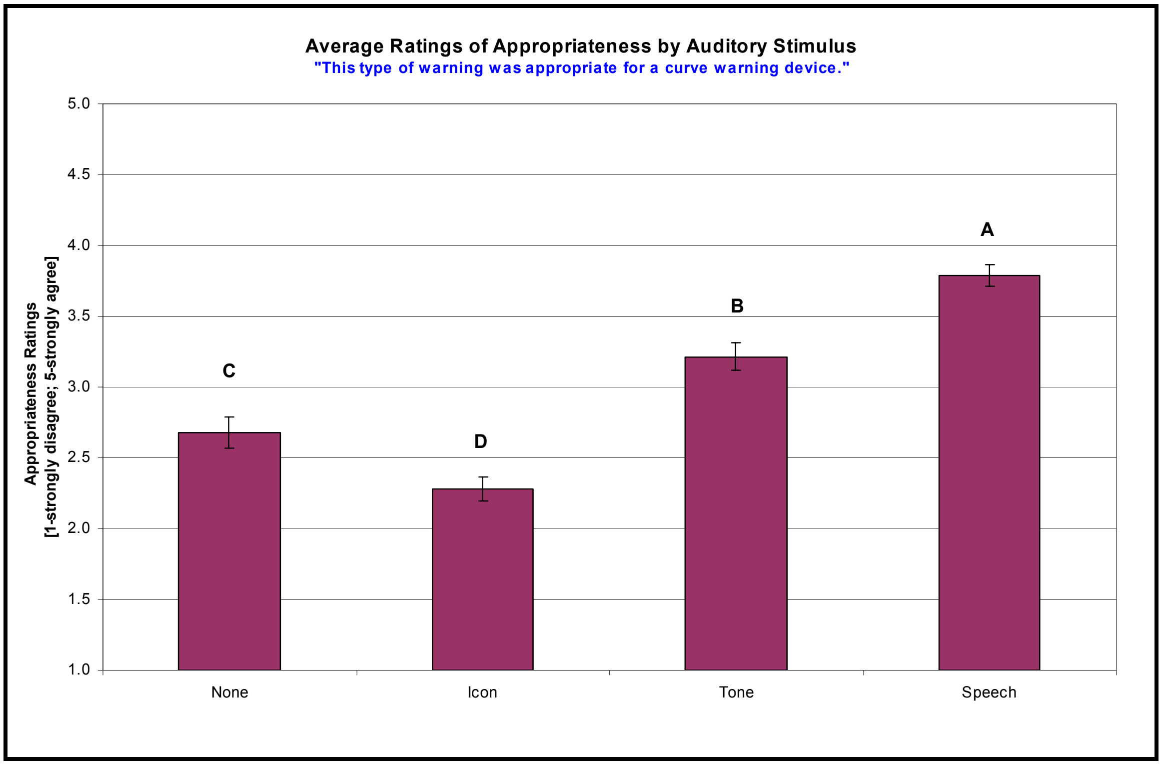

Figure 4.46 Appropriateness Ratings Comparison of Auditory Main Effect

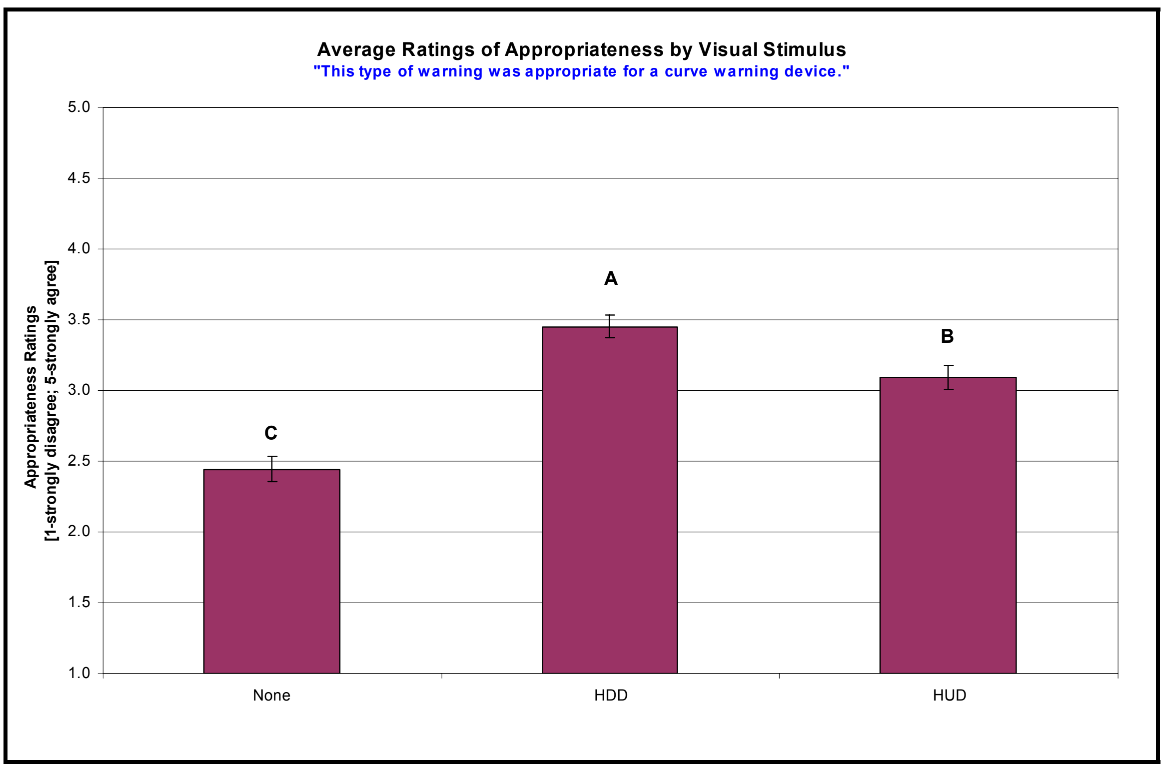

Figure 4.47 Appropriateness Ratings Comparison of Visual Main Effect

4.2.1.1.4 Interference

The fourth statement presented on the Post-Condition Questionnaire was as follows: “This type of warning interfered with my driving.” When analyzed by modality, this statement was found to be significant for the auditory and haptic main effects. An SNK *post-hoc* analysis was performed for the auditory main effect.

Based on results of the previous statements, it was not surprising that the auditory icon received the highest average rating for interference (3.2), which was significantly greater than the other two auditory stimuli and the conditions with none (Figure 4.48). The tone, speech, and no-auditory levels were not found to be significantly different from each other, although the speech stimuli received the lowest interference rating, with a 2.2, closest to the “Disagree” ranking.

The haptic main effect was also found to be significant (Figure 4.49), and the results show that, on average, participants felt that the haptic stimulus caused greater interference when it was included in the condition. The throttle push-back received an average rating of 2.8, whereas conditions with no haptic-element were closer to the “Disagree” ranking, with an average rating of 2.5.

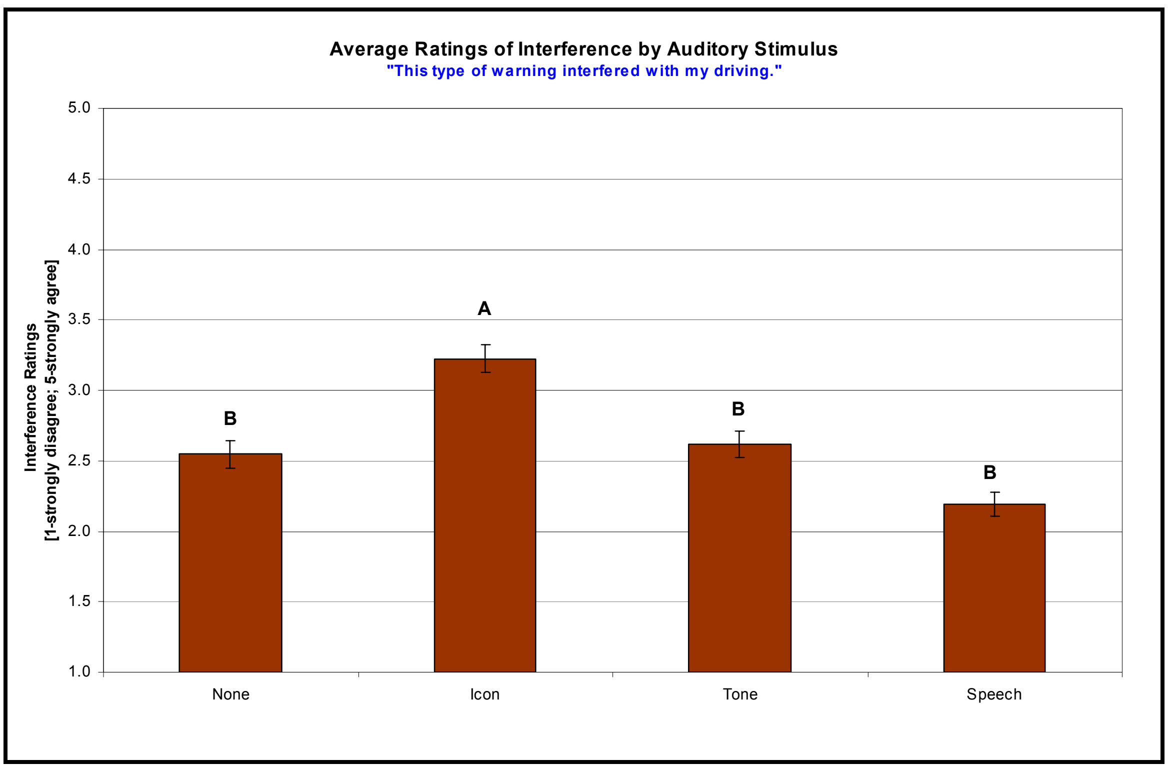

Figure 4.48 Interference Ratings Comparison of Auditory Main Effect

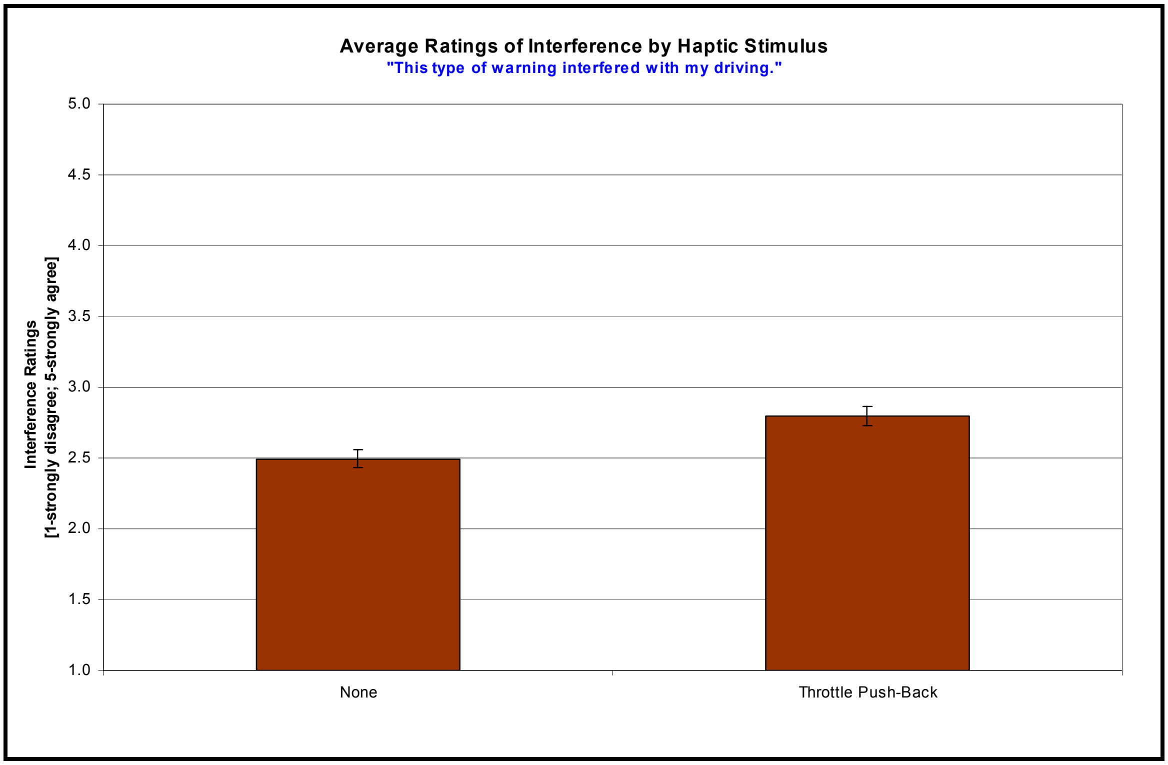

Figure 4.49 Interference Ratings Comparison of Haptic Main Effect

4.2.1.1.5 Want

The fifth statement presented on the Post Condition Questionnaire was as follows: "If my car were equipped with a curve-warning device, I would want this type of warning to be presented." This question provided the most insight into user preferences. When analyzed by modality, this statement was found to be significant for all three main effects, as well as for the interactions between the auditory and visual, visual and haptic, and all three main effects. An SNK *post-hoc* analysis was performed for the auditory and visual main effects.

Interestingly, the three-way interaction (Figure 4.50) shows the conditions split evenly in thirds: one-third of the conditions fell below the "Disagree" ranking in average want ratings; one-third fell above the "Disagree" but below the "Undecided" ranking; and the remaining third fell above the "Undecided" ranking. All six conditions that included the speech stimulus fell within the top third, which was also comprised of four HDD and two HUD inclusive conditions. Overall, the highest-rated condition was the speech and HDD condition, with an average of 3.6.

The significant interaction between the auditory and visual modalities shows that two-thirds of the combinations fall below the "Undecided" ranking for want (Figure 4.51). The three combinations that were above the "Undecided" ranking (one additional combination was right at the 3.0 mark, not above) were the only three combinations that included the speech stimulus. Overall trends include the HDD rating slightly higher than the HUD, and both the HDD and HUD rating higher than conditions with no visual element. This trend was also continued in the Visual X Haptic interaction, shown in Figure 4.52.

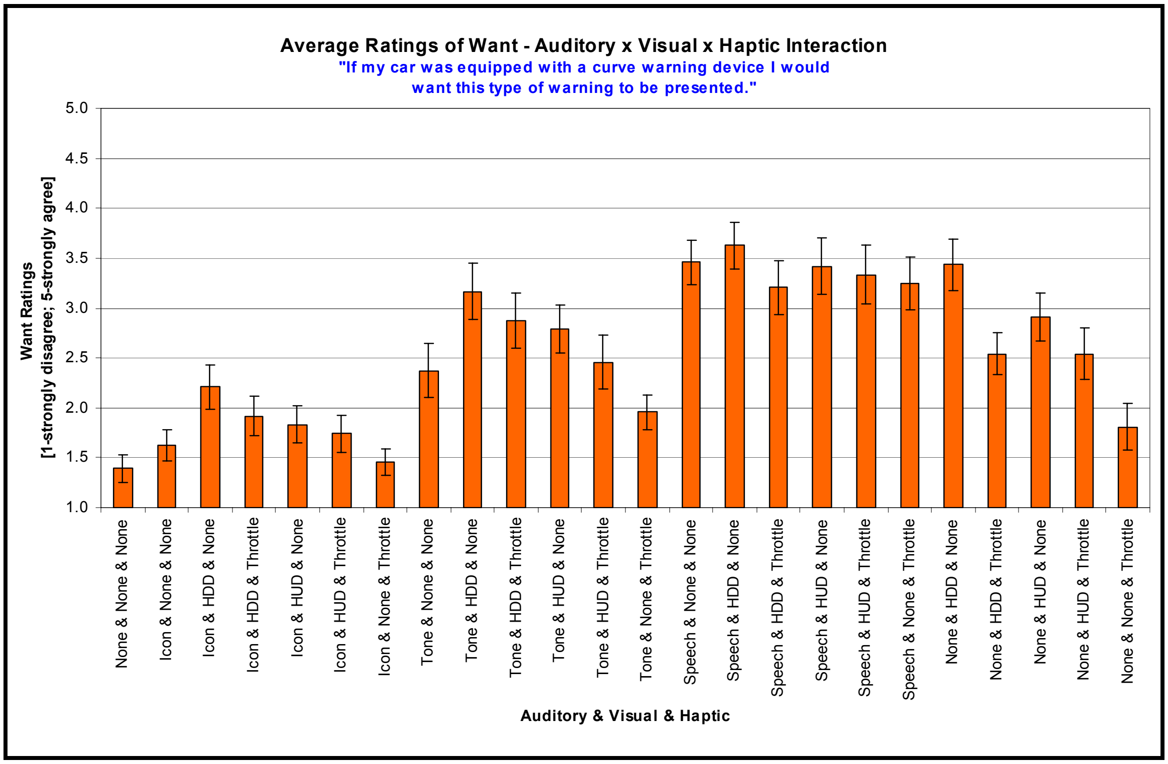

Figure 4.50 Want Ratings Comparison of Auditory X Visual X Haptic Interaction

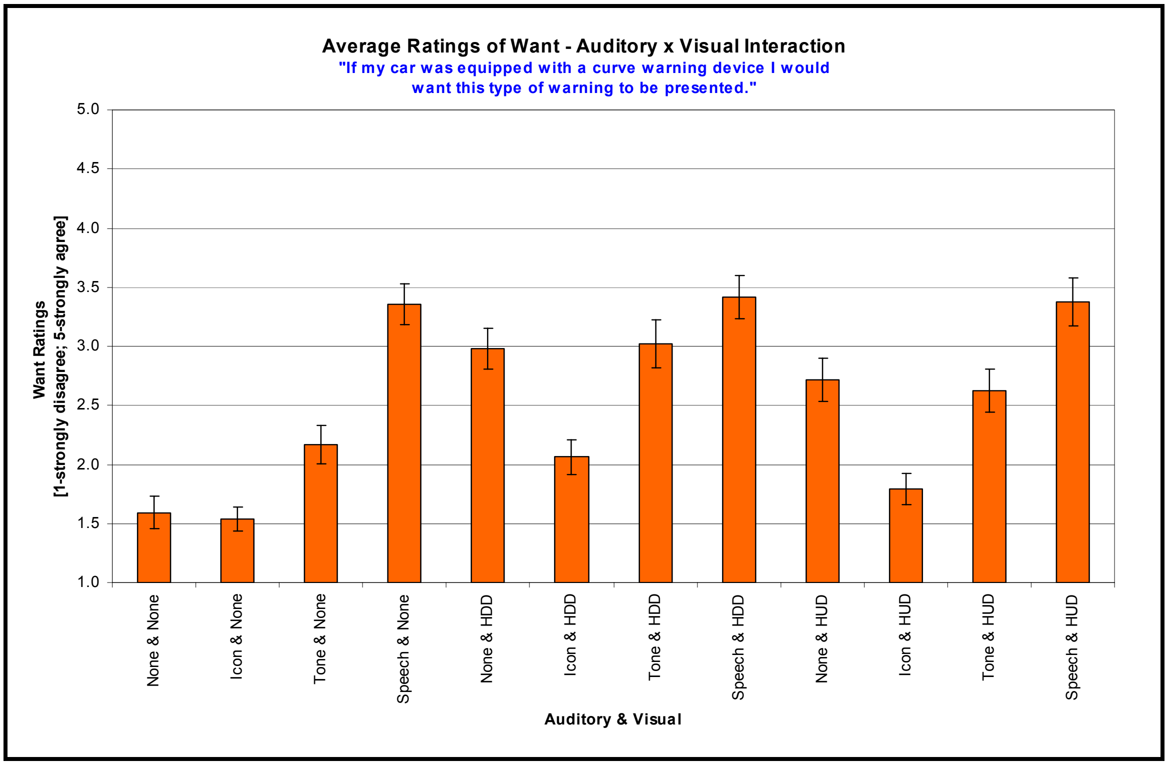

Figure 4.51 Want Ratings Comparison of Auditory X Visual Interaction

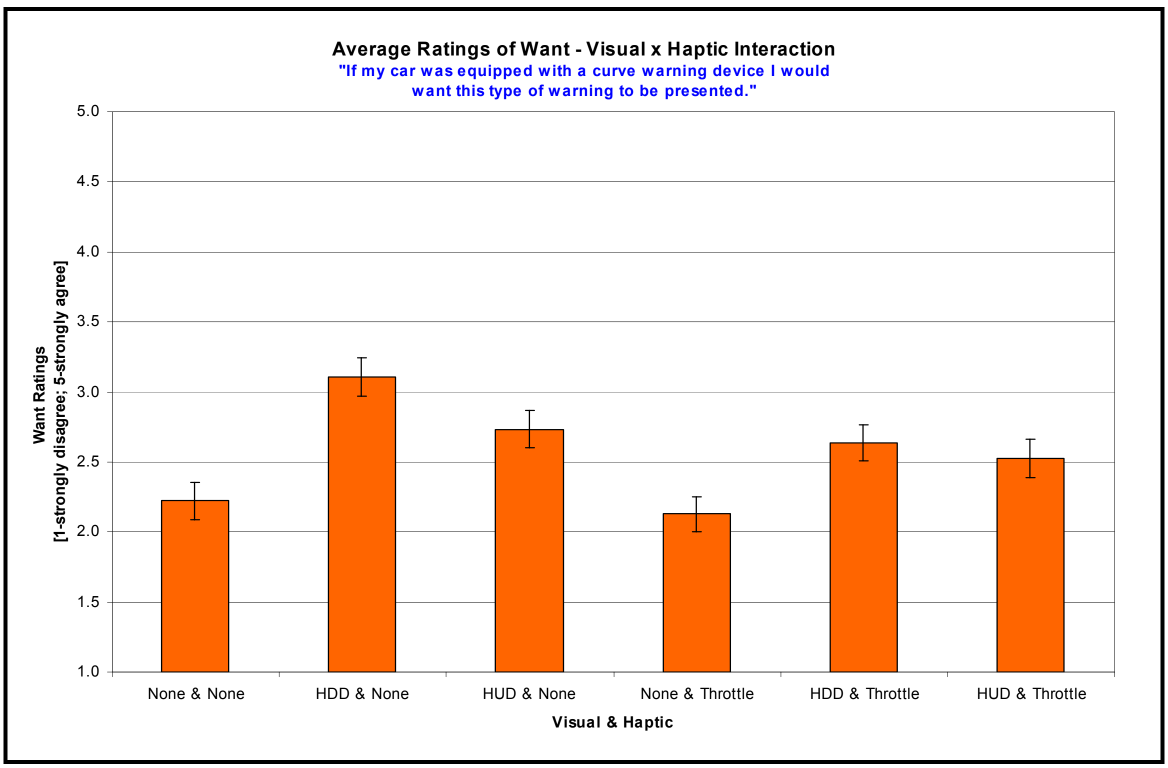

Figure 4.52 Want Ratings Comparison of Visual X Haptic Interaction

Not unexpectedly, the speech stimulus was found to be significantly more wanted than the other two auditory stimuli (Figure 4.53). On the other extreme, the auditory icon, with an average rating of 1.8 near the "Disagree" ranking, was also significantly different from the remaining auditory levels. The tone and no-auditory conditions were not significantly different, and both fell between the "Undecided" and "Disagree" rankings.

There was no significant difference between the HDD and HUD, but both icons were found to be significantly more wanted than no visual icon (Figure 4.54). Again, no significant difference between the HDD and HUD (ratings of 2.9 and 2.6, respectively) was somewhat surprising, based on observations during data collection and participant comments. Finally, the conditions in which no haptic stimulus was included had a significantly higher want rating when compared to those conditions where a throttle push-back was presented, although both fell between the "Disagree" and "Undecided" rankings (Figure 4.55).

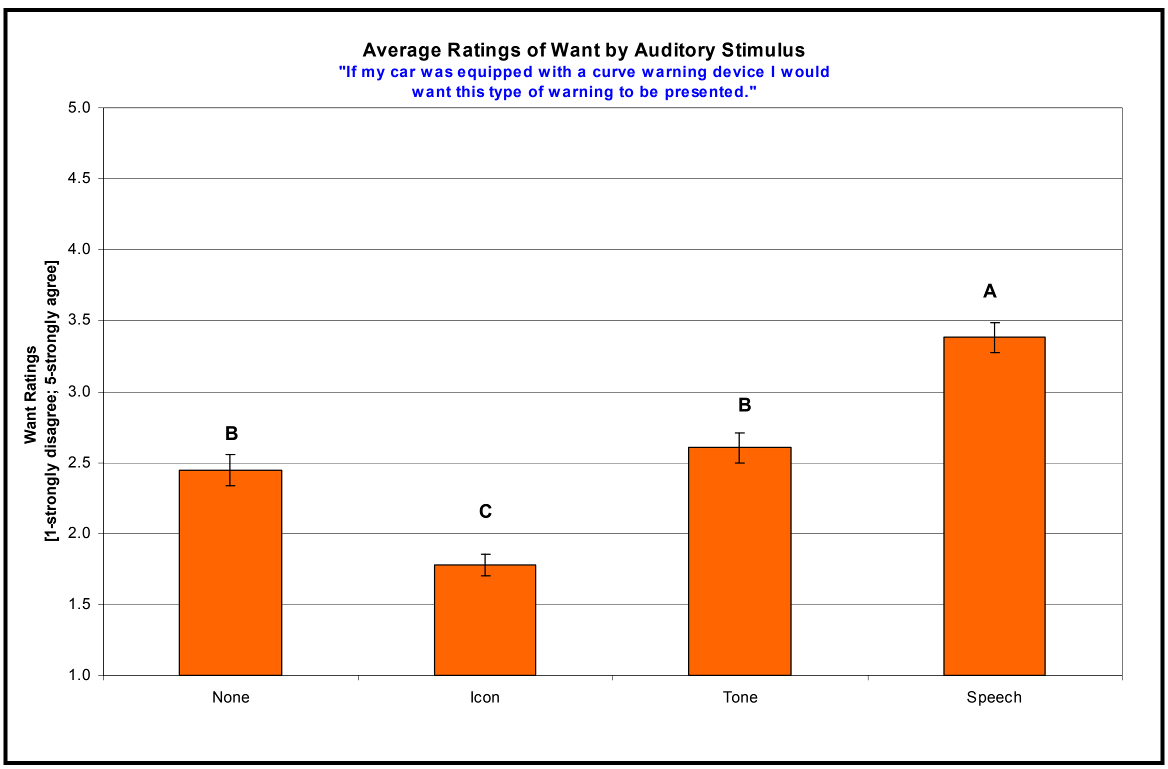

Figure 4.53 Want Ratings Comparison of Auditory Main Effect

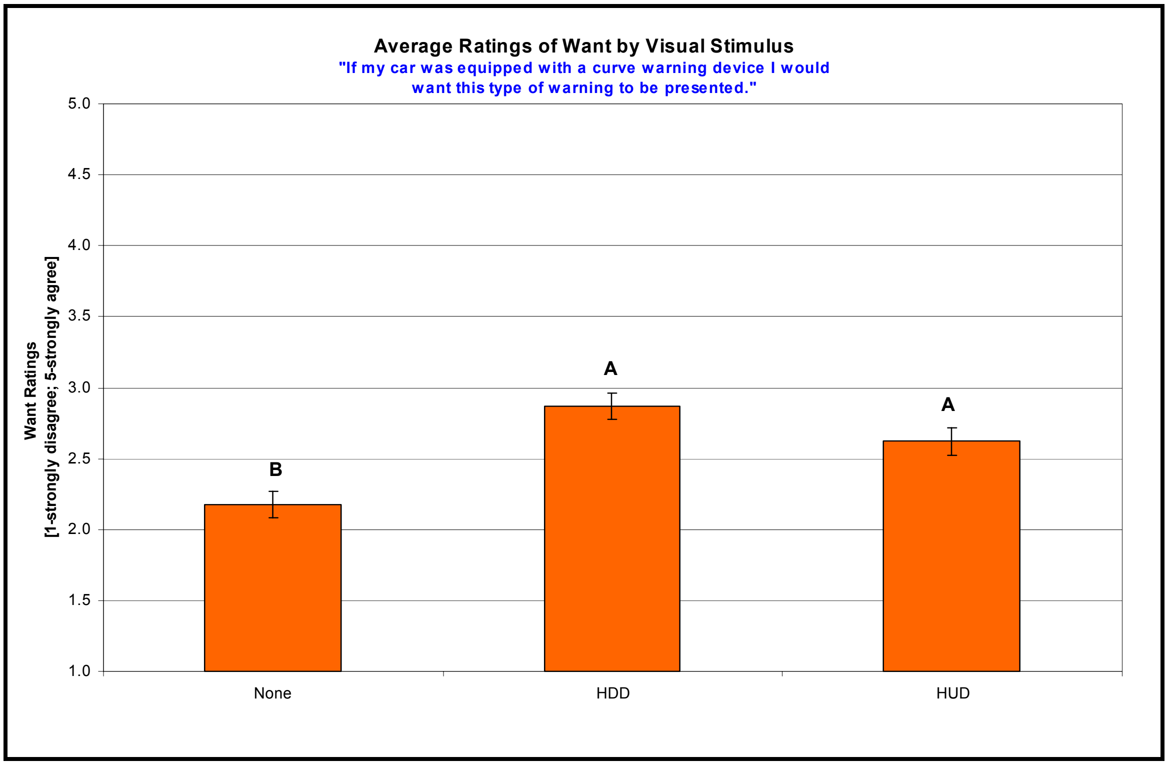

Figure 4.54 Want Ratings Comparison of Visual Main Effect

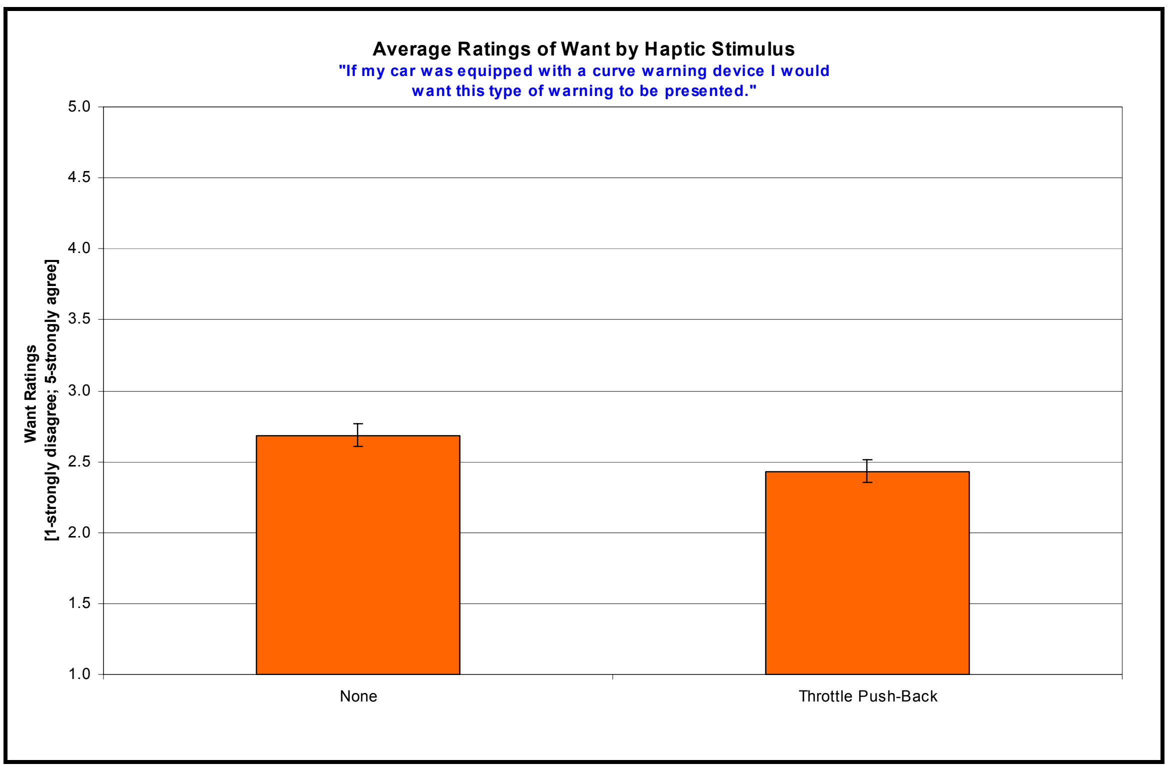

Figure 4.55 Want Ratings Comparison of Haptic Main Effect

4.2.1.2 Post Condition Questionnaire results by Age and Stimulus Condition

As with the objective data analysis, a mixed-factorial design was used to examine the effects of age, stimulus conditions, and their interaction. The significant findings are summarized in Table 4.16. All of the ANOVA summary tables can be seen in Appendix V. Stimulus condition was the only significant main effect that existed for each of the five questions. An SNK *post-hoc* analysis was used to determine any significance within the condition main effect. Due to the complexity of the *post-hoc* graphs for the condition main effect, the order of conditions is ranked from highest to lowest. This ranking allows for a better grouping of the tasks and helps with viewing similarities and significant differences; therefore, the order from figure to figure may vary. Three significant interactions between age and condition were found. As with the previous section, the significant results are grouped and discussed by question.

Table 4.16 Summary of Significant Findings for Age and Condition

Source	Urgency	Annoying	Appropriate	Interference	Want
Between					
Age					
Subject(Age)					
Within					
Condition	**x**	**x**	**x**	**x**	**x**
Age X Condition		**x**		**x**	**x**
Condition X Subject(Age)					

x = $p < 0.05$ (significant)

4.2.1.2.1 Urgency

When analyzed with respect to the ratings of urgency, the only significance found was for the condition main effect. As shown in Figure 4.56, approximately 92% of the conditions had an average urgency rating above the "Undecided" ranking. The two exceptions are the haptic-only condition and the baseline condition, both of which were found to be significant from each other as well as from all other conditions. Six of the conditions fell above the "Agree" ranking, three of which included the auditory icon. The majority of the conditions (22 out of 24) were rated above "Undecided" for urgency, but there was some significance between conditions above "Agree" and those closest to the "Undecided" ranking.

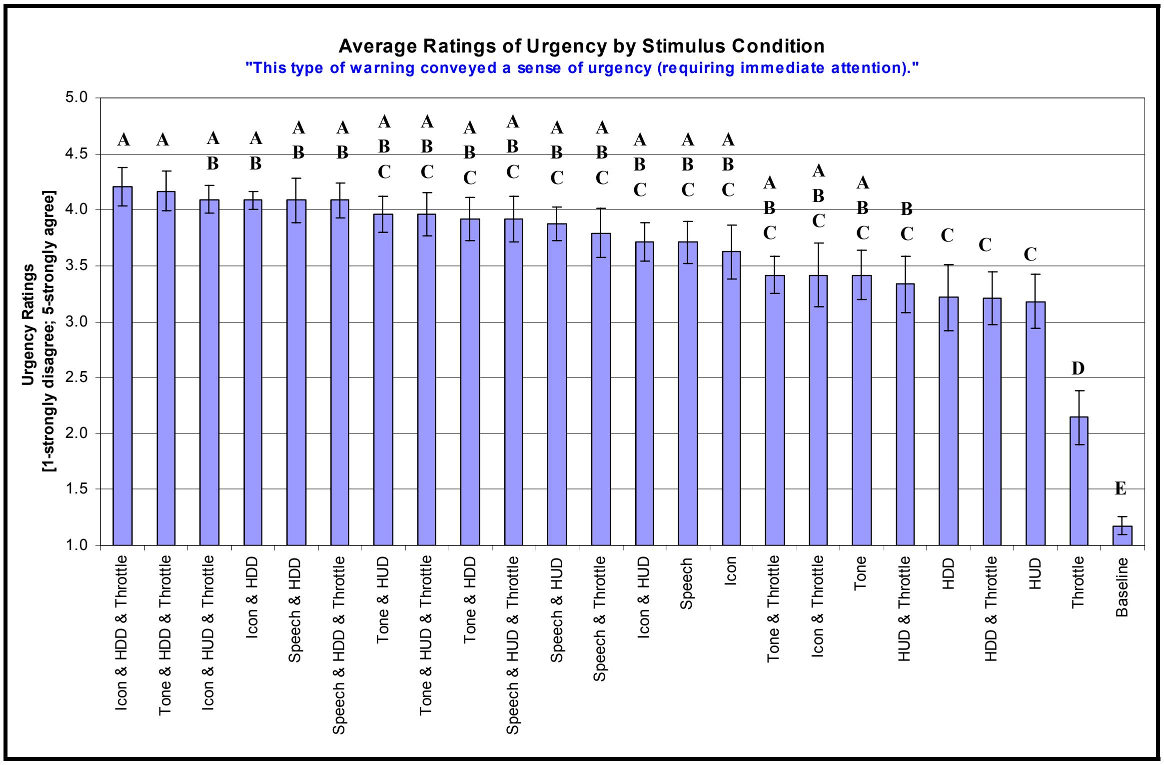

Figure 4.56 Urgency Ratings Comparison of Condition Main Effect

4.2.1.2.2 Annoyance

The interaction between condition and age and the condition main effect were found to be significant for ratings of annoyance (Figure 4.57 and Figure 4.58). When split by age, the biggest differences appear to be in the conditions containing the speech stimulus. As shown in Table 4.17 , the five conditions with the lowest annoyance ratings by age group are highlighted in bold. The age groups did share two conditions in their respective top five (lowest) based on annoyance ratings: the speech alone and speech combined with the HDD. The baseline condition was rated by the older participants as their sixth most annoying condition (rated least annoying by younger participants).

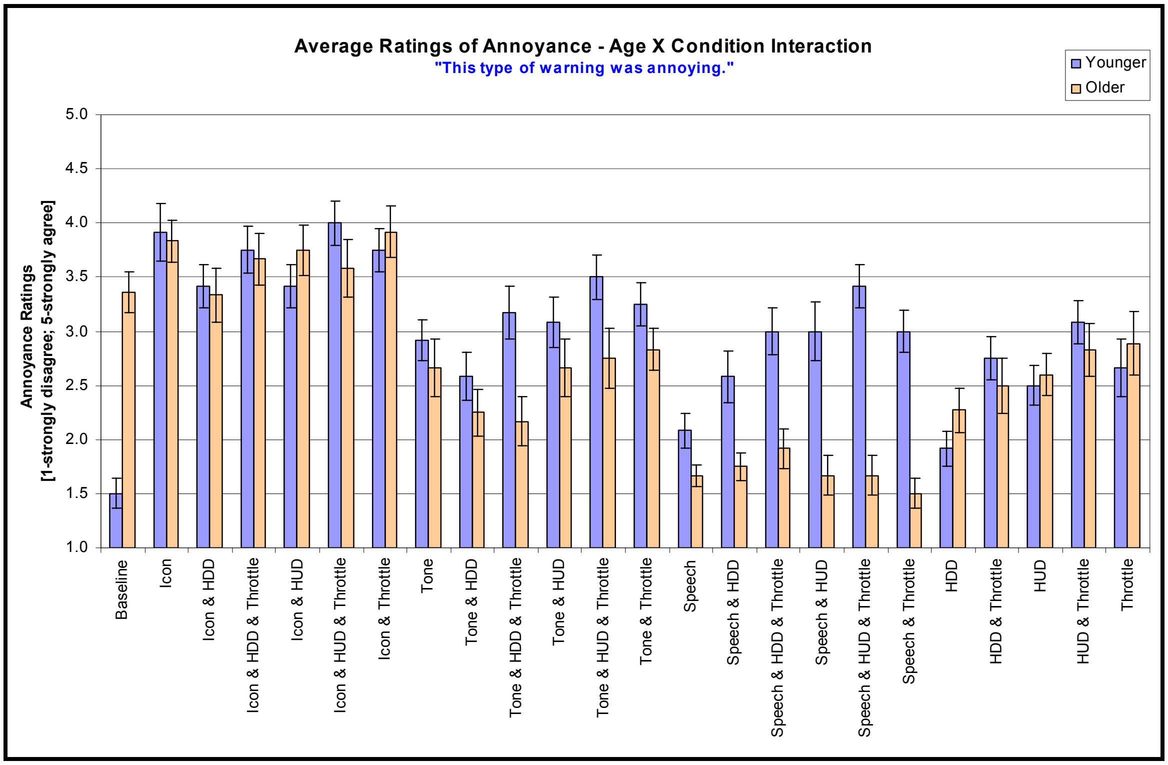

Figure 4.57 Annoyance Ratings Comparison of Age X Condition Interaction

Table 4.17 Annoyance Ratings Comparison of Age X Condition Interaction

Condition	Young	Older	Annoyance Difference
Baseline	**1.5**	3.4	-1.9
Icon	3.9	3.8	0.1
Icon & HDD	3.4	3.3	0.1
Icon & HDD & Throttle	3.8	3.7	0.1
Icon & HUD	3.4	3.8	-0.3
Icon & HUD & Throttle	4.0	3.6	0.4
Icon & Throttle	3.8	3.9	-0.2
Tone	2.9	2.7	0.3
Tone & HDD	2.6	2.3	0.3
Tone & HDD & Throttle	3.2	2.2	1.0
Tone & HUD	3.1	2.7	0.4
Tone & HUD & Throttle	3.5	2.8	0.8
Tone & Throttle	3.3	2.8	0.4
Speech	**2.1**	**1.7**	0.4
Speech & HDD	**2.6**	**1.8**	0.8
Speech & HDD & Throttle	3.0	1.9	1.1
Speech & HUD	3.0	**1.7**	1.3
Speech & HUD & Throttle	3.4	**1.7**	1.8
Speech & Throttle	3.0	**1.5**	1.5
HDD	**1.9**	2.3	-0.4
HDD & Throttle	2.8	2.5	0.3
HUD	**2.5**	2.6	-0.1
HUD & Throttle	3.1	2.8	0.3
Throttle	2.7	2.9	-0.2

All six conditions that included the auditory icon had the six highest annoyance ratings and were significantly higher than five out of the six speech conditions (Figure 4.58). Although not significantly different from the thirteen closest conditions, the speech-only warning had the lowest rating. With a rating of 1.9, it was the only condition to fall between the "Strongly Disagree" and "Disagree" rankings.

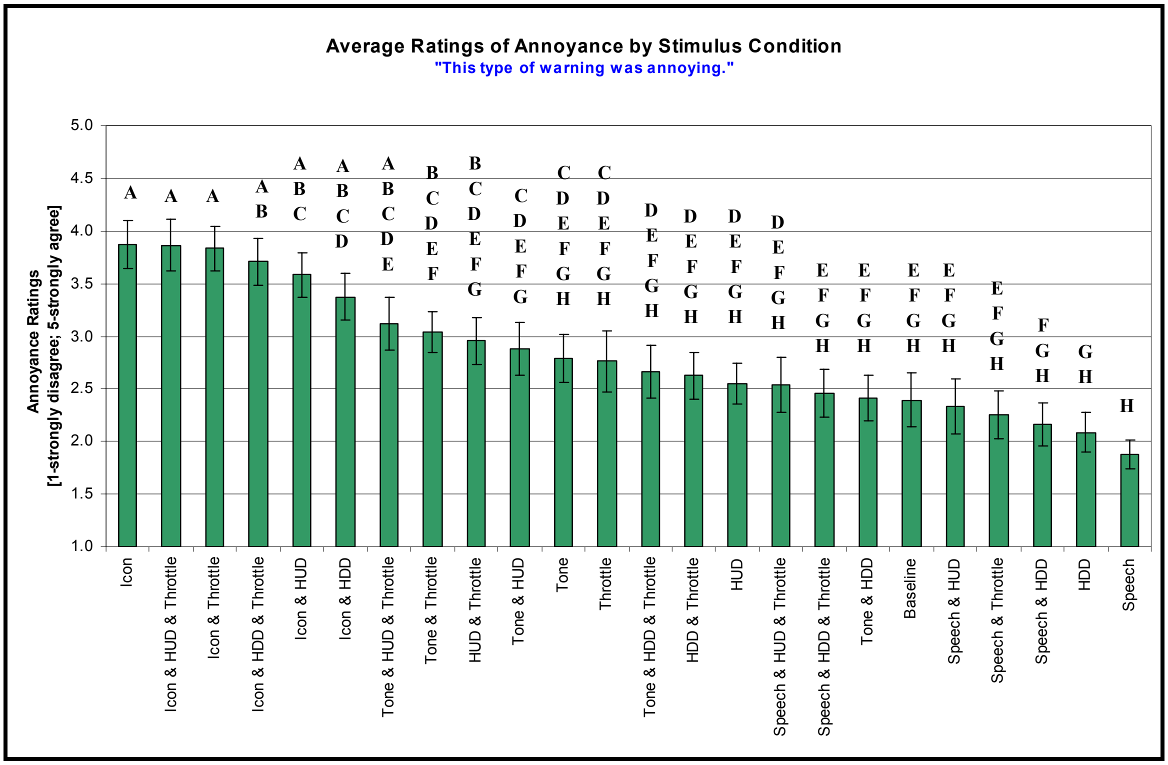

Figure 4.58 Annoyance Ratings Comparison of Condition Main Effect

4.2.1.2.3 Appropriateness

In a reversal of the annoyance ratings, all six speech conditions were found to be significantly more appropriate for a curve-warning device than were the conditions containing the auditory icon (Figure 4.59). The Speech and HDD combination received the highest appropriateness rating. Moreover, with an average rating of 4.1, this combination was significantly higher than any condition rated below 3.5 (total of 15 conditions). The Icon and None and the Icon and Throttle combination were the only two, not including the baseline, to fall below the "Disagree" rating.

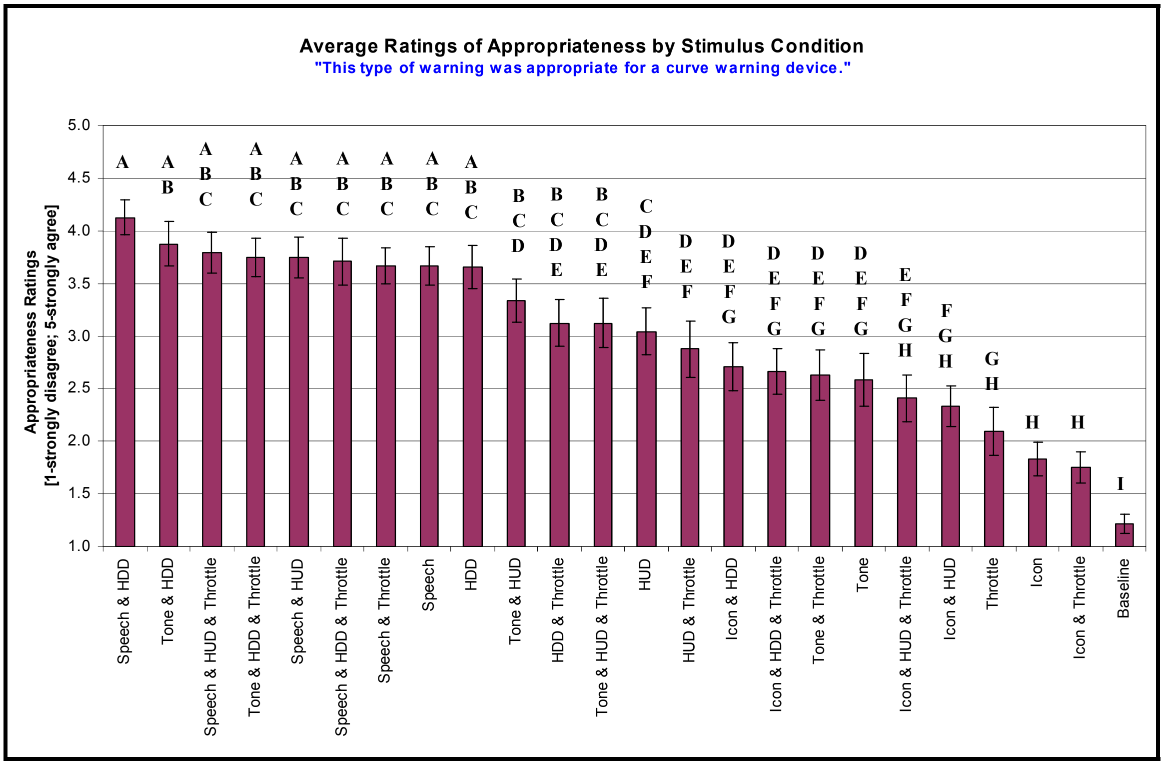

Figure 4.59 Appropriateness Ratings Comparison of Condition Main Effect

4.2.1.2.4 Interference

When separated by age (Figure 4.60), there are again large differences between the groups for conditions that included speech, as well as a couple of conditions that included the auditory tone. Table 4.18 also compares the numerical results and their differences, with the top-five least interfering conditions highlighted in bold. Interestingly, the top six (tie for the fifth spot) conditions that older participants rated as being the least interfering were all of the conditions that included the speech warning. The speech-only and Speech and HDD conditions shared spots in each of the age groups respective top five least interfering based on their ratings.

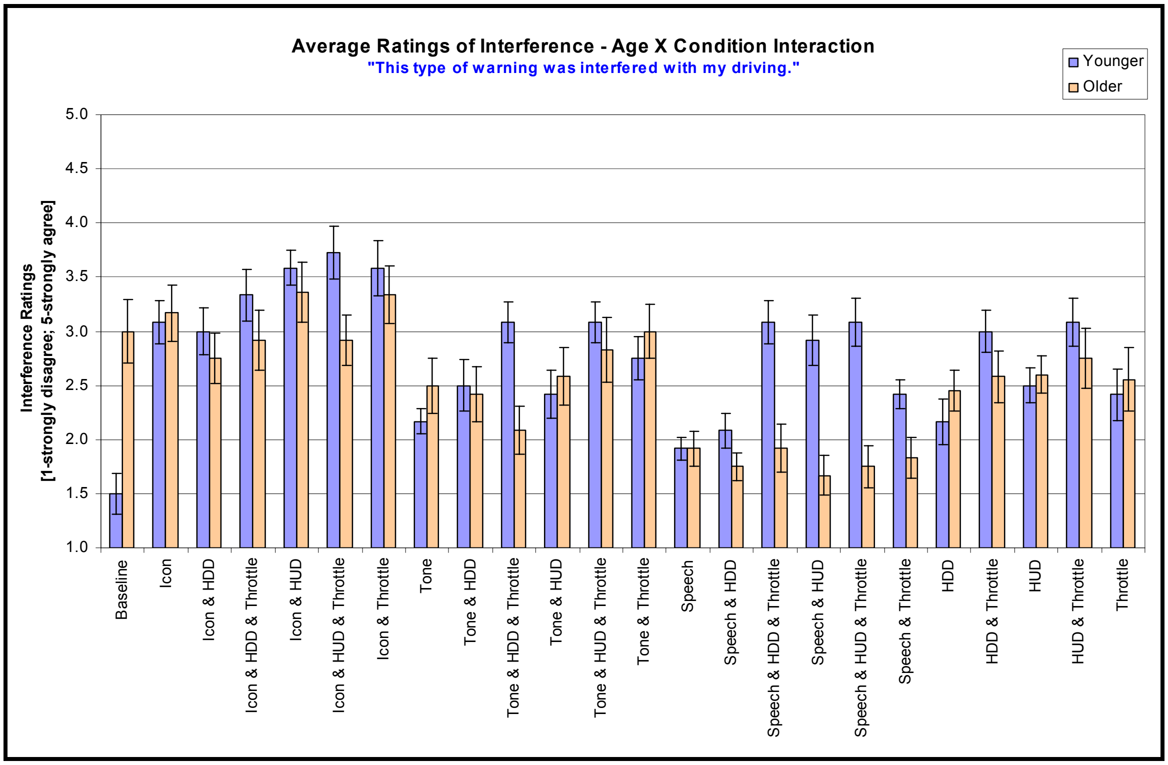

Figure 4.60 Interference Ratings Comparison of Age X Condition Interaction

Table 4.18 Interference Ratings Comparison of Age X Condition Interaction

Condition	Young	Older	Interference Difference
Baseline	**1.5**	3.0	-1.5
Icon	3.1	3.2	-0.1
Icon & HDD	3.0	2.8	0.3
Icon & HDD & Throttle	3.3	2.9	0.4
Icon & HUD	3.6	3.4	0.2
Icon & HUD & Throttle	3.7	2.9	0.8
Icon & Throttle	3.6	3.3	0.3
Tone	**2.2**	2.5	-0.3
Tone & HDD	2.5	2.4	0.1
Tone & HDD & Throttle	3.1	2.1	1.0
Tone & HUD	2.4	2.6	-0.2
Tone & HUD & Throttle	3.1	2.8	0.3
Tone & Throttle	2.8	3.0	-0.3
Speech	**1.9**	**1.9**	0.0
Speech & HDD	**2.1**	**1.8**	0.3
Speech & HDD & Throttle	3.1	**1.9**	1.2
Speech & HUD	2.9	**1.7**	1.3
Speech & HUD & Throttle	3.1	**1.8**	1.3
Speech & Throttle	2.4	**1.8**	0.6
HDD	**2.2**	2.5	-0.3
HDD & Throttle	3.0	2.6	0.4
HUD	2.5	2.6	-0.1
HUD & Throttle	3.1	2.8	0.3
Throttle	2.4	2.6	-0.1

The results for the condition main effect with respect to ratings of interference (Figure 4.61) are similar to those found for ratings of annoyance, where the auditory icon was at the higher end of the spectrum and the speech on the lower, with the auditory tone falling, for the most part, in between. With average ratings of 1.9, the speech-only and Speech and HDD conditions were the only two conditions to fall below the "Disagree" ranking. Roughly 70% of the stimulus conditions fell between the "Disagree" and "Undecided" rankings.

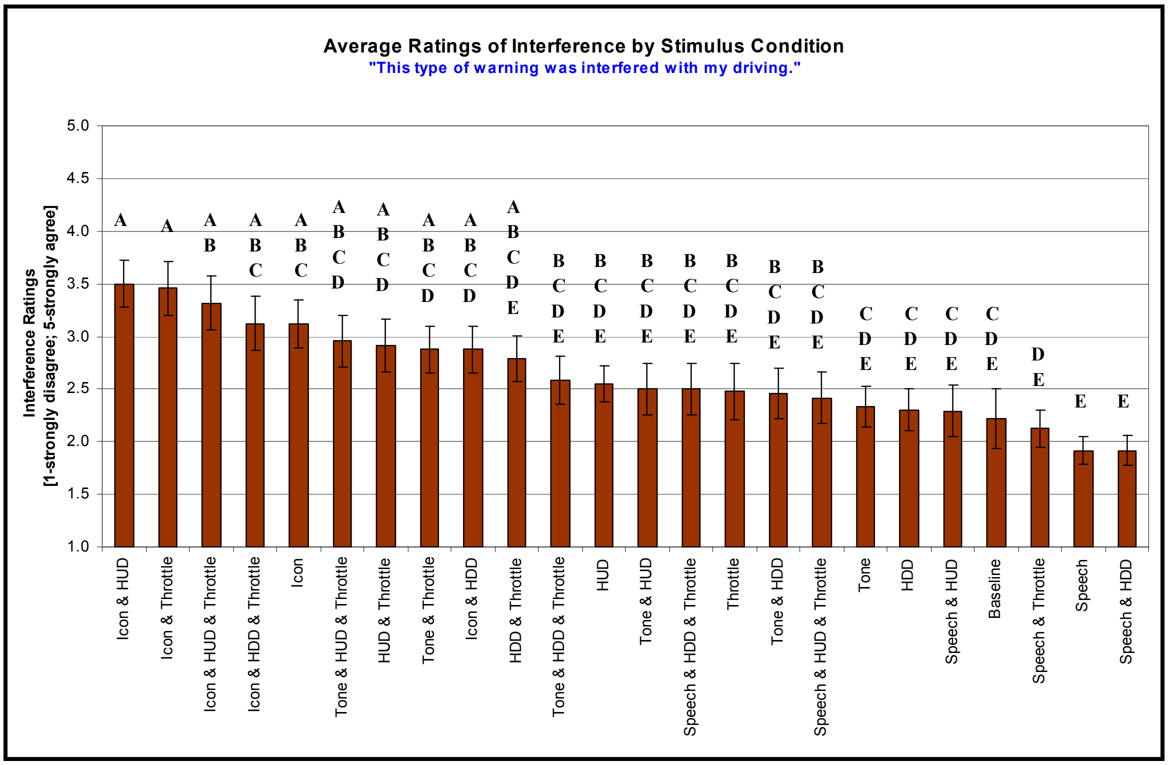

Figure 4.61 Interference Ratings Comparison of Condition Main Effect

4.2.1.2.5 Want

As in the Post-Condition Questionnaire analysis by modality, greater weight was given to the final question concerning what the participants would want in their vehicle if they could choose a specific curve warning. The same discrepancies existed between the age groups, and the preference of the speech stimulus with the older participants is apparent (Figure 4.62 and Table 4.19). Again, all six speech conditions comprised the top “five” (shown in bold) based on the ratings given by the older participants. Interestingly, two of the top-five ranked conditions based on the ratings given by the younger participants were the HDD and HUD by themselves, suggesting that no auditory element was desired. Consistently, the two age groups did share the Speech and None and the Speech and HDD conditions as top-rated conditions.

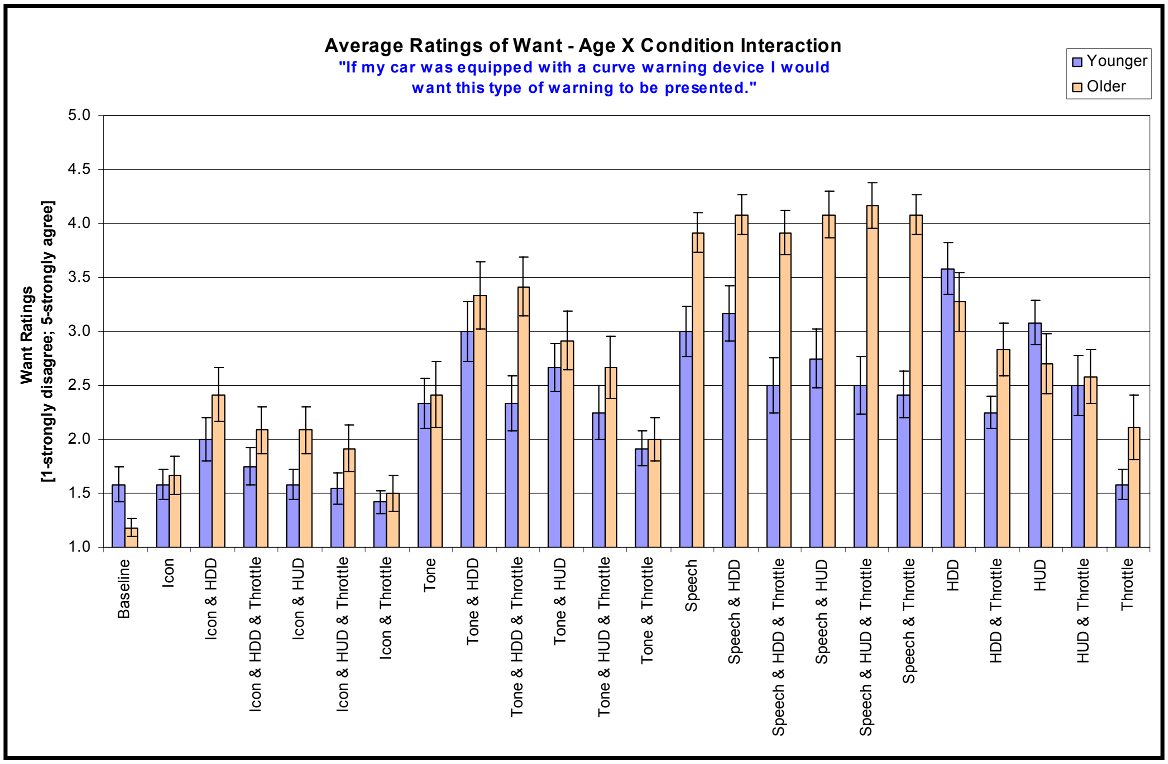

Figure 4.62 Want Ratings Comparison of Age X Condition Interaction

Table 4.19 Want Ratings Comparison of Age X Condition Interaction

Condition	Young	Older	Want Difference
Baseline	1.6	1.2	0.4
Icon	1.6	1.7	-0.1
Icon & HDD	2.0	2.4	-0.4
Icon & HDD & Throttle	1.8	2.1	-0.3
Icon & HUD	1.6	2.1	-0.5
Icon & HUD & Throttle	1.5	1.9	-0.4
Icon & Throttle	1.4	1.5	-0.1
Tone	2.3	2.4	-0.1
Tone & HDD	**3.0**	3.3	-0.3
Tone & HDD & Throttle	2.3	3.4	-1.1
Tone & HUD	2.7	2.9	-0.3
Tone & HUD & Throttle	2.3	2.7	-0.4
Tone & Throttle	1.9	2.0	-0.1
Speech	**3.0**	**3.9**	-0.9
Speech & HDD	**3.2**	**4.1**	-0.9
Speech & HDD & Throttle	2.5	**3.9**	-1.4
Speech & HUD	2.8	**4.1**	-1.3
Speech & HUD & Throttle	2.5	**4.2**	-1.7
Speech & Throttle	2.4	**4.1**	-1.7
HDD	**3.6**	3.3	0.3
HDD & Throttle	2.3	2.8	-0.6
HUD	**3.1**	2.7	0.4
HUD & Throttle	2.5	2.6	-0.1
Throttle	1.6	2.1	-0.5

As expected, the speech stimulus again monopolized the upper spots and was significantly different from all conditions that included the auditory icons, which were near the bottom (Figure 4.63). Within each auditory grouping, the HDDs ranked above their HUD counterparts, and conditions without the haptic stimulus ranked higher than those that included the throttle push-back. Two-thirds of the conditions fell below the "Undecided" ranking, and aside from one auditory tone and one non-auditory condition, the remaining third was made up of all six speech conditions.

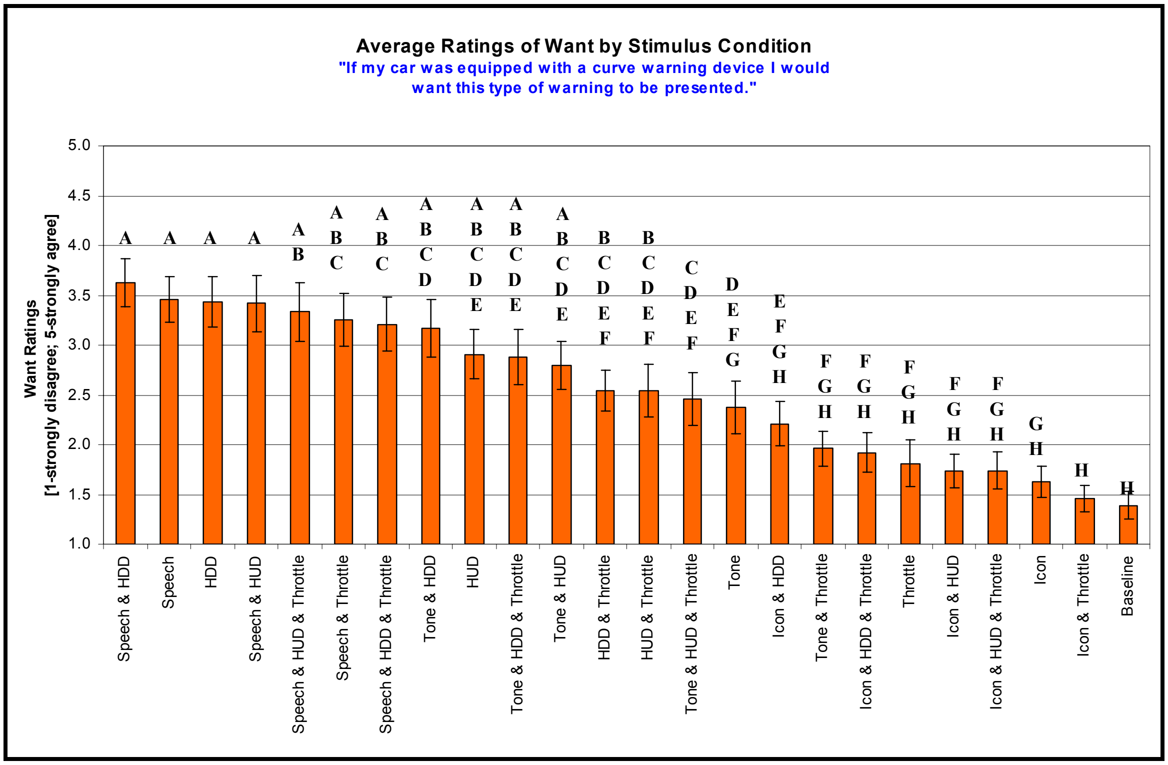

Figure 4.63 Want Ratings Comparison of Condition main effect

4.2.1.3 Post Condition Questionnaire by Gender and Stimulus Condition

There were no significant findings for the Gender main effect or the Gender X Condition interaction with respect to the Post-Condition Questionnaire. The Condition main effect was discussed in section 4.2.1.2. All ANOVAs can be seen in Appendix W.

Table 4.20 Summary of Significant Findings for Gender and Condition

Source	Urgency	Annoying	Appropriate	Interference	Want
Between					
Gender					
Subject(Gender)					
Within					
Condition	**x**	**x**	**x**	**x**	**x**
Gender X Condition					
Condition X Subject(Gender)					

x = $p < 0.05$ (significant)

4.2.1.4 Post Condition Questionnaire summary

Based on the subjective results, it appears that the most favored stimulus condition was the Speech and HDD combination. This condition received the fifth highest ranking for urgency and was the third least annoying condition, behind the two elements by themselves. This combination was also rated as being the most appropriate, having the least interference with the driving task, and being the most wanted for the personal cars of the participants. This was also one of the two conditions, the other being speech alone, to share top spots for both age groups for questions where the age and condition interaction was found to be significant.

4.2.2 Content Analysis

A coding scheme was developed in order to perform a content analysis on the open-ended question at the end of the Post-Condition Questionnaire, which was as follows: "Would you change something about this warning? If yes, what would it be." The phrases used to answer the questions were used in the analysis. Single classification, meaning that the phrase would be assigned only to one code (Insch, Moore, and Murphy, 1997), was used, unless it applied to multiple modalities. Some of the comments also included multiple phrases, whereupon each phrase was coded separately. Positive and negative codes were developed using an inferred method while reading through the participant comments. After the initial code development, the codes were subjectively analyzed to make sure there was no overlap. Once the list was finalized, a total of 13 positive and 24 negative codes were used. The codes and their respective definitions are included in Table 4.21 and Table 4.22. All comments separated by code can be seen in Appendix X. The frequency data can be seen in Table 4.23 and separated by stimulus condition in Appendix Y.

Table 4.21 Positive codes for Content Analysis

Code	Definition
pos - Good Visual Icon	Participant expressed praise for visual location, color, or any other attribute of the icon.
pos - Liked length of warning	Comments exhibiting favorable demeanor towards length of warning (time)
pos - Change Nothing	Comments expressing that warning should be left as is
pos - Could be used	Comments expressing that particular configuration could be used in this scenario
pos - Sound is nice	Participant expressed praise for auditory warning
pos - Better or Best Condition	Comments expressing that particular configuration better than previous, or is best out of those seen up to that point
pos - Combination more effective	Comments expressing that combination of the presented warnings better than warnings by themselves
pos - sound conveys urgency	Comments expressing conveyed urgency for presented auditory warning
pos - not as adverse as before	Participant states that reaction to a particular warning not as adverse as with first exposure
pos - good warning	Comments that warning was good
pos - like being visually and audibly warned	Participant expresses favorable demeanor towards combination of visual and auditory warning
pos - voice is best	Comments stating that speech warning is best out of the three auditory warnings
pos - getting used to	Participant states that he/she is getting used to warnings, becoming more comfortable

Table 4.22 Negative codes - Content Analysis

Code	Definition
neg - Not enough information	Comments suggesting that better explanation or more information was needed; confusion as a result of lack of information
neg - Change auditory warning	Comments suggesting that the auditory warning presented should be changed to one of the other two types of auditory warnings
neg - add visual warning	Comments suggesting that the warning configuration would benefit by the additional of a visual icon
neg - remove auditory warning	Comments suggesting that the auditory warning should be altogether removed from the presented configuration
neg - auditory warning is startling	Comments suggesting that the auditory warning was a surprise or startling (i.e., scary, sounded like an accident or external noise, weird, etc.)
neg - increase auditory volume	Comments suggesting that the volume for the presented auditory warning should be increased, or may not be noticed or heard in real-world (i.e., over radio, etc.)
neg - remove haptic warning	Comments suggesting that the haptic warning should be removed; may also include comments suggesting startling or unfavorable feelings towards
neg - excessive / overload	Comments suggesting that the warning configuration was excessive, disorienting, or seeming to be "overload"
neg - add auditory warning	Comments suggesting that an auditory warning should be added to the presented configuration
neg - don't use entire condition	Comments suggesting that the changes to be made should be to not use the entire configuration
neg - change the location of the visual icon	Comments suggesting that the visual icon should be changed with respect to location
neg - change aesthetic characteristics of the visual icon	Comments suggesting that the visual icon should be changed with respect to color, size, etc.
neg - took a second to notice visual	Comments suggesting that the visual icon was not noticed immediately upon presentation
neg - visual blocks roadway view	Comments suggesting that the visual icon blocks the view of the roadway, hard to view/focus on both, takes focus off road to view
neg - remove/change visual flashing	Comments suggesting that the flashing on the visual icon should either be removed or slowed down
neg - warning timing too early	Comments suggesting that the timing of the warning was too early, or too far away from the curve
neg - condition seems dangerous	Comments suggesting that the warning configuration seemed dangerous
neg - prefer other conditions	Comments suggesting that the participant preferred other conditions he/she had seen previously
neg - did not notice a warning	Comments suggesting that no warning whatsoever was noticed when one was presented (does not include Baseline)
neg - may become / is annoying	Comments suggesting that the warning may become or already is annoying
neg - have warning appear sooner	Comments suggesting that the warning should appear sooner, farther away from the curve
neg - voice is too calm	Comments suggesting that the speech auditory warning is too calm; or there is lack of notice ability
neg - change length (time) of warning	Comments suggesting that the length (in time) of the warning should be shortened (i.e., speech message too long)
neg - barely noticed haptic warning	Comments suggesting that the haptic warning was noticed but was not obvious

Table 4.23 Content Analysis - Frequency count

Code	Frequency
pos - Good Visual Icon	4
pos - Liked length of warning	2
pos - Change Nothing	38
pos - Could be used	2
pos - Sound is nice	1
pos - Best or Better Condition	8
pos - Combination more effective	1
pos - sound conveys urgency	3
pos - not as adverse as before	1
pos - good warning	3
pos - like being visually and audibly warned	1
pos - voice is best	1
pos - getting used to	1
neg - Not enough information	35
neg - Change auditory warning	34
neg - add visual warning	24
neg - remove auditory warning	16
neg - auditory warning is startling	16
neg - increase auditory volume	4
neg - remove haptic warning	29
neg - excessive / overload	8
neg - add auditory warning	13
neg - don't use entire condition	5
neg - change the location of the visual icon	28
neg - change aesthetic characteristics of the visual icon	24
neg - took a second to notice visual	2
neg - visual blocks roadway view	7
neg - remove/change visual flashing	19
neg - warning timing too early	1
neg - condition seems dangerous	1
neg - prefer other conditions	6
neg - did not notice a warning	22
neg - may become / is annoying	7
neg - have warning appear sooner	8
neg - voice is too calm	3
neg - change length (time) of warning	1
neg - barely noticed haptic warning	4

Attempts were made to test the comment frequency by modality, but no significant differences were found for any of the main effects or interactions for either positive or negative comments, and therefore the results are not presented. However, a between-subjects model was developed to test for significance between age and gender. The model and the summary of significant positive and negative comments can be seen in Table 4.24. An analysis was performed using a chi-squared analysis, using an $\alpha \leq 0.05$

as the significance cut-off. All chi-squared tables not included in this section can be seen in Appendix Z. The age main effect was found to be significant for both positive and negative comments, and the gender main effect was found to be significant for just the negative comments. The interaction between age and gender was significant for the number of positive comments only.

Table 4.24 Content Analysis Summary of Significant Findings

Source	Positive	Negative
Between		
Age	**x**	**x**
Gender		**x**
Age X Gender	**x**	
Subject(Age X Gender)		

x = $p < 0.05$ (significant)

As shown in Table 4.25, older males were more than twice as likely to make a positive comment than were both female age groups, and they were more than three times as likely to make a positive comment than were their younger counterparts. Seventy-seven percent of the positive comments made by older males were to change nothing about the condition they were just presented with, resulting in older males accounting for 60% of this comment overall. The frequency by gender and age per comment can be seen in Table 4.26, with the top 5 negative comments and top positive comment by age and gender group highlighted in bold. The younger males made 72 % (21 out of 29 total comments) of the comments suggesting that the throttle push-back should be removed, as well as approximately 71 % (20 out of 28 total comments) of the comments suggesting that the location of the visual icon should be changed. Older males made 60 % (23 out of 38 total comments) of the comments suggesting that nothing should be changed to the stimulus just presented, which is most likely the reason for the significant interaction.

Table 4.25 Positive Comments Analysis of Age X Gender Interaction

		Gender		
	Positive	Male	Female	Total
Age	Younger	9	13	22
	Older	30	14	44
	Total	39	27	**66**

DF	Value	p-value
1	4.5128	0.0358

Table 4.26 Positive Comment Comparison of Age X Gender Interaction

	Younger Male	Younger Female	Older Male	Older Female
neg - Not enough information	**10**	**8**	**12**	**5**
neg - Change auditory warning	**15**	**6**	**12**	1
neg - add visual warning	**10**	1	**10**	3
neg - remove auditory warning	3	4	3	**6**
neg - auditory warning is startling	0	**13**	1	2
neg - increase auditory volume	0	2	0	2
neg - remove haptic warning	**21**	**8**	0	0
neg - excessive / overload	3	4	1	0
neg - add auditory warning	3	0	**10**	0
neg - don't use entire condition	0	1	0	**4**
neg - change the location of the visual icon	**20**	3	4	1
neg - change aesthetic characteristics of the visual icon	7	2	3	**12**
neg - took a second to notice visual	1	0	1	0
neg - visual blocks roadway view	2	2	2	1
neg - remove/change visual flashing	0	**13**	2	**4**
neg - warning timing too early	1	0	0	0
neg - condition seems dangerous	0	1	0	0
neg - prefer other conditions	0	0	2	**4**
neg - did not notice a warning	4	3	**5**	**10**
neg - may become / is annoying	2	4	1	0
neg - have warning appear sooner	0	3	4	1
neg - voice is too calm	0	3	0	0
neg - change length (time) of warning	1	0	0	0
neg - barely noticed haptic warning	0	4	0	0
pos - Good Visual Icon	0	2	2	0
pos - Liked length of warning	0	1	1	0
pos - Change Nothing	2	**6**	**23**	**7**
pos - Could be used	0	0	0	2
pos - Sound is nice	1	0	0	0
pos - Best or Better Condition	2	3	2	1
pos - Combination more effective	0	0	1	0
pos - sound conveys urgency	**3**	0	0	0
pos - not as adverse as before	0	0	1	0
pos - good warning	1	0	0	2
pos - like being visually and audibly warned	0	1	0	0
pos - voice is best	0	0	0	1
pos - getting used to	0	0	0	1

As shown in Table 4.27 and Table 4.28, the older participants had more than twice the number of positive comments than did younger participants, who made nearly 60% of the negative comments. The frequency breakdown is shown in Table 4.29. The five comments with the highest number of negative comments are shown in bold by age, as well as the comment with the highest number of positive comments.

The biggest difference between age groups is shown for the number of comments suggesting that the throttle push-back should be removed. One-hundred percent of these comments (29 total comments) were made by younger participants. Similarly, younger participants made 82% of the comments suggesting that the location of the visual icon should be modified. Older participants, however, made approximately 79% of the comments suggesting that nothing should be changed about the condition they were just presented with.

Table 4.27 Positive Comments Analysis for Age Main Effect

	Age		
	Younger	Older	Total
Positive	22	44	**66**

DF	Value	p-value
1	7.3333	0.0072

Table 4.28 Negative Comments Analysis for Age Main Effect

	Age		
	Younger	Older	Total
Negative	188	129	**317**

DF	Value	p-value
1	10.9811	<0.001

Table 4.29 Comment Comparison of Age Main Effect

	Younger	Older	Difference
neg - Not enough information	**18**	**17**	1
neg - Change auditory warning	**21**	**13**	8
neg - add visual warning	11	**13**	-2
neg - remove auditory warning	7	9	-2
neg - auditory warning is startling	**13**	3	10
neg - increase auditory volume	2	2	0
neg - remove haptic warning	**29**	0	29
neg - excessive / overload	7	1	6
neg - add auditory warning	3	10	-7
neg - don't use entire condition	1	4	-3
neg - change the location of the visual icon	**23**	5	18
neg - change aesthetic characteristics of the visual icon	9	**15**	-6
neg - took a second to notice visual	1	1	0
neg - visual blocks roadway view	4	3	1
neg - remove/change visual flashing	**13**	6	7
neg - warning timing too early	1	0	1
neg - condition seems dangerous	1	0	1
neg - prefer other conditions	0	6	-6
neg - did not notice a warning	7	**15**	-8
neg - may become / is annoying	6	1	5
neg - have warning appear sooner	3	5	-2
neg - voice is too calm	3	0	3
neg - change length (time) of warning	1	0	1
neg - barely noticed haptic warning	4	0	4
pos - Good Visual Icon	2	2	0
pos - Liked length of warning	1	1	0
pos - Change Nothing	**8**	**30**	-22
pos - Could be used	0	2	-2
pos - Sound is nice	1	0	1
pos - Best or Better Condition	5	3	2
pos - Combination more effective	0	1	-1
pos - sound conveys urgency	3	0	3
pos - not as adverse as before	0	1	-1
pos - good warning	1	2	-1
pos - like being visually and audibly warned	1	0	1
pos - voice is best	0	1	-1
pos - getting used to	0	1	-1

The number of negative comments divided by gender was also found to be significant. Male participants, with a total of 176 comments, were found to make significantly more negative comments than were their female counterparts, with a total of 141 (Table 4.30). Table 4.31 shows the frequency differences between the genders by comment. The five conditions with the highest number of negative comments are shown in bold by age group, as is the condition with the highest number of positive comments. There is only one comment that obtained a top spot for both genders with their high number of negative comments: not enough information. Within that comment, however, there was a large discrepancy within the number of times the comment was made, with a larger number of males making the comment (difference of 9 comments).

Interestingly, approximately 94% of the comments that the auditory warning was startling were made by female participants. Similarly, females were responsible for approximately 90% of the comments suggesting that the flashing of the visual icon should be changed or removed entirely.

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Table 4.30 Negative Comments Analysis for Gender Main Effect

	Gender		
	Male	Female	Total
Negative	176	141	**317**

DF	Value	p-value
1	3.8644	0.0495

Table 4.31 Comment Comparison of Gender Main Effect

	Male	Female	Difference
neg - Not enough information	**22**	**13**	9
neg - Change auditory warning	**27**	7	20
neg - add visual warning	**20**	4	16
neg - remove auditory warning	6	10	-4
neg - auditory warning is startling	1	**15**	-14
neg - increase auditory volume	0	4	-4
neg - remove haptic warning	**21**	8	13
neg - excessive / overload	4	4	0
neg - add auditory warning	13	0	13
neg - don't use entire condition	0	5	-5
neg - change the location of the visual icon	**24**	4	20
neg - change aesthetic characteristics of the visual icon	10	**14**	-4
neg - took a second to notice visual	2	0	2
neg - visual blocks roadway view	4	3	1
neg - remove/change visual flashing	2	**17**	-15
neg - warning timing too early	1	0	1
neg - condition seems dangerous	0	1	-1
neg - prefer other conditions	2	4	-2
neg - did not notice a warning	9	**13**	-4
neg - may become / is annoying	3	4	-1
neg - have warning appear sooner	4	4	0
neg - voice is too calm	0	3	-3
neg - change length (time) of warning	1	0	1
neg - barely noticed haptic warning	0	4	-4
pos - Good Visual Icon	2	2	0
pos - Liked length of warning	1	1	0
pos - Change Nothing	**25**	**13**	12
pos - Could be used	0	2	-2
pos - Sound is nice	1	0	1
pos - Best or Better Condition	4	4	0
pos - Combination more effective	1	0	1
pos - sound conveys urgency	3	0	3
pos - not as adverse as before	1	0	1
pos - good warning	1	2	-1
pos - like being visually and audibly warned	0	1	-1
pos - voice is best	0	1	-1
pos - getting used to	0	1	-1

4.2.3 Curve Acceptance Questionnaire

The Curve-Acceptance Questionnaire was administered at the end of data collection (questionnaire can be seen in Appendix G). Its purpose was to discern participants' overall attitude towards the idea of a curve-warning system. All nine rating scales were presented on a Likert-type 5-point scale, followed by two open-ended questions asking the participant to state the most and least-liked conditions presented during the study.

A between-subjects model (the same as the one used for the content analysis) was used to test for significance between age and gender. The summary of significant findings for each rating scale can be seen in Table 4.32. The age main effect was found to be significant for the "bad – good" question, as well as for the "undesirable – desirable" question. All ANOVA summary tables can be seen in Appendix AA. For reference, the average response to each question separated by age and gender can be seen in Table 4.33.

Table 4.32 Significance Summary, Curve Acceptance Questionnaire

Source	usefulness	pleasant	bad	nice	effective	irritating	assiting	undesireable	raising alertness
Between									
Age			**x**					**x**	
Gender									
Age X Gender									
Subject(Age X Gender)									

x = *p* < 0.05 (significant)

Table 4.33 Average Acceptance Questionnaire Ratings

(1)	Useful	Pleasant	Bad	Nice	Effective	Irritating	Assisting	Undesirable	Raising Alertness
Younger Male	1.5	**2.7**	4.0	2.3	2.0	3.2	**2.0**	3.7	1.5
Younger Female	**2.3**	**2.7**	3.3	**3.2**	**2.2**	3.3	**2.0**	3.3	**1.7**
Older Male	1.3	2.0	**4.8**	2.0	1.7	**4.2**	1.3	4.3	1.5
Older Female	1.3	2.0	4.7	2.3	1.8	4.0	1.7	**4.7**	1.5
(5)	Useless	Unpleasant	Good	Annoying	Superfluous	Likeable	Worthless	Desirable	Sleep-Inducing

The third question asked participants to rate their overall "judgments of the curve-warning system" on a scale from 1 (bad) to 5 (good). With an average rating of 4.75, the older participants overwhelmingly had good judgments about the curve-warning system (Figure 4.64). All of the older participants gave this question a rating of 4 or 5. For the younger participants, however, feelings were somewhat more mixed, but they still leaned towards the positive side. Their overall average of 3.7 is still above the "neutral" (3) ranking, but their answers were interspersed with a couple of "2" ratings.

The eighth question asked participants to rate their overall "judgments of the curve-warning system" on a scale from 1 (undesirable) to 5 (desirable). The results for this question (Figure 4.65) are almost a mirror image of the "bad-good" question. Aside from one "3" rating, all of the older participants gave this question a 4 or a 5 rating, resulting in an average of 4.5. As for the younger participants, 50% gave this question a 3 (neutral) rating, and with an average of 3.5, indicating that some uncertainty still exists regarding whether or not they would want this type of feature to be available to them.

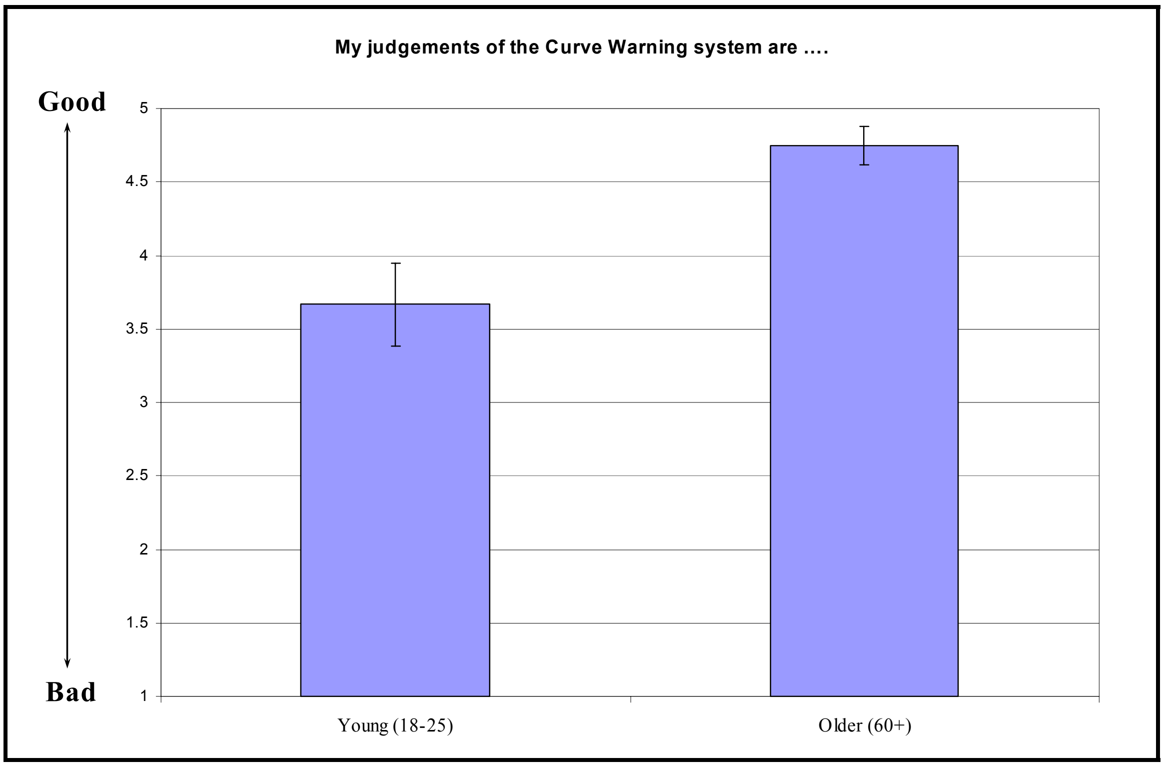

Figure 4.64 Bad – Good Ratings Comparison of Age main effect

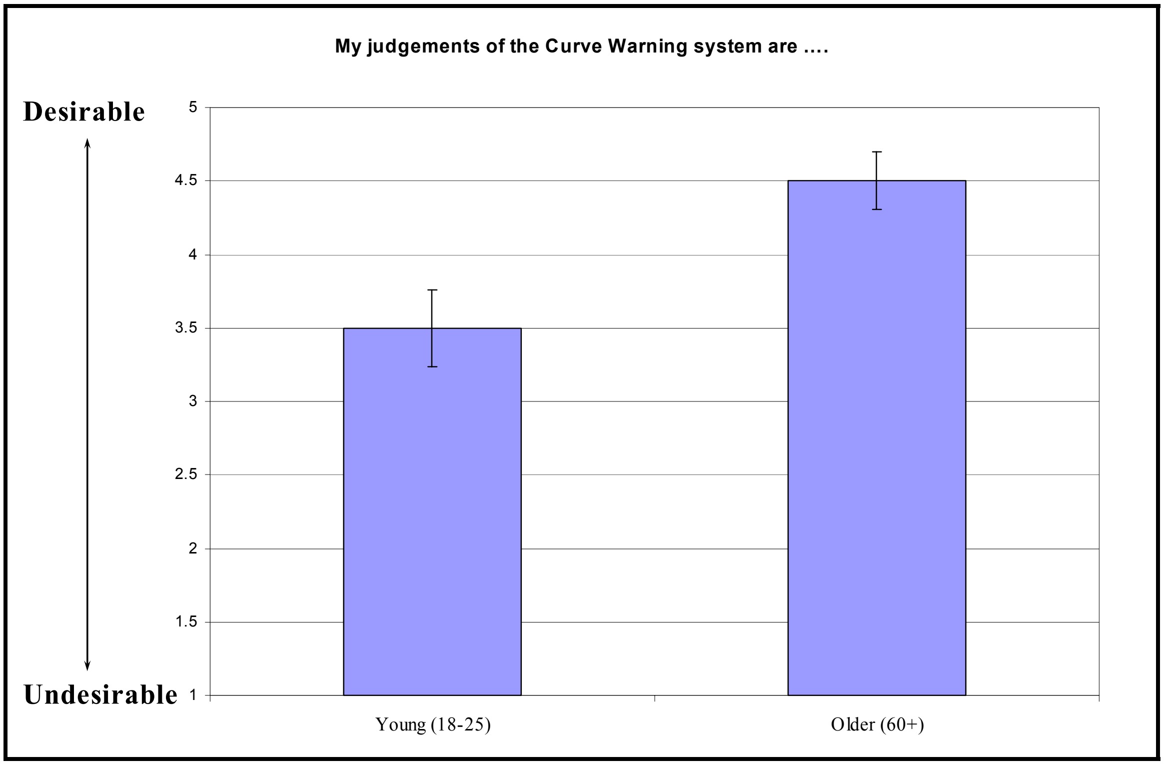

Figure 4.65 Undesirable – Desirable Ratings Comparison of Age main effect

The final two questions included in the Curve-Acceptance Questionnaire were as follows:

"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?"

The comments were subjectively analyzed. Some of the comments referred to specific conditions, while most referred to specific modalities or warnings within those modalities. All participant comments separated by question can be seen in Appendix AB. A frequency count was performed to determine which modalities and stimulus conditions received the most "votes" for each of the two questions (Table 4.34). Overall, 50% of the participants mentioned the speech stimulus when answering the "most-liked" question. Half of the participants also mentioned the visual modality, although seven of these participants did not specify between HDD and HUD. Not surprisingly, the auditory icon had the highest number of votes for the "least-liked" question, with two-thirds of the participants mentioning it. The throttle push-back was also mentioned by nine participants as being part of their "least-liked" condition.

Table 4.34 Frequency count of Most liked vs. Least liked

	Most Like	Least Like
Modality		
Icon	0	16
Tone	4	2
Speech	12	1
Auditory (not specific)	1	0
HDD	2	0
HUD	3	4
Either visual (not specific)	7	2
Accel.	1	9
Comb. Of All three modalities (not specific)	1	1
Warning		
None & None & None	0	1
Tone & HDD & None	2	0
Speech & HUD & None	1	0
None & HDD & None	1	0

Chapter 5 : Conclusions

5.1 Study Objectives

An average of 42,000 fatalities occur on America's roads each year as a result of motor-vehicle crashes, 26% of which can be attributed to curves (NHTSA, 2003). The dangers with respect to curves exist, from late notification of the direction and speed, varying methods of determining advisory speeds, and driver unfamiliarity and/or over confidence, to name a few. A curve-warning device, a system that notifies the driver of an upcoming curve and possibly conveys its vehicle-specific advisory speed and even direction, has the potential to drastically reduce the dangers of curve navigation. Based on the growing complexity and potential overload of current and future vehicle technologies, however, it must be remembered that this warning will be one of many warnings presented to the driver. Therefore, it is important that multimodal solutions be examined, incorporating the auditory, visual, and haptic channels. This study was intended to provide recommendations for future research regarding appropriate modalities and respective stimuli for this particular application.

For this study, objective and subjective measurements were collected in a simulator environment to compare conditions comprised of multiple stimuli from the auditory (icon, tone, and speech), visual (HDD and HUD), and haptic (throttle push-back) modalities. Based on the findings, recommendations will be made concerning the optimal stimuli within each modality for a curve-warning device, as well as regarding optimal combinations of the three modalities and their respective stimuli. The discussion is organized as follows:

1) Summary
    a. Dependent Variables
    b. Auditory Modality
    c. Visual Modality
    d. Haptic Modality
    e. Age
    f. Gender
    g. Stimulus Condition

2) Study Limitations
    a. Simulator
    b. Questionnaires
3) Design Recommendations
4) Future Research
5) Curve Warning – Final Thought

5.2 Summary

5.2.1 Dependent Variables

Although reaction times are important when evaluating different warning stimuli, for this particular study, it can be argued that the more important variable is the participant's speed at the entrance of the curve. Beyond having a quick reaction time, the user must also be able to understand the message the stimulus is conveying and respond accordingly. The purpose of a curve warning, at least in this study, is to notify the driver of the upcoming curve, as well as to convey the appropriate speed and, potentially, the direction as well, depending on how many modalities are used. Therefore, for the auditory modality the speech stimulus has an obvious advantage since the advisory speed is stated. Additionally, it seems that the results for the apex and exit speeds are a reflection of the curve-entrance speeds, thus reinforcing the importance of the speed at the entrance of the curve over the other positions. Overall, the analysis concerning the speed variance for the portion of the road between the stimulus onset and curve entrance also failed to provide any additional insight to that garnered from the reaction times and entry speeds.

5.2.2 Auditory

It was hypothesized in Chapter 3 of this document that the auditory icon would obtain the quickest reaction times based on the literature, followed by the tone and the speech. The rankings of the auditory stimuli for objective and subjective results can be seen in the following tables (Table 5.1 and 5.2).

Table 5.1 Auditory Stimulus Rankings by Objective Dependent Variables (1=best)

	Rank	Throttle Reaction Time (seconds)	Brake Reaction Time (seconds)	Entry Speed (mph)	Time out of Lane (seconds)	# Deviations (frequency)
Lowest	1	Icon	Icon	Speech	Speech	Speech
↕	2	Speech	Tone	Icon	Tone	Icon
	3	Tone	Speech	Tone	Icon	Tone
Highest	4	None	None	None	None	None

Table 5.2 Auditory Stimulus Rankings by Subjective Dependent Variables from Post Condition Questionnaire (1=best)

	Rank	Urgency	Appropriateness	Want		Rank	Annoyance	Interference
Highest	1	Speech	Speech	Speech	Lowest	1	Speech	Speech
↕	2	Icon	Tone	Tone	↕	2	None	None
	3	Tone	None	None		3	Tone	Tone
Lowest	4	None	Icon	Icon	Highest	4	Icon	Icon

The one favorable aspect of the auditory icon presented in this study was its ability to obtain significantly faster reaction times compared to the tone and the speech. However, this faster reaction was more likely due to its tendency to startle the participant than its effectiveness as a warning. Findings were similar to what was observed in Graham et al. (1995), with the auditory icon resulting in a more severe reaction than necessary due to a higher level of perceived urgency. This faster reaction time did not, however, result in curve-entry speeds closer to the advised 20 mph. What seemed to be effective in alerting the driver to remove their foot from the throttle was not necessarily enough to get them to slow down to the advised speed before reaching the curve entrance.

Subjectively, the auditory icon was the least-liked auditory stimulus, receiving the highest annoyance and interference ratings, as well as the lowest appropriateness and want ratings compared to the speech, tone, and no-auditory conditions. For the tire-screech icon to have such a high annoyance rating during a study in which it was presented only six times during a 1 to 1.5 hour time period does not speak well for its production-based capabilities because a curve warning is something that could be presented frequently due to the high frequency of curves in many driving scenarios. Additionally, 100% of the participants' comments that suggested removing the auditory stimulus from the condition presented (16 total comments) were made during conditions that included the auditory icon. Moreover, the auditory icon was present in conditions for which 81% of the "auditory warning is startling" comments (13 out of 16 total comments) were made. Overall, the subjective responses were overwhelmingly negative with respect to the auditory icon. Based on this fact and the auditory icon's relatively small performance benefits, its inclusion in a curve-warning device is not recommended.

The results suggest that the auditory tone by itself was ineffective, yet it appears that it performed well when paired with other modalities. However, subjective measurements placed the tone at neither end of the positive-to-negative spectrum, unlike the speech and auditory icons, respectively. Conditions that included the auditory tone resulted in the second lowest amount of time spent out of the lane, as well as the second quickest BRTs. Subjectively, the tone was not rated nearly as unfavorably as the auditory icon. Conditions that included the tone were given appropriateness and want ratings second to those that included the speech stimulus. Alternatively, conditions that included the tone were rated as being more annoying and causing more interference than conditions with no auditory stimulus. This finding contradicts previous research showing that the tone might be the more appropriate option for a warning device when compared to speech based on ratings of annoyance (Lerner et al., 1996). Approximately 50% (17 out of 35 total comments) of the comments suggesting that more information was needed were made following conditions that included the auditory tone. Some of these comments suggested that the stimulus condition should include sharpness of the upcoming curve, time allowance to decrease speed, and/or the distance to the curve. Furthermore, 32% (11 out of 34 total comments) of the comments made suggesting that the auditory warning should be changed to a different auditory stimulus were made for conditions that included the auditory tone.

Speech seemed to be the most appropriate auditory stimulus used in this study. Conditions that included the speech resulted in curve-entry speeds closest to the advised 20 mph, as well as the least amount of time spent out of the lane and the fewest number of lane deviations. Compared to the other auditory stimuli, the speech was rated the highest for urgency, appropriateness, and want (i.e., If my car was equipped with a curve warning device I would want this type of warning to be presented), as well as the lowest for annoyance and interference. With respect to positive comments, 58% (22 out of 38 total comments) of the comments suggesting that nothing should be changed to the condition presented were made for conditions that included the speech warning.

5.2.3 Visual

As explained in Chapter 3 of this document, the contrast measurement for the HDD was roughly twice that of the HUD due to its solid dark-colored background. It was hypothesized, however, that the HUD would outperform the HDD but that both would require an auditory or haptic element to be effective. Although the contrast for the HUD was greater than the minimum recommended guidelines, its transparent nature and unorthodox (unfamiliar) positioning resulted in a number of participants missing the icon (especially when it was presented alone). Some participants believed they saw it for the first time after it had already been presented in a previous condition. The objective and subjective rankings of the three levels of the visual modality can be seen in Tables 5.3 and 5.4.

Table 5.3 Visual Stimulus Rankings by Objective Dependent Variables (1=best)

	Rank	Throttle Reaction Time (seconds)	Brake Reaction Time (seconds)	Entry Speed (mph)	Time out of Lane (seconds)	# Deviations (frequency)
Lowest	1	HDD	HDD	HDD	HDD	HUD
↕	2	HUD	HUD	HUD	None	HDD
Highest	3	None	None	None	HUD	None

Table 5.4 Visual Stimulus Rankings by Subjective Dependent Variables from Post Condition Questionnaire (1=best)

	Rank	Urgency	Appropriateness	Want			Rank	Annoyance	Interference
Highest	1	HDD	HDD	HDD		Lowest	1	HDD	None
↕	2	HUD	HUD	HUD		↕	2	None	HDD
Lowest	3	None	None	None		Highest	3	HUD	HUD

Results regarding compliance showed that there was little difference between the HUD and HDD, even though the HUD was more difficult to see and was shown to have significantly slower reaction times. Subjectively, it appears that participants were sure they wanted a visual icon, but its location was not an important issue.

Two out of the seven crashes occurred during the HUD-only condition. The average curve-entry speed between the two crashes was greater than 53 mph, and one of the participants commented that no warning was presented. However, one of the crashes also occurred during the HDD-only condition, with a curve-entry speed that was also greater than 53 mph. This participant also commented that no warning was detected.

These findings further emphasize the need for an additional modality to be presented with the visual element.

Subjectively, 25% (7 out of 28 total comments) of the comments suggesting that the location of the visual icon should be changed were made for HDD conditions, compared to 75% of those that included the HUD. However, 63% (12 out of 19 total comments) of the comments recommending that the visual flashing be removed were made for HDD conditions, compared to only 37% for those that included the HUD. The HDD was also ranked higher in urgency, appropriateness, and want, as well as lower for annoyance and interference. Interestingly, unlike the auditory stimuli, no comments were ever made suggesting that the visual icon should be removed.

5.2.4 Haptic

Similar to the HUD icon, the throttle push-back was another stimulus that went unperceived by a number of participants. There were 7 participants (1 young male, 2 older males, and 4 older females) who commented that no warning was presented for the throttle-push-back-only condition (presented by itself). Based on the video of the condition, however, the push-back is obvious in that the force is visible when acting against the participant's foot, yet multiple participants disregarded it, and a few participants even applied greater pressure to the throttle until the three second presentation window had closed, resulting in a small spike in acceleration *after* the warning. Approximately 79% (19 out of 24) of the participants had a TRT greater than 3.0 seconds at least once during a condition where the throttle push-back was presented. In the end, 17% of the conditions with a throttle push-back were unable to obtain a TRT until after the presentation of the throttle push-back. However, the inclusion of the haptic stimulus did result in significantly faster throttle and brake reaction times when compared to conditions without a haptic element (Table 5.5).

Table 5.5 Haptic Stimulus Comparison of Objective Dependent Variables (1=best)

	Rank	Throttle Reaction Time (seconds)	Brake Reaction Time (seconds)	Entry Speed (mph)	Time out of Lane (seconds)	# Deviations (frequency)
Lowest	1	Throttle	Throttle	Throttle	Throttle	Throttle
Highest	2	None	None	None	None	None

Some of the results also show that the addition of the throttle push-back helped users comply to the advised speed, for those conditions in which it was noticed. This finding is most likely due to a participant's removing his/her foot entirely from the throttle pedal upon identifying the warning, which was shown earlier to be significant (throttle and brake reaction times). However, 100% (8 total comments) of the comments suggesting that the condition was excessive or overloading concerned conditions that included the throttle push-back. For conditions where a stimulus was presented, approximately 70 % (9 out of 13 total comments) of the comments suggesting that no warning was detected were made for conditions that included the throttle push-back. A possible explanation for this was thought to be shoe type (e.g., thickness of sole), but upon viewing the video these participants were found to be wearing sandals, loafers, and one was even barefoot. Conditions that included the throttle push-back were also rated as more annoying and as causing more interference than conditions without, and they were found to be less appropriate and less wanted. Interestingly, 58% of the comments suggesting that nothing should be changed were made with regard to conditions that included the haptic stimulus. These subjective findings contradict the overwhelmingly positive feelings toward the same throttle push-back used in the Bloomfield et al. (1998) study, although it should be noted that it was used as a collision-warning device as opposed to the curve-warning application examined in this study.

Table 5.6 Haptic Stimulus Comparison of Subjective Dependent Variables from Post Condition Questionnaire (1=best)

	Rank	Urgency	Appropriateness	Want			Rank	Annoyance	Interference
Highest	1	Throttle	None	None		**Lowest**	1	None	None
Lowest	2	None	Throttle	Throttle		**Highest**	2	Throttle	Throttle

Finally, three of the seven crashes occurred during the haptic-only condition. There was no BRT for the three crashes, and the average curve-entry speed was greater than 51 mph. Overall, the objective and subjective results for the throttle push-back used in this study were mixed, which could mean that the throttle push-back used may be inappropriate for this scenario, but not necessarily that the haptic modality is inappropriate in general. It is recommended that future research look at other aspects of the haptic modality for use in a curve-warning device.

5.2.5 Age

There were a few notable differences between the two age groups used in this study. From the significance of the Age X Condition interaction for the TRT and BRT, it was discovered that, while not by much, the younger participants acted more quickly in removing their foot from the throttle (by 0.14 seconds) than did older participants, but they also waited longer than older participants to apply the brakes (by 0.41 seconds). Younger participants were also shown to have significantly higher curve speeds (entrance, apex, and exit) compared to the older participants, with differences ranging up to 14 mph.

Subjectively, older participants seemed more accepting of the idea of a curve-warning device, and they were also less likely than younger participants to give high annoyance and interference ratings. This acceptance carried over to their answers for the open-ended question in the Post-Condition Questionnaire, during which older participants were twice as likely to provide positive feedback, including being more than three times more likely than younger participants to suggest that nothing should be changed to the warning just presented. Finally, older participants were found to be significantly more positive on the Curve Acceptance Questionnaire, specifically for the "bad-good" and "undesirable-desirable" questions. This subjective difference could be linked to literature suggesting that younger drivers perceive the act of driving as being less risky than do their older counterparts (Finn and Bragg, 1986), which could explain why older participants are more accepting of a device that is intended to reduce the risk associated with driving. Younger drivers may not see the advantage of a curve-warning device as readily as older drivers; therefore, younger drivers may be more inclined to view such a device as annoying and interference causing.

5.2.6 Gender

Differences between genders were less apparent, especially for the performance data. Only the Gender X Condition interaction was found to be significant for participants' speed at the curve apex and exit, with significantly higher speeds obtained by the male participants. Subjectively, no significance was found for gender with respect to the closed-ended questions on the Post-Condition Questionnaire, nor for the Curve

Acceptance Questionnaire. However, the gender main effect was significant for the number of negative comments made for the open-ended question on the Post-Condition Questionnaire. On this question, males (176 total) made significantly more negative comments than females (141 total).

Female participants were responsible for 94% (15 out of 16 total comments) of the comments suggesting that the auditory warning presented was startling. Similarly, approximately 90% (17 out of 19 total comments) of the comments made suggesting that the flashing in the visual icon should be removed were made by female participants. Alternatively, males made approximately 80% (27 out of 34 total comments) of the comments suggesting that the auditory warning presented should be changed to one of the other auditory stimuli. It should be pointed out, however, that the comments suggesting that the auditory warning presented was startling and the comments suggesting that the auditory warning presented should be changed could have some overlap. In other words, the females may have been more willing to verbalize their startled reaction as opposed to males, who may have instead suggested only for its removal.

5.2.7 Stimulus Condition

In contrast to expectations of the optimal stimulus combination (i.e., Tone and HUD and Throttle, see section 3.10), it appears that the optimal stimulus condition presented in this study was the Speech and HDD condition. The top-five rankings of the objective and subjective dependent variables can be seen in Tables 5.7 and 5.8.

Table 5.7 Stimulus Condition Rankings (Top 5) for Objective Dependent Variables (1=best) (Note that these rankings do not denote significance)

	Rank	Throttle Reaction Time (seconds)	Brake Reaction Time (seconds)	Entry Speed (mph)	Time out of Lane (seconds)	# Deviations (frequency)
Lowest	1	Icon & HUD & Throttle	Icon & HDD & Throttle	Speech & HDD & Throttle	Speech & Throttle	Speech & HDD
	2	Icon & HDD & Throttle	Icon & HUD & Throttle	Tone & HUD & Throttle	Speech & HDD	Icon & HUD
↕	3	Tone & HDD & Throttle	Icon & HDD	Speech & HUD & Throttle	Speech & HUD & Throttle	Tone & HUD & Throttle
	4	Icon & HDD	Tone & HDD & Throttle	Speech & HDD	Speech	Speech & HUD & Throttle
Highest	5	Icon & HUD	Icon & HUD	Speech & HUD	Tone & Throttle	Speech & Throttle

Table 5.8 Stimulus Condition Rankings (Top 5) for Post Condition Questionnaire (1=best)
(Note that these rankings do not denote significance)

	Rank	Urgency	Appropriateness	Want			Rank	Annoyance	Interference
Highest	1	Icon & HDD & Throttle	Speech & HDD	Speech & HDD		Lowest	1	Speech	Speech
	2	Tone & HDD & Throttle	Tone & HDD	Speech			2	HDD	Speech & HDD
↕	3	Icon & HUD & Throttle	Speech & HUD & Throttle	HDD		↕	3	Speech & HDD	Speech & Throttle
	4	Icon & HDD	Tone & HDD & Throttle	Speech & HUD			4	Speech & Throttle	Baseline
Lowest	5	Speech & HDD Speech & HDD & Throttle	Speech & HUD	Speech & HUD & Throttle		Highest	5	Speech & HUD	Speech & HUD

The Speech and HDD resulted in the fourth lowest curve-entry speeds (21.4 mph), the second lowest average total time out of lane (1 second), and the lowest total number of lane deviations (only 11 total deviations for all 24 participants during this condition). Subjectively, this combination was rated as the third least annoying condition and tied for first place for lowest interference, in addition to being rated the most appropriate and most wanted combination.

In order to further clarify the optimal stimulus presented in this study, an equation was developed that applied weighted values to performance measurements and the closed-ended questions from the Post Condition Questionnaire. The respective weights and reasons for inclusion are as follows:

1) Performance measurements:
    a. Brake Reaction Time (BRT) – although it has been argued that the reaction time to the various stimulus conditions did not prove to be the most important objective measure, an appropriate warning should still be able to elicit a reaction equal to or less than the 2.5 seconds allowance incorporated into the warning design for this study. Therefore, all stimulus conditions will be penalized for the amount of average Brake Reaction Time over the 2.5 second allowance that they elicited, by a weight of -0.5.
    b. Curve Entrance Speed (CES) – this measurement was shown to be the most important of the objective measurements, as it demonstrated the conditions ability to convey the appropriate information concerning the upcoming curve. Therefore, all stimulus conditions will be penalized for

the amount of average Curve Entrance Speed over the 20 mph advised speed, by a weight of -2.0.

2) Subjective measurements:
    a. Urgency (U) – as with the BRT, the ability for the stimulus condition to obtain a high urgency rating was not as important as the other subjective measurements, and therefore will receive a weight of only 0.5 applied to the average ratings (1 = strongly disagree; 5 = strongly agree).
    b. Annoyance (An) – this type of warning device has the potential to be heard frequently. It is important that the warning selected have low ratings of annoyance and, therefore, the average annoyance rating for each stimulus will be penalized with a weight of -1.0 (1 = strongly disagree; 5 = strongly agree).
    c. Appropriateness (Ap) – it is important for the user to feel that the stimulus presented is appropriate for a curve-warning device. Therefore, average ratings of appropriateness for each stimulus condition will be rewarded with a weight of 1.5 (1 = strongly disagree; 5 = strongly agree).
    d. Interference (I) – as with the annoyance ratings, this is a type of warning that has the potential to be heard frequently. The average interference ratings for each stimulus condition will also be penalized with a weight of -1.0 (1 = strongly disagree; 5 = strongly agree).
    e. Want (W) – this questions was likely the most important of the subjective measurements, as it allowed the participants to rate conditions based on if they would want the type of stimulus just presented as a curve-warning in their vehicle if it had such a system. Therefore, the average ratings for each stimulus condition will be rewarded with a weight of 2.0 (1 = strongly disagree; 5 = strongly agree).

With the variables and respective weights described above, the final equation is as follows:

$$Total = -0.5(BRT - 2.5) + -2.0(CES - 20) + 0.5(U) + -1.0(An) + 1.5(Ap) + -1.0(I) + 2.0(W)$$

The values for each stimulus condition can be seen in Table 50. This weighted equation further validates the Speech and HDD condition as the optimal out of the 24 conditions tested in this experiment. It is also worth pointing out that all 6 conditions that included the Speech stimulus obtained the highest 6 weighted values.

Table 5.9 Weighted Rankings of Stimulus Conditions

Condition	BRT - 2.5	CES - 20	urg	any	app	inte	want	Total
Speech & HDD	0.50	1.40	4.08	2.17	4.13	1.92	3.63	**8.35**
Speech & HDD & Accel.	0.42	0.88	4.08	2.46	3.71	2.50	3.21	**7.09**
Speech & HUD & Accel.	0.69	1.36	3.92	2.54	3.79	2.42	3.33	**6.29**
Speech & HUD	0.81	1.68	3.88	2.33	3.75	2.29	3.42	**6.00**
Speech & Accel.	0.78	1.78	3.79	2.25	3.67	2.13	3.25	**5.57**
Speech	1.12	2.41	3.71	1.88	3.67	1.92	3.46	**5.10**
Tone & HDD	0.07	2.49	3.92	2.42	3.88	2.46	3.17	**4.21**
Tone & HUD & Accel.	0.20	0.91	3.96	3.13	3.13	2.96	2.46	**3.58**
Tone & HDD & Accel.	-0.25	3.07	4.17	2.67	3.75	2.58	2.88	**2.20**
HDD & Accel.	0.56	1.86	3.21	2.63	3.13	2.79	2.54	**1.95**
HDD	0.58	4.14	3.22	2.09	3.65	2.30	3.43	**0.99**
Icon & HDD	-0.32	2.86	4.08	3.38	2.71	2.88	2.21	**-1.29**
Tone & HUD	0.43	4.14	3.96	2.88	3.33	2.50	2.79	**-1.30**
Icon & HDD & Accel.	-0.58	2.69	4.21	3.71	2.67	3.13	1.92	**-1.98**
Icon & HUD & Accel.	-0.43	2.61	4.09	3.78	2.48	3.30	1.74	**-2.86**
Icon & HUD	-0.14	2.99	3.70	3.65	2.26	3.48	1.74	**-4.33**
HUD	0.95	5.87	3.18	2.55	3.05	2.55	2.91	**-5.32**
Tone	1.44	6.91	3.42	2.79	2.58	2.33	2.38	**-9.34**
Icon	0.93	4.86	3.63	3.88	1.83	3.13	1.63	**-9.37**
Icon & Accel.	0.56	4.55	3.42	3.83	1.75	3.46	1.46	**-9.42**
HUD & Accel.	1.12	7.75	3.33	2.96	2.88	2.92	2.54	**-10.87**
Tone & Accel.	1.73	8.29	3.42	3.04	2.63	2.88	1.96	**-13.80**
Accel.	2.52	11.03	2.14	2.76	2.10	2.48	1.81	**-20.72**
Baseline	3.91	19.30	1.17	2.39	1.22	2.22	1.39	**-39.98**

5.3 Limitations

5.3.1 STI Simulator

As discussed in Chapter 3, issues exist concerning the fidelity of simulators for research purposes, particularly with fixed-base simulators. Overall, the fixed-base STI simulator used in this study was effective, and although strong generalizations should not be made from the performance data, it can be assumed that the results are representative of data that would have been acquired through a naturalistic study. Some limitations do exist, however.

The fixed-base attribute of the simulator failed to provide any realistic forces acting on the body during acceleration, braking, and cornering, the latter two being important aspects of this study. If this study were replicated in a realistic environment, it is expected, based on previous research (Boer et al., 2001), that the average rate of deceleration would be significantly less than that collected using the simulator. However, as mentioned before, it is expected that the relationships identified in this study between the modalities, age, gender, and conditions are representative of the data that would be collected if this study were run in a naturalistic environment.

The seating position was modeled closely to an actual car, although modifications were necessary due to the height and depth of the table on which the simulator's steering wheel and monitors were positioned. The relationship between the pedal and seat positioning was similar to that found in an actual vehicle, but the lack of horizontal steering wheel adjustments caused participants to either be farther away from the steering wheel than during normal driving, or to be closer to the pedals than during normal driving (to obtain the normal driver and steering wheel distance). Comments were made by participants during data collection suggesting discomfort as a result of the seating position. The diameter of the steering wheel was also smaller than normal, although none of the participants stated it to be a problem. However, the "soft" steering exhibited by the simulator did cause problems for some participants in the very beginning, with two older female participants crashing before the first turn in the training loop. However, all participants seemed to be well-adjusted by the end of the 5-minute training loop.

5.3.2 Questionnaires

One issue with the Post-Condition Questionnaire was the lack of a way to answer the questions differently if a warning was not presented or if one was not noticed. Otherwise, it is difficult to make sense of the fact that five conditions had lower warning annoyance ratings than when no warning was presented. It appears that the high annoyance rating was more due to the fact that a warning was expected but not presented. In other words, the desire for a warning presentation was not fulfilled during the baseline condition, resulting in feelings of annoyance, also possibly due to understimulation in an environment that may have been perceived as cumbersome by some participants. This was the only questionnaire (of the three) that was developed specifically for this study, and the exclusion of this element became apparent only after data collection was underway. Otherwise, the questionnaires were very effective at garnering desired responses.

5.4 Design Recommendations

Due to the hazards they pose, the need for a warning device that notifies drivers of an upcoming curve is apparent. This study was intended to provide a starting point for the design of appropriate modalities and respective stimuli that should be included in such a device. The characteristics of a curve-warning device differ from those of a collision-warning device in that a curve warning is an advanced warning that is meant to advise -- not necessarily to indicate immediate action. Therefore, stimuli that have been deemed inappropriate for collision warnings, such as speech (due to time constraints), may be applicable in a scenario that notifies the driver of the existence of a curve. The potential is also there to notify the driver of the curve's advised speed and direction, as was done in this study using multiple modalities.

The following recommendations are based on the objective and subjective findings of this study.

- The speech stimulus resulted in the lowest average curve-entry speed, as well as the least amount of time spent out of the lane and the lowest number of lane deviations. Subjectively, it was the most preferred of the auditory stimuli and should be strongly considered for a curve-warning device.
- Conditions that included the HDD resulted in faster reaction times, lower curve-entry speeds, and less time spent out of the lane compared to the HUD. Subjectively, the HDD was preferred over the HUD in all categories and should also be considered for a curve-warning device.
- The throttle push-back, although effective with respect to performance measurements when paired with other modalities, was not well received subjectively. It is recommended that due to its effectiveness, the haptic modality

should still be considered applicable for a curve-warning device; however, other haptic presentations may need to be considered instead of the throttle push-back.

- Modality combinations performed better than modalities presented by themselves for all performance measurements, particularly the combinations between the auditory and visual modalities and combinations of all three modalities. The subjective results showed added preference for conditions that combined the auditory and visual modalities. More than one modality should be considered when designing a curve-warning device.
- The Speech and HDD combination resulted in one of the slowest curve-entrance speeds and the least number of lane deviations and amount of time spent out of the lane. Subjectively, it was rated as the most appropriate and most wanted. This combination should be strongly considered as a potential stimulus for a curve-warning device.

5.5 Future Research

Although this study addressed a specific gap in the literature, the need for more research on this topic exists. Primarily, the methods (adapted) and stimuli conditions used in this study should be tested in a naturalistic environment. This would not only result in real-world performance data, but would also add to the literature on simulator fidelity if the results were compared with those presented in this document. More importantly, participants should be studied while they go about their normal daily activities, allowing for performance and subjective data to be collected in real-world driving scenarios (i.e., with vehicle passengers, radio turned on, cell phones, etc.). The stimuli used in this study were also narrowed down, and there are other potentially appropriate auditory, visual, and haptic stimuli that should be considered for this type of device. More subjective research is also needed, especially concerning annoyance ratings of a curve-warning device in a naturalistic environment. This applies especially to the phenomenon exhibited in this study of higher annoyance ratings when no warning was presented compared to a number of warning conditions. It is important to determine whether this phenomenon was or was not a result of understimulation or boredom created by the simulator environment.

5.6 Curve Warning – Final Thought

Overall, participants were accepting towards the idea of a curve-warning device. Such a device, if designed properly, could potentially be very effective in reducing the number of crashes occurring on curves. The results obtained in this study are intended to be used as recommendations for future curve-warning research.

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APPENDICES

Appendix A: Deceleration Rate Calculations

$$d = 1.47Vt + 1.075\frac{V^2}{a}$$

Where: d = stopping (in this case, slowing down) distance = 225 ft + 250 ft (sign legibility)
t = Brake Response Time = 2.5s
V = design speed = 55 mph to 20 mph
a = deceleration rate, ft/s^2

$$475 = 1.47(55 * 2.5) + 1.075\frac{(55-20)^2}{a}$$

$$475 = 202.125 + \frac{1316.88}{a}$$

$$272.88 = \frac{1316.88}{a}$$

$$272.88a = 1316.88$$

$$a = \underline{\underline{4.83\,ft/s^2}}$$

Appendix B: Curve Speed Warning System Guidelines (CSWS)

(* denotes guidelines most applicable to this study)

[C-1] A CSWS should be able to accurately determine the distance to the sharpest part of the upcoming curve. It is recommended that this distance be estimated to an accuracy of ± 5m.

[C-2] A CSWS should be able to detect and estimate the distance to an upcoming curve at least 200m prior to the curve's apex.*

[C-3] A CSWS should be able to detect when it is unable to determine the vehicle position relative to an upcoming curve. In such a condition, it should make the driver aware of its degraded status through the driver interface.

[C-4] A CSWS should account for the roll stability of the vehicle when determining the safe speed for traversing an upcoming curve. The roll stability of commercial vehicles can change dramatically depending on the load, so in-vehicle load sensors should be incorporated into a CSWS intended for commercial vehicles.

[C-5] A CSWS should measure the vehicle's forward velocity to an accuracy of 4 fps (1.2m/s)**.**

[C-6] A CSWS should measure the vehicle's forward acceleration (or deceleration) to an accuracy of 1 foot per second^2 (0.3m/s^2).

[C-7] A CSWS should be capable of detecting when the vehicle is traveling on a road, as opposed to a parking lot or other unstructured environment.

[C-8] When traveling in an unstructured environment, the CSWS should suppress warnings to avoid nuisance alarms.

[C-9] A CSWS should be able to detect the presence of cross streets, forks in the road and exit ramps at least 200m ahead.

[C-10] A CSWS should operate effectively on roads with a radius of curvatures as low as 200ft (60m).

[C-11] A CSWS should operate effectively on roads with a maximum superelevation of 12 percent.

[C-12] A CSWS should determine the curvature of the upcoming roadway segment to an accuracy of 10 percent of the actual curvature. The determination could be made by direct measurement, a roadside transponder or a reliable map database.

Appendix B: Curve Speed Warning System Guidelines

[C-13] A CSWS should determine the superelevation of the upcoming roadway segment to an accuracy of 3% (e.g. 0.03ft/ft). The determination could be made by direct measurement, a roadside transponder or a reliable map database.

[C-14] A CSWS should be able to detect when it is unable to determine the geometry of the upcoming road segment. In such a condition, it should make the driver aware of its degraded status through the driver interface.

[C-15] A CSWS should determine the available side friction coefficient on the upcoming road segment to an accuracy of 0.05, to a distance ahead of the vehicle of at least 200m.

[C-16] A CSWS should determine the available longitudinal friction coefficient on the upcoming road segment to an accuracy of 0.05, to a distance of at least 200m ahead of the vehicle.

[C-17] A CSWS should be able to detect when it is unable to determine the condition of the pavement for the upcoming road segment. In such a condition, it should make the driver aware of its degraded status through the driver interface.

[C-18] A CSWS should monitor the vehicle's turn signals to determine the driver's intended path of travel, so it can effectively determine the upcoming road geometry.

[C-19] A sophisticated CSWS may model a particular driver's curve negotiation behavior, such as brake onset time, deceleration rate, tolerance for lateral acceleration, etc. Deviations from this model may be used to determine when the driver is unaware of the severity of an upcoming curve.

[C-20] A CSWS should monitor for brake pedal activation and, if practical, throttle pedal release, as a means of detecting the driver's awareness of the upcoming curve. If one or both of these events is detected, the CSWS should delay triggering a curve speed warning for up to 0.5 seconds to determine if the driver's response is aggressive enough to slow the vehicle to a safe speed for the upcoming curve.

[C-21] The maximum safe speed for the approaching segment should be determined from the equation:

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

Where:

R = the minimum curvature of the vehicle's path through the road segment
g = the acceleration due to gravity
f = the planned side friction factor
e = the estimated superelevation of the road segment.

Appendix B: Curve Speed Warning System Guidelines

The values for *R*, *e*, and *f* may be measured directly by the vehicle, retrieved from a reliable database, or acquired from the infrastructure, subject to the accuracy constraints imposed by other specifications.*

[C-22] A CSWS should adjust the maximum safe speed according to vehicle-specific parameters such as rollover susceptibility, roll stiffness, mass distribution, and tire condition**.**

[C-23] The combined errors in all the above measurements should be such that the CSWS has a TBD% confidence that the actual maximum safe speed is equal to or less than the estimated maximum safe speed for the upcoming road segment.

[C-24] A CSWS should attempt to maximize detection of crash hazard due to excessive speed for an upcoming curve, while minimizing false and nuisance alarms.

[C-25] A CSWS should compute the danger of a road departure crash by determining how much the vehicle must decelerate from its current speed to reach the maximum acceptable speed for negotiating the upcoming curve before actually reaching the curve. A warning should be triggered if the deceleration required exceeds a threshold.

[C-26] The maximum acceptable speed for negotiating a curve should be set to at most 90% of the maximum safe speed. The driver may be given the option to adjust the maximum acceptable speed to be less than 90% of the maximum safe speed to give an earlier warning if desired.*

[C-27] A CSWS should use the following equation to determine the deceleration required to slow the vehicle to the maximum acceptable speed at any point prior to a curve:

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

Where:

- a = the required deceleration
- V = the vehicle's current speed
- V_c = the maximum acceptable speed for negotiating the curve
- d = the distance between the current vehicle position and apex of the curve
- t_r = the estimated reaction time of the driver *

[C-28] A CSWS should assume a driver reaction time of no less than 1.5 seconds.*

[C-29] A CSWS should trigger a warning if the longitudinal deceleration required to slow the vehicle to the maximum acceptable speed prior to the curve excess 50% of the estimated deceleration limit of the vehicle in the current conditions.

Appendix B: Curve Speed Warning System Guidelines

[C-30] The recommended nominal longitudinal deceleration threshold for a CSWS is 0.15g (1.5m/s^2). Either automatic or manual adjustment of the longitudinal deceleration threshold should be included to help minimize nuisance alarms. But in no case should the longitudinal deceleration threshold exceed 50% of the estimated maximum deceleration achievable by the vehicle in the current conditions.

[C-31] The system should provide one or more signals to alert the driver to the crash hazard. To the extent feasible, the signal onset should be such that the driver has sufficient time to become aware of the alert and execute an appropriate crash avoidance maneuver.

[C-32] The system may signal the driver through visual, audible, or haptic means. Due to the importance of visual attention in highway safety, the visual demand on the driver away from the driving scene should be minimized.*

[C-33] To the extent possible, the signals should convey the urgency of the danger. Urgency may be conveyed through the choice of modality (e.g. visual for low urgency, audible or haptic for higher urgency) or through the characteristics of the signal itself (e.g. louder or higher pitch audible tones for higher urgency). If sufficient time is available, several signals of increasing urgency may be provided to the driver.*

[C-34] The signal should be easily interpretable, and distinct enough so as not to be confused with other in-cab signals. If graded urgency signals are provided, the signal for an imminent crash should be distinct from other warning signals.*

[C-35] The signal should be designed such that they are not masked by other signals or stimuli normally present in the cab. This may necessitate suppression of other in-cab distractions (e.g. radio) during countermeasure signaling.*

[C-36] The signal should not be so intense or complex as to overload the driver's sensing and processing capabilities, or startle the driver into an inappropriate response.*

[C-37] The countermeasure signal intensity may be adjustable by the driver. However if such an adjustment is provided, there should be a minimum signal intensity, below which it cannot be adjusted. This minimum intensity level will depend on the modality and other characteristics of the signal, but will be no lower than the intensity detectable by 95 percent of the population under typical in-cab conditions. Feedback on the results of driver adjustment of signal intensity should be provided to the driver during the adjustment process.*

[C-38] When practical, the CSWS signal should in some way indicate the appropriate driver response, as long as this information can be conveyed without reducing the signal's interpretability or increasing the driver's confusion.*

Appendix B: Curve Speed Warning System Guidelines

[C-39] When practical, a CSWS should provide for adjustment of the warning threshold to cope with variations in driver behavior and vehicle characteristics. These adjustments may be made manually by the driver, or automatically by the CSWS. Manual adjustment of the warning threshold should be accompanied by feedback to the driver as to the current setting.

[C-40] Manual adjustment of CSWS operation should not result in a significant distraction of driver attention from the driving task. Any manual adjustments should be easy to make and understand. Complex interaction with the system should be reserved for times when the vehicle is stopped.

[C-41] The allowable range of warning threshold adjustment should be limited to avoid unintentional compromising of system effectiveness. If adjustable, the maximum allowable speed for negotiating a curve should be no more than 90% of the estimated maximum safe speed. If adjustable, the estimate of deceleration prior to the curve should be no more than 50% of the estimated maximum deceleration achievable by the vehicle in the current circumstances.*

[C-42] A CSWS should not trigger a warning less than 1.5-2.0 seconds prior to the apex of a curve to avoid distracting the driver with warnings that are too late to prevent or significantly mitigate the severity of a crash.

[C-43] A CSWS should be equipped with a clearly marked on/off switch, to allow the driver to disable warnings.*

[C-44] A CSWS should power-on with application of ignition power if the on/off switch is in the on position.

[C-45] A CSWS should be capable of providing status information to the driver under the following conditions:

- The system fails its power-on self test
- The system is not working due to component failure or other cause during operation
- The system detects conditions having rendered it ineffective (e.g., loosing GPS lock, or not having a digital map of the upcoming road segment).

[C-46] A CSWS should provide a continuous visual indication to the driver that the system is on and operating properly.

[C-47] As a supplement the continuous visual status indicator, a CSWS should employ an audible or haptic signal to indicate system status transitions, as long as the signal does not distract or disturb the driver.

[C-48] If the system goes off-line for one of the above reasons, all warning displays should remain inactive.

[C-49] When off-line due to a temporary condition (e.g. loosing GPS lock), a CSWS should continuously monitor for disappearance of the condition preventing effective operation. If the condition disappears and proper operation is again possible, a CSWS should automatically transition back to the enabled state, without requiring explicit input from the driver. This transition should be accompanied by an audible or haptic signal, as long as the signal does not distract or disturb the driver.

[C-50] Detailed system design features shall incorporate human factors design guidelines and principles as contained in COMSIS, MIL-STD-1472D, and other human factors documents as appropriate.

[C-51] User orientation to the system should be provided via documentation, video, demonstration or hands-on training.

[C-52] When practical, CSWS functions and/or sensing results should be integrated with other services to reduce costs, improve overall performance and reduce driver confusion.

Appendix C: Auditory Sound Measurements

Table C.1 Conference Room Sound Measurements

1/3 OB (Hz)	Room Noise (dB)	Masked Threshold (dB)	Masked Threshold + 13dB	1KHz tone (dB) [Vol 6]	2KHz tone (dB) [Vol 3]	3KHz tone (dB) [Vol 1.5]	4KHz tone (dB) [Vol 1.5]
200	51.1	51.1		48.1	50.9	49.1	50.1
250	53.3	53.3		51.5	52.5	52.7	52.4
315	49	50.8	**63.8**	46.7	46.4	45.9	48.5
400	39.6	46.5	**59.5**	41.8	42.6	39.6	41.7
500	37.5	37.5	**50.5**	38.9	38.7	39.2	39.2
630	38.9	38.9	**51.9**	39.4	39.1	37.9	38.9
800	36.3	36.4	**49.4**	38.4	38	38.6	38.5
1000	34.5	34.5	**47.5**	**53.6**	37.4	37.1	37.5
1250	31.2	32	**45**	32.1	33.6	32.2	34.1
1600	28	28.7	**41.7**	30.3	32.4	30.4	33.4
2000	28.7	28.7	**41.7**	28.6	**47.5**	28.5	30.5
2500	26.3	26.3	**39.3**	28.3	28.9	28.3	39.8
3150	26	26	**39**	28	30.8	**45.6**	32.6
4000	25.3	25.3	**38.3**	26.1	33.7	26.5	**41.4**
5000	24.5	24.5		25.6	27.8	24.8	28.1

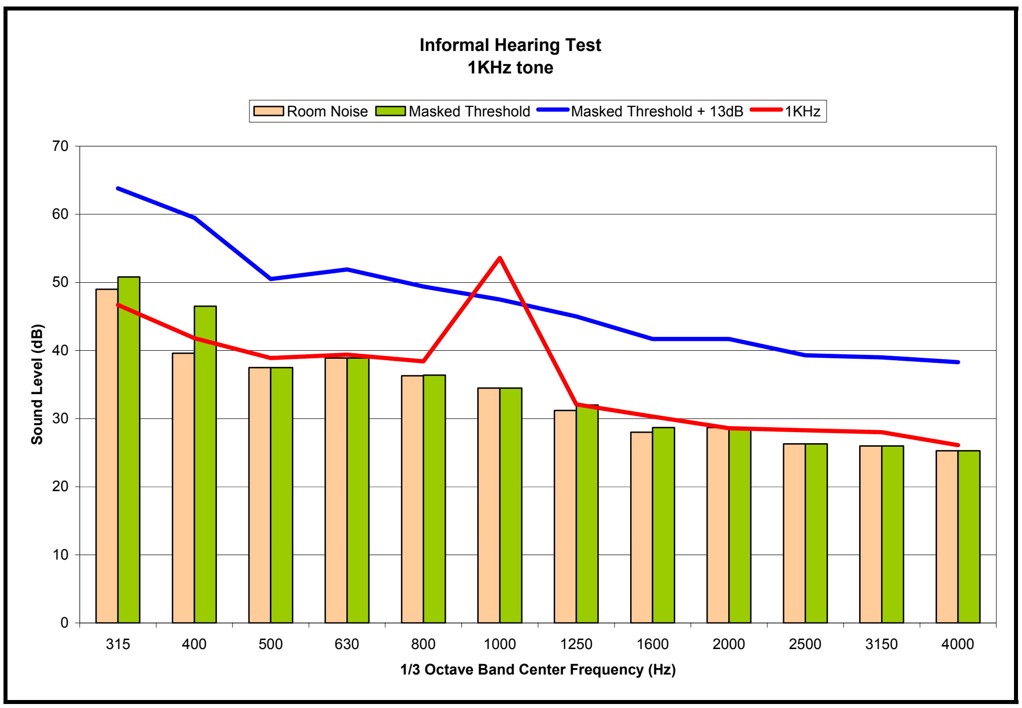


Figure C.1 1KHz tone sound measurements

Appendix C: Auditory Sound Measurements

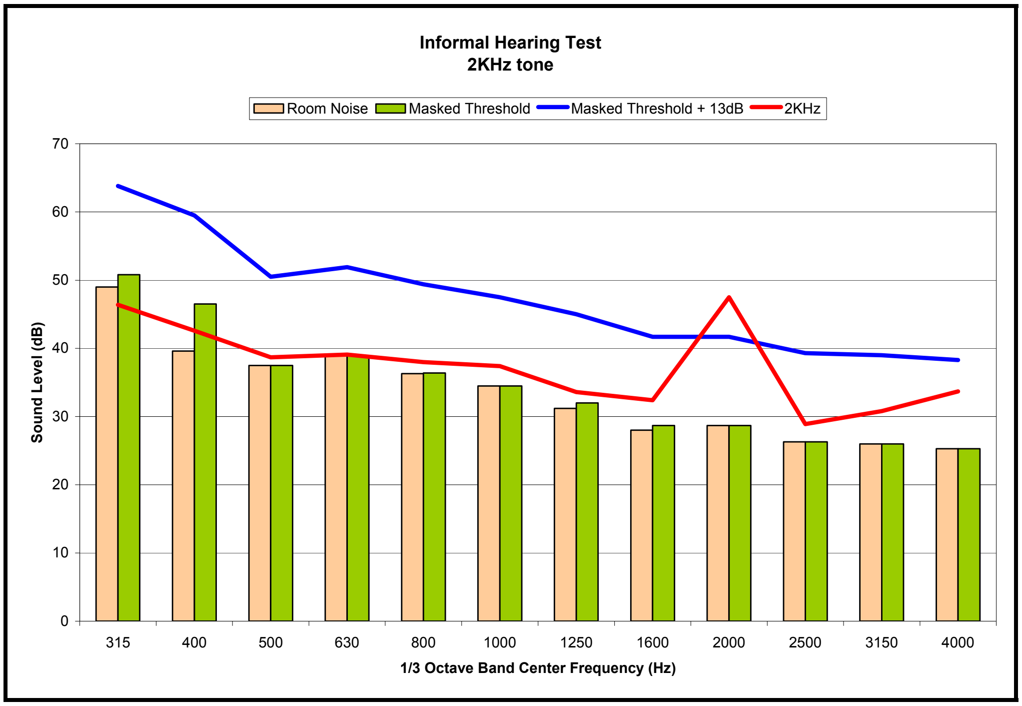


Figure C.2 2KHz tone sound measurements

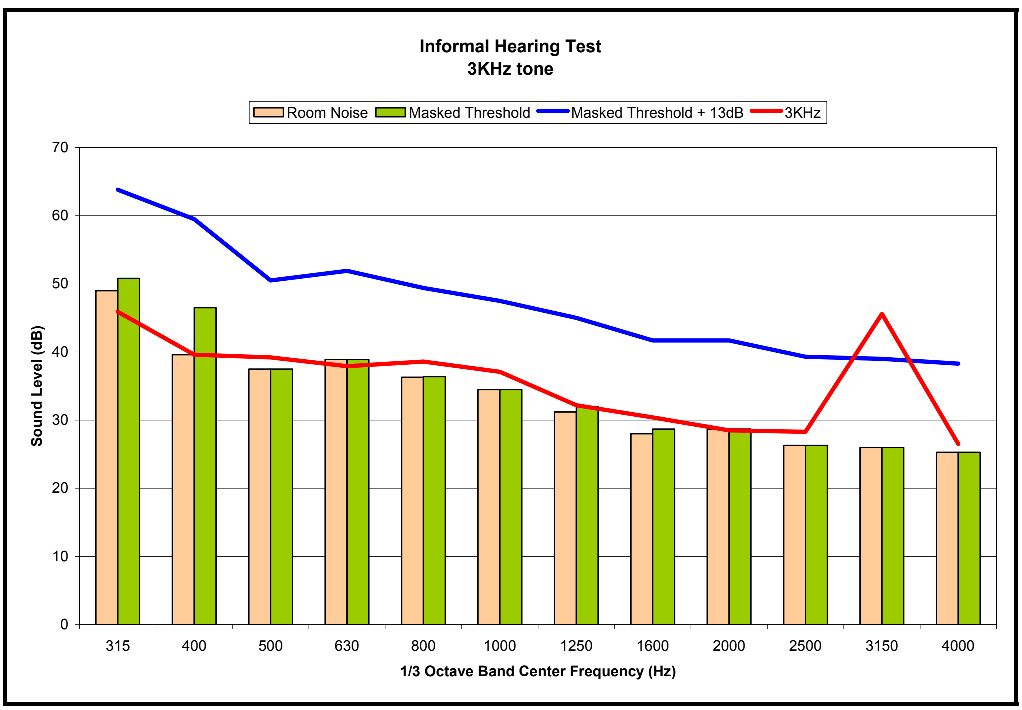


Figure C.3 3KHz tone sound measurements

Appendix C: Auditory Sound Measurements

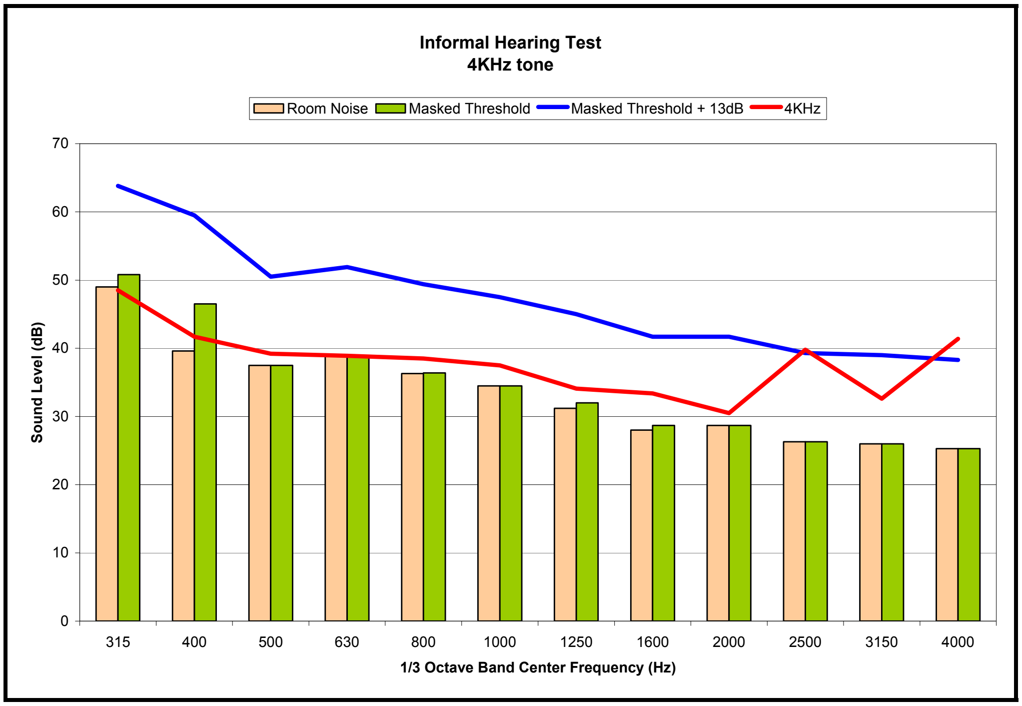


Figure C.4 4KHz tone sound measurements

Table C.2 Simulator Sound Measurements

1/3 OB (Hz)	Room Noise w/ STI @ 55mph (dB)	Masked Threshold (dB)	Masked Threshold + 13dB	Auditory Icon (dB) [Vol 4]	Auditory Tone (dB) [Vol 2]	Speech (dB) [Vol 3]
200	46.5	46.5		45.5	45.4	49.9
250	45.6	45.6		42.9	41.5	44.3
315	48.8	48.8	**61.8**	42.6	43.3	49.4
400	42.2	46.3	**59.3**	39.1	39.8	42.9
500	35.0	39.7	**52.7**	38.2	36.9	48.2
630	34.2	34.2	**47.2**	36.3	34.5	49.4
800	41.7	41.7	**54.7**	39.9	38.6	46.5
1000	36.6	39.2	**52.2**	49.3	35.6	**56.9**
1250	34.5	34.5	**47.5**	43.0	34.2	47.9
1600	35.5	35.5	**48.5**	**49.0**	34.7	46.6
2000	32.4	33.0	**46.0**	**47.1**	**54.6**	40.4
2500	30.3	30.3	**43.3**	41.2	32.4	42.7
3150	28.6	28.6	**41.6**	37.0	**49.6**	34.2
4000	27.8	27.8		28.7	28.5	33.4
5000	28.0	28.0		28.3	28.6	29.3

Appendix C: Auditory Sound Measurements

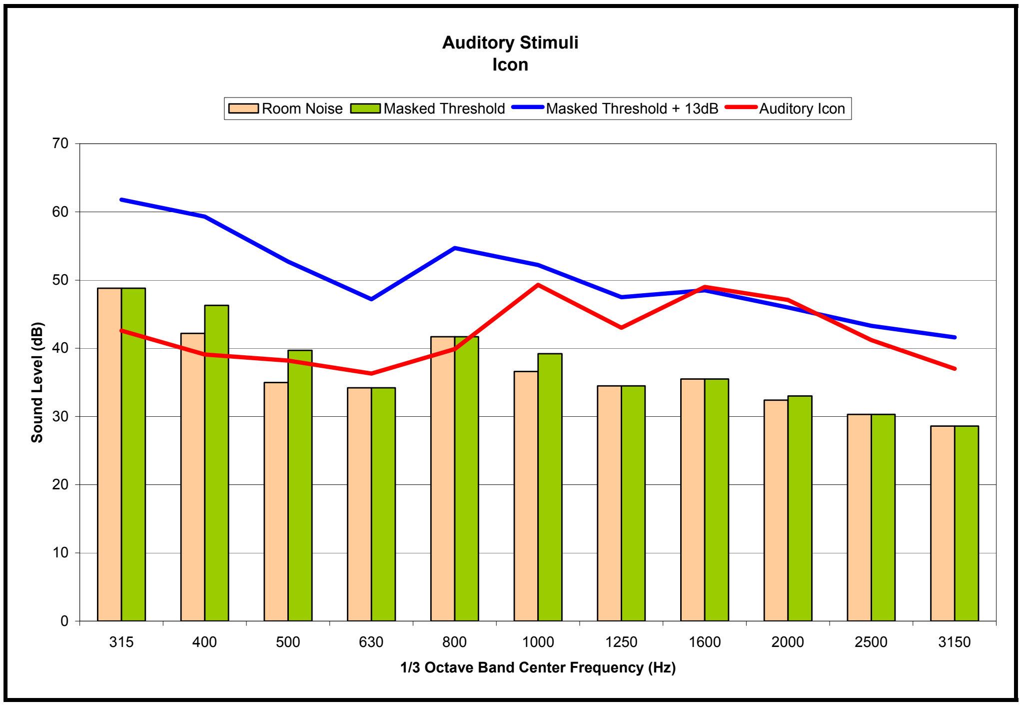


Figure C.5 Auditory Icon Sound Measurements

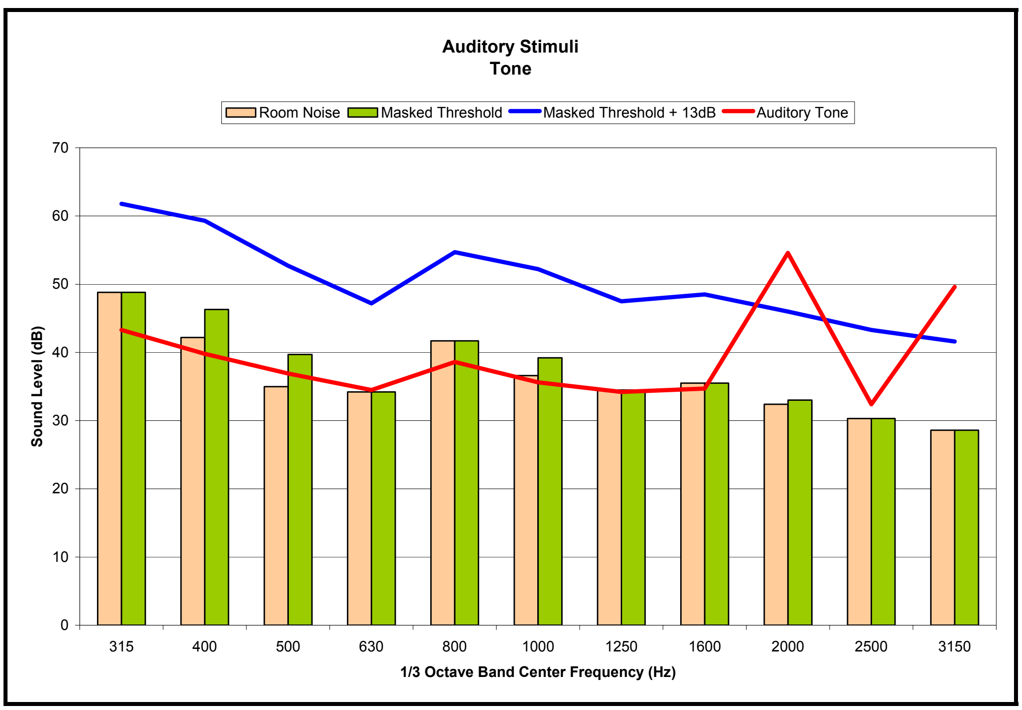


Figure C.6 Auditory Tone Sound Measurements

Appendix C: Auditory Sound Measurements

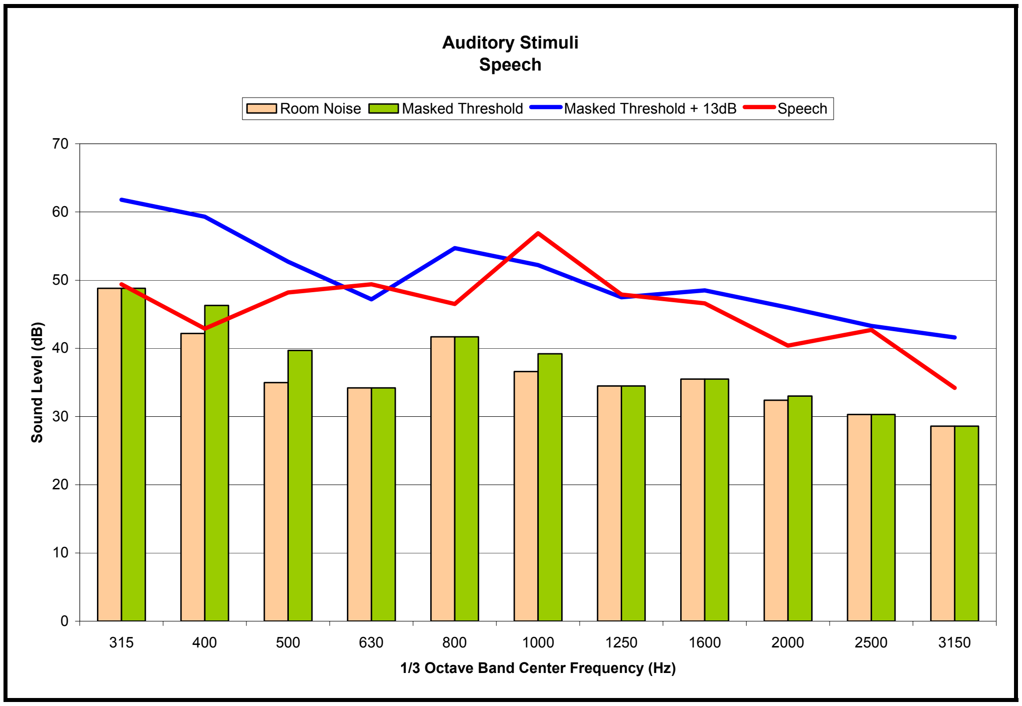
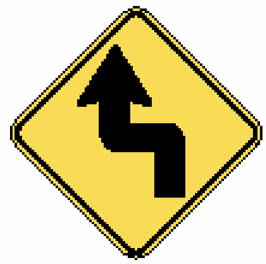


Figure C.7 Auditory Speech Sound Measurements

Appendix D: Manual on Uniform Traffic Control Devices 2C.06
[note: all signs shown depict a black icon over a yellow background]


W1-1


W1-2


W1-3


W1-4


W1-5

W1-9


W1-10

Appendix E: Post Condition Questionnaire

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 F: Simulator Sickness Questionnaire

Simulator Sickness Evaluation

Please rate the existence of the following symptoms on a scale from None to Severe.

1. General Discomfort None_____Slight_____Moderate_____Severe____
2. Fatigue None_____Slight_____Moderate_____Severe____
3. Headache None_____Slight_____Moderate_____Severe____
4. Eyestrain None_____Slight_____Moderate_____Severe____
5. Difficulty Focusing None_____Slight_____Moderate_____Severe____
6. Increase Salivation None_____Slight_____Moderate_____Severe____
7. Sweating None_____Slight_____Moderate_____Severe____
8. Nausea None_____Slight_____Moderate_____Severe____
9. Difficulty Concentrating None_____Slight_____Moderate_____Severe____
10. Fullness of Head None_____Slight_____Moderate_____Severe____
11. Blurred Vision None_____Slight_____Moderate_____Severe____
12. Dizzy – with eyes open None_____Slight_____Moderate_____Severe____
13. Dizzy – with eyes closed None_____Slight_____Moderate_____Severe____
14. Vertigo None_____Slight_____Moderate_____Severe____
15. Stomach Awareness None_____Slight_____Moderate_____Severe____
16. Burping None_____Slight_____Moderate_____Severe____

Appendix G: Curve Warning Acceptance Questionnaire

Participant #:_________

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 H: Curve Design Calculations

Curve Radius Calculations

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

Where:

V = vehicle speed (22.2 mph = 32.6 ft/s^2)
R = radius of curve (ft)
g = gravitational constant (32.2 ft/s^2)
e = rate of superelevation (0%)
f = side friction factor (0.21)

Therefore:

$$32.6 = \sqrt{R(32.2)\frac{0.21}{1}}$$

$$32.6^2 = R(6.762)$$

$$1060.2 = 6.762R$$

$$R = \underline{\underline{156.8\,ft.}}$$

Appendix H: Curve Design Calculations

Warning Distance Onset Calculations

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

Where:

- a = deceleration (4.92 ft/s)
- V = vehicle speed (80.67 ft/s)
- V_c = maximum safe speed for curve (32.6 ft/s)
- d = distance to curve apex (ft)
- t_r = reaction time (2.5s)

Therefore:

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

$$d = \frac{(80.67)^2 - (32.56)^2}{2(4.92)} + 2.5(80.67)$$

$$d = \frac{5446.96}{9.84} + 201.675$$

$$d \approx \underline{\underline{755\,ft}}$$

Appendix I: Participant Screening Script

Hello my name is *first name* from the Virginia Tech Transportation Institute. Could I speak with *participant's name*?

I understand you may be interested in participating in one of our driving studies. We are currently running a study to determine how to best present a curve warning device to the driver. This study will take place in a driving simulator and will take approximately *4* hours of your time. You will be paid $20.00 per hour. Does this sound like something you may want to do?

<u>If they say no, ask them if they would like us to keep them on the potential driver list to call for future studies.</u>

<u>If they say yes continue.</u>

a. Do you have a valid driver's license? [Exclude if 'NO']

   Yes _____ No _____ Expiration Date:_______________

b. Have you participated in a driving simulator study before? [Exclude if they have participated in a simulator study before.] "Unfortunately this study requires people who have never driven a simulator before. If it is okay, we would like to keep you on our list for future studies. Thank you for your time."

   Yes _____ No _____

c. How often do you drive each week? [Exclude if < 2 times a week)

   Every day ____ At least 2 times a week___ Less than 2 times a week_____

d. How old are you? ______ (stop if not 18-25 or 60+ years old.)

e. How long have you held your drivers' license?______ [Exclude if < 2 yrs]

f. On average, how many hours do you spend playing video games…
   per week?__________ per month?___________
   [Exclude if greater than 1 hour per week or 4 hours per month]

g. Do you have normal or corrected to normal hearing and vision? If no, please explain. [Exclude if not normal (or corrected to normal) hearing and vision]

   Yes _____ No ______

h. Are you color blind? Yes_______ No_________ [Exclude if yes]

i. Do you have experience with a Heads Up Display? Yes___ No___ [Exclude if yes]

Appendix I: Participant Screening Script

"Because of pre-existing health conditions, some people are not eligible for participation in this study. I need to ask you several health-related questions before you can be scheduled for a study session. Your response is voluntary and all responses are confidential. This means that you can refuse to answer any question that you choose and that we will not keep any record of your response. Please answer yes or no to the following questions:"

Health Questionnaire

1) **Do you suffer from a heart condition such as disturbance of the heart rhythm or the experience of a heart attack?** If yes, please describe.
   <u>(Exclude</u> participant if there has been a heart attack within the past 6 months, or if there is a history of ventricular flutter or fibrillation, or systole requiring cardioversion. Potential participants with atrial fibrillation may be acceptable, given that their heart rhythm is now stable following medical treatment or pacemaker implants.)

   ☐ Heart attack within past 6 months *(exclude)*
   ____
   ☐ History of Ventricular Flutter or Fibrillation *(exclude)*
   ____
   ☐ History of systole requiring cardioversion *(exclude)*
   ____
   ☐ Atrial fibrillation
   ____

2) **Have you ever suffered brain damage from a stroke, tumor, head injury, or infection?**
   If yes, what are the resulting effects? Do you have:
   ☐ visual loss
   ☐ blurring
   ☐ double vision
   ☐ weakness
   ☐ numbness
   ☐ funny feelings in arms, legs, or face
   ☐ trouble swallowing
   ☐ slurred speech
   ☐ uncoordination or loss of control
   ☐ trouble walking
   ☐ trouble thinking
   ☐ remembering
   ☐ talking
   ☐ understanding

Appendix I: Participant Screening Script

(Exclude participant if there has been a stroke within the past 3 months, there is an active tumor, or if there are lingering effects.)

3) **Have you been diagnosed with a serious or terminal illness?** If yes, is the condition still active? Are there any lingering effects? If yes, do you care to describe? (Exclude participant if he/she has a current serious condition.)

4) **Have you ever been diagnosed with seizures or epilepsy?** If yes, how frequently and what type? (Exclude participant if there has been a seizure within the past 2 months)

5) **Do you suffer from a respiratory disorder such as asthma or chronic bronchitis?** If yes, please describe. (Exclude participant if disorder results in obvious or continuous shortness of breath)

6) **Do you ever suffer from motion sickness?** If yes, on what mode of transportation and under what conditions (e.g., rough sea, back seat, etc.)?

   What symptoms did you experience?

   How old were you when this occurred?

   (Exclude participant if sickness occurs often, or results in severe symptoms [i.e., vomiting])

7) **Do you suffer from inner ear, dizziness, vertigo, or balance problems?** If yes, please describe.

   Do you have Meniere's disease?

   (Exclude participant if there is any history of inner ear, dizziness, vertigo, or balance problem.)

Appendix I: Participant Screening Script

8) **Do you have migraine or tension headaches?**
How often and when was the last headache?

(Exclude participant if headaches occurred in the last three months or if they are taking regular medication for migraines.)

9) **Are you currently taking any medications?** If yes, what is the medication and what is it for?

(Exclude participant if medication is for motion sickness [Transderm Scop, Anergan, Phenergan, Dramamine, Benadryl, Marezine, Bucladin-S Softabs, Antivert] or for any of the conditions mentioned above that may indicate that a problem mentioned above may have been incorrectly denied.)

10) **Are you, or is there a possibility that you are pregnant?**
Yes _____ No _____ (If "yes" then read the following statement to the subject: *"It is not recommended that pregnant women participate in this study. However, female subjects who are pregnant and wish to participate must first consult with their personal physician for advice and guidance regarding participation in a study where risks, although minimal, include the possibility of nausea."*

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."

If the participant is eligible, then schedule him/her for the study.
Give directions to ____ and where to park. Tell he/she to come to the participant prep room upon arrival.

Appendix I: Participant Screening Script

Do you wear glasses? If he/she wears glasses, please ask the participant to bring them -- even if they are only reading glasses.

When contacting subjects for scheduling purposes, the following statement must be included in the conversation. *"We ask that all subjects refrain from drinking alcohol and taking any substances that will impair their ability to drive prior to participating in our study."*

End the conversation by thanking the participant and telling he/she that we will see you at the scheduled time and day in ___.

Appendix I: Participant Screening Script

Subject Contact Form

Name: ________________ Gender: M or F

Phone #: (H) ____________________ (W) _____________________

Valid Driver's License? _________________ Expiration Date:___________

Driving Simulator Experience? Yes_______ No________

How often do they drive? _____________

Age? __________

How long have they had their license? _____________

Video Game Usage: per week-___________ per month-___________

Normal (or corrected to normal) Hearing and Vision? _____________________

Color blindness?________________

Medical History: (Pass/Fail): ____________________
If not, why? Medical Conditions? ____

Scheduled day and time: ________________________

Notes:

Who contacted this person? ________________________

Appendix J: Vision and Hearing Test 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

1KHz ______

2KHz ______

3KHz ______

4KHz ______

Appendix K: IRB / Informed Consent

Request for Expedited Approval of Research Involving Human Subjects

[please print or type responses below]

Investigator(s): Myra Blanco, Tonya Smith-Jackson, Luke Neurauter

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

Project Title: Multidimensional Warnings: Determining the Appropriate Combination for a Curve Warning Device.

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 ___].

[ ] 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, Luke Neurauter 8/28/03

Investigator(s) Date

Departmental Reviewer Date

Chair, Institutional Review Board Date

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

Appendix K: IRB / Informed Consent

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. 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 auditory (icon, tone, and speech), visual (in dash cluster and Heads-Up Display), and haptic (throttle push-back) warnings, as well as combinations of these seven warnings. Intelligent Transportation Systems such as curve warning devices can be effective in reducing crashes and fatalities, but only if they are used 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 1) 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 35 participants will be recruited.

Screening

Prior to coming in for testing, participants will be provided with a general description of the study 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 2.

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 four 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 3). After the participant signs the form and answers all questions, the experimenter will sign the form. Both the experimenter and participant will keep a signed copy of the form.

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. 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. If the participant is unable to detect any of the tones, he/she will be paid $20.00, thanked, and dismissed.

Data Collection

The participant will then undergo a short training session in a driving simulator. After the training session, participants will be asked to drive the simulator while multiple warning conditions are displayed as they approach an upcoming curve. After each of these conditions, participants will be asked three questions by the experimenter (Appendix 4). Finally, a Simulator Sickness Questionnaire (Appendix 5) will be administered at the beginning, middle, and end of data collection to monitor for any side effects (motion sickness) resulting from the use of the driving simulator.

Risks and Benefits

There are risks or discomforts to which test participants may be exposed while volunteering for this experiment. They include the following:

1) Possible fatigue due to the length of the experiment.
2) Risks normally present in working at a desk or computer station.
3) Possible motion sickness or associated symptoms.

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

1) Participants will be given a quick break between conditions to answer questions.
2) The experimenter will monitor participants for motion sickness or associated symptoms using the Simulator Sickness Questionnaire (Appendix 5). A participant who scores moderate or higher on the questionnaire will immediately be offered fluids. He/she will then be observed for 10-15 minutes before continuing the study. If the participant chooses not to continue with the study, he/she will be asked to wait until he/she is feeling better before leaving the building.

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 subjects to participate. Subject 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 names will be separated from their data. A coding scheme will be employed to identify the data by participant number only (e.g., Participant No. 1). Participants will be allowed to see their data and to withdraw themselves 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.

Appendix K: IRB / Informed Consent

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Informed Consent for Participants in
Research Projects Involving Human Subjects

Title of Project: Multidimensional Warnings: Curve Warning Device

Investigator(s): Luke Neurauter, Myra Blanco, and Tonya Smith-Jackson

I. Purpose of this Research/Project

The purpose of this research is to gather information about new in-vehicle technology. In the near future, when curve warnings are readily available in all vehicles, it is important to ensure that they do not create a safety hazard. This project will use a driving simulator to investigate several alternative warnings with respect to a curve warning device.

II. Procedures

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

- Show your valid driver's license
- Read and sign an Informed Consent Form
- Complete simple vision tests
- Complete informal hearing test
- Participate in the Experiment

The experiment will last approximately four hours. After a short training session on a driving simulator, a questionnaire will be administered. The purpose of this questionnaire is to help us to be aware of any negative side effects you may be experiencing as a result of the driving simulator. This questionnaire will also be administered in the middle and end of the study.

While using the driving simulator, you will be presented with various warnings to be used in conjunction with a curve warning device. These warnings are meant to signal the driver that he/she needs to slow down in order to navigate through an upcoming curve safely. After each warning condition you will be asked to rate three questions based on the condition and to comment on the condition you experienced.

You will be expected to drive as you would normally, while obeying the speed limit of 55mph during the straight portions of the road.

III. Risks

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

Appendix K: IRB / Informed Consent

1) Possible fatigue due to the length of the experiment.
2) Risks normally present in working at a desk or computer station.
3) Possible motion sickness or associated symptoms

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

1) Participants will be given a quick break between conditions to answer questions.
2) The experimenter will monitor participants for motion sickness or associated symptoms.
3) Participants will be screened to ensure that they do not have any medical condition that would put them at a greater risk, including but not restricted to epilepsy, balance disorders, inner ear infection, and/or vertigo.

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

IV. Benefits

There are no direct benefits to you from this research other than payment for participation. No promise or guarantee of benefits will be made to encourage you to participate. Your participation will provide baseline data for curve warning devices, as well as driver preference data for these warnings. Your participation may have a significant impact on future intelligent transportation systems technology.

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 to 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.

VI. Compensation

You will receive $20.00 per hour for your participation in this study. This payment will be made to you at the end of your voluntary participation in this study. If you choose to withdraw before completing all scheduled experimental conditions, you will be compensated for the portion of time during which you participated.

VII. Freedom to Withdraw

As a participant in this research, you are free to withdraw at any time, for any reason. If you choose to withdraw, you will be compensated for the portion of time during which you participated. Furthermore, you are free not to answer any questions or to respond to any research situations without penalty.

VIII. Approval of Research

This research has been 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.

X. Participant's Responsibilities

If you voluntarily agree to participate in the study, you will have the following responsibilities: to be physically free from any substances that impair your ability to drive (alcohol, drugs, etc), for 24 hours prior to the experiment.

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:

____Date__________

Participant's signature

Should I have any pertinent questions about this research or its conduct, the rights of research participants, or whom to contact in the event of a research-related injury, I may contact:

Luke Neurauter	(540) 231-1500
Myra Blanco	(540) 231-1500
Tonya Smith-Jackson	(540) 231-4119
David Moore, Chair, IRB	(540) 231-4991

____ ________________________

Experimenter's Signature Date

Appendix L: Experimenter Protocol – VTTI Location

MDW Set Up – VTTI Location

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1. Set up the VDOT conference room
    - Close all shades
    - Set up eye chart at marked location outside of VDOT conference room
    - Set up laptop for hearing test [type 'win' in dos to startup Windows] – check that volume is set to 6th bar; Open up Sound Recorder (Programs/Accessories/Entertainment), and open up 1KHz tone (Desktop/MDW Informal Hearing)

2. Go through participant packets to make sure all the forms are there and participant number is on the vision & hearing form [Time In/Out form (1); Informed Consent (2); Form W-9 (1); Vision & Hearing (1);

Conference Room

---

1. Greet participant and record the time that the participant arrived on the debriefing form [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 APTE lab for any messages. If none, go into the Participants folder in MDW to find their contact information. Call the numbers listed]

2. Ask participant to show driver's license (Must be a valid Class A driver's license to proceed with the study. Out of state is fine. Check the expiration date).

3. *This project is sponsored by the Virginia Transportation Research Council. The goal of this project is to determine which warnings are most appropriate for use in a curve warning device.*

4. Informed Consent – Give the participant the informed consent form. Encourage him/her to read it before signing it. Answer any questions and make sure the participant has signed and dated the form.

5. Sign form below the participant's signature. Give the participant a copy of the informed consent.

6. Prompt the participant to complete the W-9 tax form. Make sure the "Name", "Address", and "Tax ID number (social security number)" have been completed and the form is signed and dated at the bottom. Explain that: *If participants make more than $500.00 doing studies from Jan1 to Dec 31, this will be reported to the IRS as income.*

Appendix L: Experimenter Protocol – VTTI Location

Back side of tax form. Print participants name on the top line. If they question what it is for…
This says that we are not hiring them full time. There won't be any health benefits or paid vacation etc. We can not fire them because we aren't really hiring them. They can quit at any time without being held liable for services by the university. They are a one-time contractor. If they already work for Tech, this is completely separate from their job, and their performance will not have any effect on their employment with Tech.

7. Perform the two vision tests

a) The first test is the Snellen eye chart test
Take the participant over to the eye chart test are
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.*
- If the participant gets every letter on the first line they try correct have him/her try the next smaller line. Continue until he/she misses a letter. At that time, record the one that he/she was able to read in full (line above).
- If the participant gets the first line attempted incorrect, have him/her read the previous line. Repeat as needed until one line is read correctly. Record this acuity. Participant must have 20/40 or better vision using both eyes to participate in the study.

b) The second vision test is the 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 participant's answers on the Vision Tests form

8. Administer the informal hearing test

- Procedure: Please turn so that your back is towards me. Please notify me when you hear a tone by raising your hand.
- Play each tone in succession, but make sure volume setting is correct:
    - 1Khz – 6^{th} bar (should already be set)
    - 2Khz – 3^{rd} bar
    - 3Khz – halfway between 1^{st} and 2^{nd} bar
    - 4Khz – halfway between 1^{st} and 2^{nd} bar
- Participant must be able to hear all four tones presented to participate in the study.

9. Orientation to the study

Appendix L: Experimenter Protocol – VTTI Location

Today you will drive using a simulator, following the speed limit and responding to warnings. There will be two questionnaires that will be administered during the study. After the training, the Simulator Sickness Questionnaire will be presented. SHOW QUESTIONNAIRE. For each statement we want you to rank your answer on a scale from none to severe. Let's go over each of the statements. Please stop me at anytime if you have a question. This questionnaire will be administered at the midpoint and end of the study.

[Note: If the participant asks or expresses concern over getting sick read the following: *We are administering the Simulator Sickness Questionnaire as a formality for simulator studies as opposed to an expectation that participants will become sick. We anticipate only a small percentage of participants, if any, to show signs of simulator sickness.]*

The Post Condition Questionnaire will be completed after each warning condition. SHOW QUESTIONNAIRE. *For each statement we want you to rank your answer on a scale from one to five, except for the final question which is open-ended. One means you strongly disagree with the statement. Five means you strongly agree with the statement. Let's go over each of the statements. Please stop me at anytime if you have a question.* [point out that they may use the space at the bottom for any additional comments they have concerning the condition presented]

If you would like to take a break at any time during the study, just let the experimenter know. We will be giving you a ride to and from the simulator location which is on campus. The drive will last approximately 5 to 10 minutes.

Ask participant if he/she wants to use the restroom before beginning.

10. Participant Drop Off

If the experimenter at the STI location is not with a participant, call him at **605-0159** when you are ready to bring the participant.

When ready, show participant to the vehicle and drive them to the parking lot behind Williams hall off of West Campus Dr (you can park in one of the Service vehicle spaces if you have state tags). Walk with the participant to Williams hall and wait outside of room 234 (two chairs will be set up). When the experimenter at the STI location is ready he will open up the door and greet the participant.

Post Data Collection

11. Participant Pick Up

Appendix L: Experimenter Protocol – VTTI Location

The experimenter at the STI location will call to let you know when to be there to pick up his participant. When ready, park the car at the same parking lot and meet the participant outside of room 234. Walk with them back to the car and bring them back to VTTI.

12. Payment

Note the finish time on the debriefing form. Pay the participant, have them sign the payment log, and thank them for their time.

Appendix M: Experimenter Protocol – Simulator Location

MDW Set Up – Simulator Location

Before heading over to campus:

1. Check the voice mail on 231-1582 phone (APTE lab) to make sure there aren't any messages from participants calling to cancel/asking for directions.

Simulator Set Up

1. Set up the main room
    a. Close all shades
    b. Turn off all overhead lights

2. Make sure you have all the forms and that the participant number is on all of them [Experimenter note sheet (1); Post Condition Questionnaires (24) (place in binder); Curve Acceptance Questionnaire (1); SSQ Answer Sheet (1)]

3. Turn on lights to Simulator room – set at line on light bar

4. Turn center computer and monitor on and make sure steering wheel is on

5. Boot up the Warnings computer; Pull up warning program when loaded – Type in 2866 for start distance and 3500 for end. Select visual warning and set both LCD's to the off position until needed.

6. Check that the volume setting on the speakers is where it is supposed to be (position is marked with white out).

7. Label and place participant tape into VCR and set channel to L-1 and record speed to Extended Play; turn on camera monitor and check camera positions.

8. Log onto Experimenter computer (password is STISIM)

9. Open up Stisim Drive program

10. Load the 'MDW.CFG configuration (option in file menu) located in C:\STISIM\Projects\Luke\Other (Copy of folder and contents will be located on Verbatim 512 USB Drive.

11. In 'Events or Project File' dialog box bring up the training loop (C:\STISIM\Projects\Luke\Training.EVT)

Appendix M: Experimenter Protocol – Simulator Location

12. In the 'Output Data File' dialog box put in Participant_ _run00. [Training will be set as 00, and with each following condition the run number will increase by 1]

13. Select Run\Begin Simulation Run

14. Select New; for last name type in participant # (01, etc.); for first name type in 'Participant'; for ID type in 'Participant #'' and hit Add; for training, set run to 0. Select OK and allow route to load

Participant Arrival at Williams 234 – Data Collection

Greet participant upon arrival. Show them where the restrooms are located that are closest to Williams 234. Ask them if they have any questions before they begin. Once they are ready:

1. Press Record on the VCR.

2. Orient driver to the vehicle
- Seat Adjustment
- Throttle & Brake pedals

3. Training

We are about to begin the first driving portion of the study. This is a practice drive to help you get the feel of the simulator. Please drive as you normally would, and obey the speed limit of 55mph. It is very important that you obey this speed limit. If you exceed the speed of 55mph you will be asked to watch your speed. [Don't give the upper value for which the "Please Maintain 55mph"will be presented]

The training loop consists of multiple left and right turns of various curvatures. Preceding each curve is an advisory sign showing the curve direction and recommended speed. Please decelerate to the recommended speed by the time you reach the entrance of the curve. Once you are exiting the curves please resume maintaining 55mph.

In order to begin driving you must follow the directions that appear on the center screen (read directions on screen). *You will be asked to center the steering wheel and, when ready, push the start button (horn) to begin the training loop. This training portion will last for approximately five minutes.*

Do you have any questions before we begin?

Appendix M: Experimenter Protocol – Simulator Location

Please center the steering wheel and press the horn when you are ready to begin. I will be on the other side of the glass while you are driving but I will be able to hear you if you have any questions during the run.

4. Have participant perform training loop. Play the "Please Maintain 55mph" recording when their speed goes above (sustained) 58mph or below (sustained) 52mph. Make sure not to present during curves: **1500-2000; 4500-5000; 8000-8500; 11500-12000; 15000-15500; 17500-18000.**

5. Administer the SSQ

If at this point the participant shows signs of simulator sickness (scoring moderate or higher on any of the symptoms), he/she will be offered fluids immediately (have 4 bottles of water in a small portable cooler). He/she will then be observed for ten to fifteen minutes before being allowed to continue the study. If the participant chooses not to continue with the study, he/she will then be asked to wait until he/she is feeling better before leaving the building. If after an extended period of time, participants, if necessary, will be driven home in their own vehicle.

6. Tell the participant: *I need to do some final set up before we continue with the data collection portion of the study. This won't take but a couple of minutes.*

7. Pull up first condition: In the 'Events of Project File' box bring up either the 'MDW-right.EVT' or 'MDW-left.EVT' file (located in C:\STISIM\Projects\Luke\) depending on the experimenter order sheet; in the 'Output Data File' dialog box put in Participant_ _run01. Select Begin Simulation Run in the Run pull down menu; Leave information as is (was already set before training), but change Run # to 1 (this will follow the order so increment with each condition).

8. Set up Warning condition by selecting the auditory, visual, and haptic warnings if applicable [conditions can be found on experimenter notesheet]. Check the box if the haptic pedal is needed for the particular condition. Check the box for Auditory if an auditory alarm is needed – auditory files are located in 'C:MDW\Sounds'; Check the box for Visual if a HDD or HUD is needed – visual files are located in 'C:MDW\Images'. Always keep visual setting to 'Both LCD's off' until one is needed – otherwise the participant can see what you see on the screen. Press start, make sure synch numbers are increasing (monitor and video), and make sure to move the mouse curser from the field of view on the monitor screen.
Auditory Conditions: **Icon – Volume 4; Speech – Volume 3; Tone – Volume 2;**

9. Instruct the participant to begin the 1st condition

Appendix M: Experimenter Protocol – Simulator Location

We will now begin the remaining portion of the study. You will be presented with several separate conditions, each followed by the questionnaire you went over earlier. For each condition you will begin on a straight portion of roadway. Please obey the 55mph speed limit on this road. When the condition is over the screen will go blank. Please follow the directions to start the condition as you did for the training portion.

Do you have any questions before we begin? (Answer any questions). *Please begin when you are ready.*

Following the 1st condition administer the post condition questionnaire: *After each condition that is presented you are asked to fill out the questionnaire that was covered during your orientation at VTTI. Next to you is a white binder. Inside the binder you will see colored tabs numbered 1-24. We will follow these in succession. In other words, since this was the first scenario, please go ahead and fill out the questionnaire for presentation #1, then after the next condition complete the questions for #2, etc. As a reminder, I will state the corresponding number of the questionnaire to go to after each presentation.*

10. Repeat steps 7 and 8 for conditions 2 - 12. When the computers are ready:
Please begin the next condition when ready.

11. After the 12th condition and post drive questionnaire, administer the SSQ.
If at this point the participant shows signs of simulator sickness (scoring moderate or higher on any of the symptoms), he/she will be offered fluids immediately. He/she will then be observed for ten to fifteen minutes before being allowed to continue the study. If the participant chooses not to continue with the study, he/she will then be asked to wait until he/she is feeling better before leaving the building. If after an extended period of time, participants, if necessary, will be driven home in their own vehicle.

12. Offer a 10-minute break at this time. If participant declines continue with remaining conditions.

13. Repeat steps 7 and 8 for conditions 13 – 24.
Please begin the next condition when ready.

14. If this is the last participant of the day call the VTTI experimenter at 239-2698 after condition 18 to let them know they can head over and meet the participant upon completion of data collection.

15. After the 24th condition and post drive questionnaire, administer the SSQ for the final time.

Appendix M: Experimenter Protocol – Simulator Location

If at this point the participant shows signs of simulator sickness (scoring moderate or higher on any of the symptoms), he/she will be offered fluids immediately. He/she will then be asked to wait until he/she is feeling better before leaving the building. If after an extended period of time, participants, if necessary, will be driven home in their own vehicle (if they drove).

16. Once data collection is complete, hand them the Curve Warning Acceptance Questionnaire

17. Wait for VTTI experimenter to arrive before escorting the participant out of the room.

Appendix N: Debriefing Form

NAME:____________________________

Virginia Tech

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 systems.

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

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

TOTAL PAYMENT:_______________

VTTI Staff Signature:_______________

Appendix O: ANOVAs for Objective Data

Table O.1 Throttle Reaction Time

Source	DF	SS	MS	F value	P value
Between					
Subject	23	222.41	9.67		
Within					
Auditory	3	171.60	57.20	25.86	<.0001 *
Auditory X Subject	69	148.20	2.21		
Visual	2	164.60	82.30	49.49	<.0001 *
Visual X Subject	45	73.17	1.67		
Haptic	1	61.24	61.24	29.25	<.0001 *
Haptic X Subject	22	46.06	2.09		
Auditory X Visual	6	86.68	14.45	11.39	<.0001 *
Auditory X Visual X Subject	129	163.67	1.27		
Auditory X Haptic	3	4.35	1.45	1.39	0.2540
Auditory X Haptic X Subject	66	68.92	1.04		
Visual X Haptic	2	8.86	4.43	3.92	0.0271 *
Visual X Haptic X Subject	44	49.70	1.13		
Auditory X Visual X Haptic	6	12.30	2.05	2.06	0.0629
Auditory X Visual X Haptic X Subject	119	118.32	0.99		
TOTAL	540	1400.08			

* $p < 0.05$ (significant)

Table O.2 Brake Reaction Time

Source	DF	SS	MS	F value	P value
Between					
Subject	23	287.71	12.51		
Within					
Auditory	3	152.08	50.69	22.77	<.0001 *
Auditory X Subject	67	149.17	2.23		
Visual	2	214.95	107.48	49.25	<.0001 *
Visual X Subject	44	96.02	2.18		
Haptic	1	8.56	8.56	4.60	0.0429 *
Haptic X Subject	23	42.82	1.86		
Auditory X Visual	6	52.57	8.76	6.41	<.0001 *
Auditory X Visual X Subject	130	177.80	1.37		
Auditory X Haptic	3	1.11	0.37	0.23	0.8736
Auditory X Haptic X Subject	66	105.10	1.59		
Visual X Haptic	2	3.13	1.56	1.60	0.2132
Visual X Haptic X Subject	44	42.95	0.98		
Auditory X Visual X Haptic	6	10.48	1.75	1.37	0.2308
Auditory X Visual X Haptic X Subject	113	143.58	1.27		
TOTAL	533	1488.03			

* $p < 0.05$ (significant)

Appendix O: ANOVAs for Objective Data

Table O.3 Curve Entrance Velocity

Source	DF	SS	MS	F value	P value
Between					
Subject	23	7773.46	337.98		
Within					
Auditory	3	3342.38	1114.13	31.71	<.0001 *
Auditory X Subject	69	2423.96	35.13		
Visual	2	2587.73	1293.86	41.11	<.0001 *
Visual X Subject	46	1447.93	31.48		
Haptic	1	140.29	140.29	4.72	0.0404 *
Haptic X Subject	23	683.56	29.72		
Auditory X Visual	6	1848.87	308.14	9.16	<.0001 *
Auditory X Visual X Subject	137	4606.58	33.62		
Auditory X Haptic	3	176.21	58.74	1.75	0.1643
Auditory X Haptic X Subject	69	2311.99	33.51		
Visual X Haptic	2	50.24	25.12	0.84	0.4401
Visual X Haptic X Subject	46	1383.10	30.07		
Auditory X Visual X Haptic	6	540.54	90.09	2.95	0.0099 *
Auditory X Visual X Haptic X Subject	129	3943.08	30.57		
TOTAL	565	33259.92			

* $p < 0.05$ (significant)

Table O.4 Curve Entrance Lane Position

Source	DF	SS	MS	F value	P value
Between					
Subject	23	179.66	7.81		
Within					
Auditory	3	4.59	1.53	1.20	0.3179
Auditory X Subject	69	88.27	1.28		
Visual	2	12.76	6.38	4.67	0.0143 *
Visual X Subject	46	62.89	1.37		
Haptic	1	3.45	3.45	0.98	0.3333
Haptic X Subject	23	81.27	3.53		
Auditory X Visual	6	6.03	1.01	0.74	0.6146
Auditory X Visual X Subject	137	184.92	1.35		
Auditory X Haptic	3	1.46	0.49	0.22	0.8803
Auditory X Haptic X Subject	69	150.62	2.18		
Visual X Haptic	2	0.81	0.40	0.23	0.7970
Visual X Haptic X Subject	46	81.25	1.77		
Auditory X Visual X Haptic	6	10.31	1.72	1.18	0.3187
Auditory X Visual X Haptic X Subject	129	187.15	1.45		
TOTAL	565	1055.44			

* $p < 0.05$ (significant)

Appendix O: ANOVAs for Objective Data

Table O.5 Curve Apex Velocity

Source	DF	SS	MS	F value	P value
Between					
Subject	23	6389.50	277.80		
Within					
Auditory	3	157.58	52.53	3.37	0.0234 *
Auditory X Subject	69	1076.71	15.60		
Visual	2	216.93	108.47	5.28	0.0086 *
Visual X Subject	46	944.93	20.54		
Haptic	1	33.01	33.01	3.15	0.0891
Haptic X Subject	23	240.98	10.48		
Auditory X Visual	6	113.25	18.87	1.16	0.3338
Auditory X Visual X Subject	137	2237.41	16.33		
Auditory X Haptic	3	23.37	7.79	0.78	0.5071
Auditory X Haptic X Subject	69	685.81	9.94		
Visual X Haptic	2	16.28	8.14	0.92	0.4059
Visual X Haptic X Subject	46	407.13	8.85		
Auditory X Visual X Haptic	6	32.12	5.35	0.49	0.8181
Auditory X Visual X Haptic X Subject	129	1421.94	11.02		
TOTAL	565	13996.96			

* $p < 0.05$ (significant)

Table O.6 Curve Apex Lane Position

Source	DF	SS	MS	F value	P value
Between					
Subject	23	215.61	9.37		
Within					
Auditory	3	8.41	2.80	1.29	0.2858
Auditory X Subject	69	150.21	2.18		
Visual	2	22.25	11.12	2.22	0.1201
Visual X Subject	46	230.44	5.01		
Haptic	1	0.41	0.41	0.07	0.7884
Haptic X Subject	23	127.59	5.55		
Auditory X Visual	6	20.17	3.36	0.49	0.8144
Auditory X Visual X Subject	137	938.60	6.85		
Auditory X Haptic	3	27.11	9.04	1.78	0.1586
Auditory X Haptic X Subject	69	349.76	5.07		
Visual X Haptic	2	0.66	0.33	0.06	0.9399
Visual X Haptic X Subject	46	243.82	5.30		
Auditory X Visual X Haptic	6	29.57	4.93	0.75	0.6094
Auditory X Visual X Haptic X Subject	129	846.18	6.56		
TOTAL	565	3210.78			

* $p < 0.05$ (significant)

Appendix O: ANOVAs for Objective Data

Table O.7 Curve Exit Velocity

Source	DF	SS	MS	F value	P value
Between					
Subject	23	14533.18	631.88		
Within					
Auditory	3	58.22	19.41	0.63	0.5994
Auditory X Subject	69	2132.52	30.91		
Visual	2	85.99	43.00	3.42	0.0412 *
Visual X Subject	46	578.01	12.57		
Haptic	1	67.99	67.99	3.75	0.0652
Haptic X Subject	23	416.94	18.13		
Auditory X Visual	6	66.28	11.05	0.76	0.6023
Auditory X Visual X Subject	137	1990.44	14.53		
Auditory X Haptic	3	6.82	2.27	0.20	0.8986
Auditory X Haptic X Subject	69	799.66	11.59		
Visual X Haptic	2	4.62	2.31	0.21	0.8089
Visual X Haptic X Subject	46	498.27	10.83		
Auditory X Visual X Haptic	6	38.64	6.44	0.53	0.7852
Auditory X Visual X Haptic X Subject	129	1569.49	12.17		
TOTAL	565	22847.07			

* $p < 0.05$ (significant)

Table O.8 Curve Exit Lane Position

Source	DF	SS	MS	F value	P value
Between					
Subject	23	39.90	1.73		
Within					
Auditory	3	2.39	0.80	1.24	0.3021
Auditory X Subject	69	44.36	0.64		
Visual	2	1.55	0.77	0.61	0.5503
Visual X Subject	46	58.80	1.28		
Haptic	1	0.53	0.53	0.42	0.5234
Haptic X Subject	23	29.01	1.26		
Auditory X Visual	6	5.70	0.95	0.95	0.4612
Auditory X Visual X Subject	137	136.90	1.00		
Auditory X Haptic	3	12.95	4.32	3.69	0.0159 *
Auditory X Haptic X Subject	69	80.71	1.17		
Visual X Haptic	2	4.23	2.12	1.33	0.2738
Visual X Haptic X Subject	46	73.07	1.59		
Auditory X Visual X Haptic	6	9.75	1.63	0.93	0.4757
Auditory X Visual X Haptic X Subject	129	225.41	1.75		
TOTAL	565	725.26			

* $p < 0.05$ (significant)

Appendix O: ANOVAs for Objective Data

Table O.9 Speed Variance

Source	DF	SS	MS	F value	P value
Between					
Subject	23	1152896.97	50125.96		
Within					
Auditory	3	246391.74	82130.58	24.44	<.0001 *
Auditory X Subject	69	231832.91	3359.90		
Visual	2	160809.92	80404.96	17.50	<.0001 *
Visual X Subject	46	211382.20	4595.27		
Haptic	1	3052.71	3052.71	0.72	0.4043
Haptic X Subject	23	97286.47	4229.85		
Auditory X Visual	6	147539.11	2459.85	8.09	<.0001 *
Auditory X Visual X Subject	137	416190.03	3037.88		
Auditory X Haptic	3	13448.25	4482.75	1.91	0.1366
Auditory X Haptic X Subject	69	162243.76	2351.36		
Visual X Haptic	2	347.74	173.87	0.07	0.9321
Visual X Haptic X Subject	46	113501.76	2467.43		
Auditory X Visual X Haptic	6	58999.65	9833.27	3.52	0.0029 *
Auditory X Visual X Haptic X Subject	129	359893.26	2789.87		
TOTAL	565	3375816.48			

* $p < 0.05$ (significant)

Table O.10 Time-Out-Of-Lane

Source	DF	SS	MS	F value	P value
Between					
Subject	23	1099.44	47.80		
Within					
Auditory	3	99.76	33.25	7.96	0.0001 *
Auditory X Subject	69	288.43	4.18		
Visual	2	9.55	4.77	1.29	0.2838
Visual X Subject	46	169.60	3.69		
Haptic	1	0.29	0.29	0.17	0.6804
Haptic X Subject	23	38.93	1.69		
Auditory X Visual	6	13.79	2.30	0.64	0.6941
Auditory X Visual X Subject	137	488.32	3.56		
Auditory X Haptic	3	14.40	4.80	1.37	0.2578
Auditory X Haptic X Subject	69	240.99	3.49		
Visual X Haptic	2	4.34	2.17	0.64	0.5314
Visual X Haptic X Subject	46	155.63	3.38		
Auditory X Visual X Haptic	6	14.15	2.36	0.62	0.7120
Auditory X Visual X Haptic X Subject	128	484.85	3.79		
TOTAL	564	3122.47			

* $p < 0.05$ (significant)

Appendix P: Remaining Chi-Squared Tables for Objective Data

Table P.1 Visual Main Effect

	Visual			
	None	Icon	Tone	Total
Lane Deviations	149	140	132	**421**

DF	Value	*p* -value
2	1.0838	0.6123

Table P.2 Haptic Main Effect

	Haptic		
	Icon	Tone	Total
Lane Deviations	212	209	**421**

DF	Value	*p* -value
1	0.0214	0.8885

Table P.3 Auditory X Visual Interaction

		Auditory				
Lane Deviations		None	Icon	Tone	Speech	Total
Visual	None	45	36	41	27	149
	HDD	46	32	34	28	140
	HUD	45	31	26	30	132
	Total	136	99	101	85	**421**

DF	Value	*p* -value
6	2.9310	0.8161

Table P.4 Auditory X Haptic Interaction

		Auditory				
Lane Deviations		None	Icon	Tone	Speech	Total
Haptic	None	68	48	54	42	212
	Acc	68	51	47	43	209
	Total	136	99	101	85	**421**

DF	Value	*p* -value
3	0.5665	0.9038

Appendix P: Remaining Chi-Squared Tables for Objective Data

Table P.5 Visual X Haptic Interaction

	Lane Deviations	Visual: None	HDD	HUD	Total
Haptic	None	81	68	63	212
	Acc	68	72	69	209
	Total	149	140	132	**421**

DF	Value	*p* -value
2	1.4999	0.4777

Table P.6 Auditory X Visual X Haptic Interaction

Visual / Haptic	**Lane Deviations**	Auditory: None	Icon	Tone	Speech	Total
None	None	26	18	23	14	81
	Acc	19	18	18	13	68
HDD	None	22	18	17	11	68
	Acc	24	14	17	17	72
HUD	None	20	12	14	17	63
	Acc	25	19	12	13	69
	Total	136	99	101	85	**421**

DF	Value	*p* -value
6	7.8775	0.2475

Appendix Q: ANOVAs for Objective Data – by Age and Condition

Table Q.1 Throttle Reaction Time by Age and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	2.16	2.16	0.22	0.6471
Subject(Age)	22	220.38	10.02		
Within					
Condition	23	505.29	21.97	17.46	<.0001 *
Age X Condition	23	96.69	4.20	3.34	<.0001 *
Condition X Subject(Age)	471	592.53	1.26		
TOTAL	540	1417.04			

* $p < 0.05$ (significant)

Table Q.2 Brake Reaction Time by Age and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	35.82	35.82	2.97	0.0991
Subject(Age)	22	265.78	12.08		
Within					
Condition	23	465.35	20.23	13.91	<.0001 *
Age X Condition	23	114.12	4.96	3.41	<.0001 *
Condition X Subject(Age)	466	677.84	1.45		
TOTAL	535	1558.91			

* $p < 0.05$ (significant)

Table Q.3 Curve Entrance Velocity by Age and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	3296.40	3296.40	15.29	0.0007 *
Subject(Age)	22	4741.59	215.53		
Within					
Condition	23	8779.16	381.70	11.95	<.0001 *
Age X Condition	23	1241.05	53.96	1.69	0.0242 *
Condition X Subject(Age)	496	15837.56	31.93		
TOTAL	565	33895.76			

* $p < 0.05$ (significant)

Appendix Q: ANOVAs for Objective Data – by Age and Condition

Table Q.4 Curve Entrance Lane Position by Age and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	9.71	9.71	1.25	0.2750
Subject(Age)	22	170.46	7.75		
Within					
Condition	23	42.47	1.85	1.16	0.2728
Age X Condition	23	42.99	1.87	1.18	0.2590
Condition X Subject(Age)	496	787.12	1.59		
TOTAL	565	1052.75			

* $p < 0.05$ (significant)

Table Q.5 Curve Apex Velocity by Age and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	3046.48	3046.48	19.97	0.0002 *
Subject(Age)	22	3355.96	152.54		
Within					
Condition	23	550.83	23.95	1.72	0.0203 *
Age X Condition	23	342.23	14.88	1.07	0.3750
Condition X Subject(Age)	496	6895.89	13.90		
TOTAL	565	14191.39			

* $p < 0.05$ (significant)

Table Q.6 Curve Apex Lane Position by Age and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	37.93	37.93	5.01	0.0357 *
Subject(Age)	22	166.59	7.57		
Within					
Condition	23	104.79	4.56	0.82	0.7039
Age X Condition	23	90.47	3.93	0.71	0.8374
Condition X Subject(Age)	496	2747.93	5.54		
TOTAL	565	3147.71			

* $p < 0.05$ (significant)

Appendix Q: ANOVAs for Objective Data – by Age and Condition

Table Q.7 Curve Exit Velocity by Age and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	7301.59	7301.59	22.25	0.0001 *
Subject(Age)	22	7218.83	328.13		
Within					
Condition	23	321.33	13.97	0.96	0.5190
Age X Condition	23	828.54	36.02	2.47	0.0002 *
Condition X Subject(Age)	496	7230.00	14.58		
TOTAL	565	22900.30			

* $p < 0.05$ (significant)

Table Q.8 Curve Exit Lane Position by Age and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	3.18	3.18	2.03	0.1687
Subject(Age)	22	34.51	1.57		
Within					
Condition	23	24.26	1.05	0.86	0.6476
Age X Condition	23	40.40	1.76	1.44	0.0859
Condition X Subject(Age)	496	605.09	1.22		
TOTAL	565	707.43			

* $p < 0.05$ (significant)

Table Q.9 Speed Variance by Age and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	534364.88	534364.88	19.00	0.0003 *
Subject(Age)	22	618844.90	28129.31		
Within					
Condition	23	642575.92	27938.08	9.24	<.0001 *
Age X Condition	23	115265.19	5011.53	1.66	0.0288 *
Condition X Subject(Age)	496	1499336.01	3022.86		
TOTAL	565	3410386.90			

* $p < 0.05$ (significant)

Appendix Q: ANOVAs for Objective Data – by Age and Condition

Table Q.10 Time-Out-Of-Lane by Age and Condition

Source	DF	SS	MS	F value	P value	
Between						
Age	1	2.72	2.72	0.05	0.8183	
Subject(Age)	22	1105.34	50.24			
Within						
Condition	23	154.67	6.72	1.83	0.0110	*
Age X Condition	23	112.06	4.87	1.33	0.1425	
Condition X Subject(Age)	495	1817.03	3.67			
TOTAL	564	3191.81				

* $p < 0.05$ (significant)

Appendix R: Chi-Squared Tables for Objective Data – by Age and Condition

Table R.1 Age Main Effect

	Age		
	Young	Older	Total
Lane Deviations	214	207	**421**

DF	Value	*p*-value
1	0.1164	0.7343

Table R.2 Condition Main Effect

	Condition																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total
Lane Deviations	26	18	18	14	12	19	18	23	17	17	14	12	18	14	11	17	17	13	13	22	24	20	25	19	**421**

DF	Value	*p*-value
23	23.5986	0.4315

Table R.3 Age X Condition Interaction

		Condition																								
Lane Deviations		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total
Age	Younger	16	10	9	7	8	8	10	15	9	7	7	7	7	11	6	9	9	5	7	11	8	8	8	12	214
	Older	10	8	9	7	4	11	8	8	8	10	7	5	11	3	5	8	8	8	6	11	16	12	17	7	207
	Total	26	18	18	14	12	19	18	23	17	17	14	12	18	14	11	17	17	13	13	22	24	20	25	19	**421**

DF	Value	*p*-value
23	21.038	0.5979

Appendix S: ANOVAs for Objective Data – by Gender and Condition

Table S.1 Throttle Reaction Time by Gender and Condition

Source	DF	SS	MS	F value	P value
Between					
Gender	1	2.51	2.51	0.25	0.6214
Subject(Gender)	22	219.82	9.99		
Within					
Condition	23	508.97	22.13	16.15	<.0001 *
Gender X Condition	23	43.81	1.90	1.39	0.1083
Condition X Subject(Gender)	471	645.41	1.37		
TOTAL	540	1420.52			

* $p < 0.05$ (significant)

Table S.2 Brake Reaction Time by Gender and Condition

Source	DF	SS	MS	F value	P value
Between					
Gender	1	46.37	46.37	4.03	0.0571
Subject(Gender)	22	253.05	11.50		
Within					
Condition	23	458.47	19.93	12.45	<.0001 *
Gender X Condition	23	45.92	2.00	1.25	0.1991
Condition X Subject(Gender)	466	746.04	1.60		
TOTAL	535	1549.84			

* $p < 0.05$ (significant)

Table S.3 Curve Entrance Velocity by Gender and Condition

Source	DF	SS	MS	F value	P value
Between					
Gender	1	450.91	450.91	1.31	0.2650
Subject(Gender)	22	7582.73	344.67		
Within					
Condition	23	8758.84	380.82	11.57	<.0001 *
Gender X Condition	23	758.62	32.98	1.00	0.4602
Condition X Subject(Gender)	496	16319.99	32.90		
TOTAL	565	33871.09			

* $p < 0.05$ (significant)

Appendix S: ANOVAs for Objective Data – by Gender and Condition

Table S.4 Curve Entrance Lane Position by Gender and Condition

Source	DF	SS	MS	F value	P value
Between					
Gender	1	12.50	12.50	1.67	0.2095
Subject(Gender)	22	134.49	7.48		
Within					
Condition	23	42.63	1.85	1.15	0.2829
Gender X Condition	23	33.08	1.44	0.89	0.6060
Condition X Subject(Gender)	496	797.03	1.61		
TOTAL	565	1019.73			

* $p < 0.05$ (significant)

Table S.5 Curve Apex Velocity by Gender and Condition

Source	DF	SS	MS	F value	P value
Between					
Gender	1	296.79	296.79	1.06	0.3153
Subject(Gender)	22	6182.55	281.02		
Within					
Condition	23	570.78	24.82	1.83	0.0111 *
Gender X Condition	23	513.03	22.31	1.65	0.0308 *
Condition X Subject(Gender)	496	6725.09	13.56		
TOTAL	565	14288.24			

* $p < 0.05$ (significant)

Table S.6 Curve Apex Lane Position by Gender and Condition

Source	DF	SS	MS	F value	P value
Between					
Gender	1	10.45	10.45	1.20	0.2858
Subject(Gender)	22	192.01	8.73		
Within					
Condition	23	104.64	4.55	0.83	0.6934
Gender X Condition	23	120.90	5.26	0.96	0.5176
Condition X Subject(Gender)	496	2717.49	5.48		
TOTAL	565	3145.49			

* $p < 0.05$ (significant)

Appendix S: ANOVAs for Objective Data – by Gender and Condition

Table S.7 Curve Exit Velocity by Gender and Condition

Source	DF	SS	MS	F value	P value
Between					
Gender	1	489.95	489.95	0.76	0.3919
Subject(Gender)	22	14132.74	642.40		
Within					
Condition	23	326.18	14.18	0.94	0.5474
Gender X Condition	23	556.34	24.19	1.60	0.0391 *
Condition X Subject(Gender)	496	7502.20	15.13		
TOTAL	565	23007.42			

* $p < 0.05$ (significant)

Table S.8 Curve Exit Lane Position by Gender and Condition

Source	DF	SS	MS	F value	P value
Between					
Gender	1	4.43	4.43	2.91	0.1021
Subject(Gender)	22	33.50	1.52		
Within					
Condition	23	25.76	1.12	0.91	0.5906
Gender X Condition	23	32.47	1.41	1.14	0.2945
Condition X Subject(Gender)	496	613.02	1.24		
TOTAL	565	709.17			

* $p < 0.05$ (significant)

Table S.9 Speed Variance by Gender and Condition

Source	DF	SS	MS	F value	P value
Between					
Gender	1	61172.15	61172.15	1.23	0.2799
Subject(Gender)	22	1096775.72	49853.44		
Within					
Condition	23	631205.62	27443.72	8.83	<.0001 *
Gender X Condition	23	73055.74	3176.34	1.02	0.4349
Condition X Subject(Gender)	496	1541545.45	3107.96		
TOTAL	565	3403754.69			

* $p < 0.05$ (significant)

Appendix S: ANOVAs for Objective Data – by Gender and Condition

Table S.10 Time-Out-Of-Lane by Gender and Condition

Source	DF	SS	MS	F value	P value
Between					
Gender	1	9.48	9.48	0.19	0.6668
Subject(Gender)	22	1095.14	49.78		
Within					
Condition	23	151.81	6.60	1.76	0.0161 *
Gender X Condition	23	77.40	3.37	0.90	0.5996
Condition X Subject(Gender)	495	1851.69	3.74		
TOTAL	564	3185.52			

* $p < 0.05$ (significant)

Appendix T: Remaining Chi-Squared Tables for Objective Data – by Gender and Condition

Table T.1 Gender Main Effect

	Gender		
	Male	Female	Total
Lane Deviations	226	195	**421**

DF	Value	*p*-value
1	2.2827	0.1398

Table T.2 Condition Main Effect

	Condition																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total
Lane Deviations	26	18	18	14	12	19	18	23	17	17	14	12	18	14	11	17	17	13	13	22	24	20	25	19	**421**

DF	Value	*p*-value
23	23.5986	0.4315

Table T.3 Gender X Condition Interaction

		Condition																								
Lane Deviations		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total
Age	Male	14	12	12	6	4	6	11	13	11	11	6	7	13	7	4	9	9	5	9	9	12	9	13	14	226
	Female	12	6	6	8	8	13	7	10	6	6	8	5	5	7	7	8	8	8	4	13	12	11	12	5	195
	Total	26	18	18	14	12	19	18	23	17	17	14	12	18	14	11	17	17	13	13	22	24	20	25	19	**421**

DF	Value	*p*-value
23	24.622	0.3759

Appendix U: ANOVAs for Post Condition Questionnaire

Table U.1 Urgency Ratings

Source	DF	SS	MS	F value	P value
Between					
Subject	23	180.22	7.84		
Within					
Auditory	3	130.84	43.61	23.75	<.0001 *
Auditory X Subject	69	126.70	1.84		
Visual	2	64.11	32.06	40.65	<.0001 *
Visual X Subject	46	36.27	0.79		
Haptic	1	3.03	3.03	4.78	0.0392 *
Haptic X Subject	23	14.60	0.63		
Auditory X Visual	6	29.86	4.98	8.64	<.0001 *
Auditory X Visual X Subject	137	78.86	0.58		
Auditory X Haptic	3	2.85	0.95	3.07	0.0333 *
Auditory X Haptic X Subject	69	21.36	0.31		
Visual X Haptic	2	0.34	0.17	0.50	0.6116
Visual X Haptic X Subject	46	15.59	0.34		
Auditory X Visual X Haptic	6	6.94	1.16	4.31	0.0005 *
Auditory X Visual X Haptic X Subject	130	34.87	0.27		
TOTAL	566	746.45			

* $p < 0.05$ (significant)

Table U.2 Annoyance Ratings

Source	DF	SS	MS	F value	P value
Between					
Subject	23	154.15	6.70		
Within					
Auditory	3	158.25	52.75	16.23	<.0001 *
Auditory X Subject	69	224.28	3.25		
Visual	2	8.11	4.06	2.84	0.0688
Visual X Subject	46	65.74	1.47		
Haptic	1	12.38	12.38	7.45	0.0119 *
Haptic X Subject	23	38.21	1.66		
Auditory X Visual	6	7.96	1.33	2.04	0.0642
Auditory X Visual X Subject	137	89.07	0.65		
Auditory X Haptic	3	1.69	0.56	1.21	0.3139
Auditory X Haptic X Subject	69	32.29	0.47		
Visual X Haptic	2	0.22	0.11	0.36	0.7029
Visual X Haptic X Subject	46	13.93	0.30		
Auditory X Visual X Haptic	6	1.12	0.19	0.59	0.7339
Auditory X Visual X Haptic X Subject	130	40.69	0.31		
TOTAL	566	848.10			

* $p < 0.05$ (significant)

Appendix U: ANOVAs for Post Condition Questionnaire

Table U.3 Appropriateness Ratings

Source	DF	SS	MS	F value	P value
Between					
Subject	23	159.28	6.93		
Within					
Auditory	3	181.13	60.38	35.52	<.0001 *
Auditory X Subject	69	117.28	1.70		
Visual	2	101.38	50.69	32.87	<.0001 *
Visual X Subject	46	70.94	1.54		
Haptic	1	0.15	0.15	0.19	0.6631
Haptic X Subject	23	18.16	0.79		
Auditory X Visual	6	31.21	5.20	8.48	<.0001 *
Auditory X Visual X Subject	137	84.02	0.61		
Auditory X Haptic	3	0.95	0.32	1.01	0.3949
Auditory X Haptic X Subject	69	21.78	0.32		
Visual X Haptic	2	4.76	2.38	5.51	0.0072 *
Visual X Haptic X Subject	46	19.89	0.43		
Auditory X Visual X Haptic	6	7.12	1.19	3.09	0.0073 *
Auditory X Visual X Haptic X Subject	130	49.86	0.38		
TOTAL	566	867.91			

* $p < 0.05$ (significant)

Table U.4 Interference Ratings

Source	DF	SS	MS	F value	P value
Between					
Subject	23	175.20	7.62		
Within					
Auditory	3	78.20	26.07	10.52	<.0001 *
Auditory X Subject	69	171.03	2.48		
Visual	2	7.32	3.66	1.76	0.1833
Visual X Subject	46	95.62	2.08		
Haptic	1	14.23	14.23	7.92	0.0099 *
Haptic X Subject	23	41.35	1.80		
Auditory X Visual	6	3.40	0.57	0.88	0.5108
Auditory X Visual X Subject	137	88.02	0.64		
Auditory X Haptic	3	1.11	0.37	1.03	0.3833
Auditory X Haptic X Subject	69	24.70	0.36		
Visual X Haptic	2	1.08	0.54	1.27	0.2902
Visual X Haptic X Subject	46	19.55	0.42		
Auditory X Visual X Haptic	6	2.93	0.49	1.34	0.2451
Auditory X Visual X Haptic X Subject	130	47.52	0.37		
TOTAL	566	771.25			

* $p < 0.05$ (significant)

Appendix U: ANOVAs for Post Condition Questionnaire

Table U.5 Want Ratings

Source	DF	SS	MS	F value	P value
Between					
Subject	23	247.57	10.76		
Within					
Auditory	3	184.63	61.54	21.71	<.0001 *
Auditory X Subject	69	195.59	2.83		
Visual	2	50.19	25.09	17.04	<.0001 *
Visual X Subject	46	67.76	1.47		
Haptic	1	9.74	9.74	7.22	0.0132 *
Haptic X Subject	23	31.05	1.35		
Auditory X Visual	6	28.23	4.71	8.63	<.0001 *
Auditory X Visual X Subject	137	74.68	0.55		
Auditory X Haptic	3	0.31	0.10	0.22	0.8791
Auditory X Haptic X Subject	69	31.70	0.46		
Visual X Haptic	2	2.78	1.39	3.91	0.0270 *
Visual X Haptic X Subject	46	16.32	0.35		
Auditory X Visual X Haptic	6	5.45	0.91	2.59	0.0211 *
Auditory X Visual X Haptic X Subject	130	45.62	0.35		
TOTAL	566	991.62			

* $p < 0.05$ (significant)

Appendix V: ANOVAs for Post Condition Questionnaire by Age and Condition

Table V.1 Urgency Ratings by Age and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	19.06	19.06	2.62	0.1197
Subject(Age)	22	160.04	7.27		
Within					
Condition	23	248.91	10.82	17.19	<.0001 *
Age X Condition	23	18.78	0.82	1.30	0.1620
Condition X Subject(Age)	497	312.96	0.63		
TOTAL	566	759.76			

* $p < 0.05$ (significant)

Table V.2 Annoyance Ratings by Age and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	15.99	15.99	2.54	0.1252
Subject(Age)	22	138.44	6.29		
Within					
Condition	23	191.04	8.31	9.43	<.0001 *
Age X Condition	23	74.49	3.24	3.68	<.0001 *
Condition X Subject(Age)	497	437.73	0.88		
TOTAL	566	857.70			

* $p < 0.05$ (significant)

Table V.3 Appropriateness Ratings by Age and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	3.93	3.93	0.56	0.4606
Subject(Age)	22	153.13	6.96		
Within					
Condition	23	332.34	14.45	19.97	<.0001 *
Age X Condition	23	22.19	0.96	1.33	0.1387
Condition X Subject(Age)	497	359.56	0.72		
TOTAL	566	871.15			

* $p < 0.05$ (significant)

Appendix V: ANOVAs for Post Condition Questionnaire by Age and Condition

Table V.4 Interference Ratings by Age and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	7.76	7.76	1.03	0.3215
Subject(Age)	22	166.00	7.55		
Within					
Condition	23	106.93	4.65	5.28	<.0001 *
Age X Condition	23	52.80	2.30	2.61	<.0001 *
Condition X Subject(Age)	497	437.83	0.88		
TOTAL	566	771.32			

* $p < 0.05$ (significant)

Table V.5 Want Ratings by Age and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	33.88	33.88	3.52	0.0740
Subject(Age)	22	211.84	9.63		
Within					
Condition	23	282.13	12.27	14.80	<.0001 *
Age X Condition	23	50.09	2.18	2.63	<.0001 *
Condition X Subject(Age)	497	411.86	0.83		
TOTAL	566	989.79			

* $p < 0.05$ (significant)

Appendix W: ANOVAs for Post Condition Questionnaire by Gender and Condition

Table W.1 Urgency Ratings by Gender and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	0.00	0.00	0.85	0.3662
Subject(Age)	22	0.00	0.00		
Within					
Condition	23	701.74	30.51	1.03E30	<.0001 *
Age X Condition	23	0.00	0.00	0.35	0.9982
Condition X Subject(Age)	497	0.00	0.00		
TOTAL	566	701.74			

* $p < 0.05$ (significant)

Table W.2 Annoyance Ratings by Gender and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	0.00	0.00	0.67	0.4211
Subject(Age)	22	0.00	0.00		
Within					
Condition	23	375.32	16.32	7.05E29	<.0001 *
Age X Condition	23	0.00	0.00	0.64	0.9030
Condition X Subject(Age)	497	0.00	0.00		
TOTAL	566	375.32			

* $p < 0.05$ (significant)

Table W.3 Appropriateness Ratings by Gender and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	0.00	0.00	0.81	0.3780
Subject(Age)	22	0.00	0.00		
Within					
Condition	23	141.60	6.16	5.8E29	<.0001 *
Age X Condition	23	0.00	0.00	0.21	1.0000
Condition X Subject(Age)	497	0.00	0.00		
TOTAL	566	141.60			

* $p < 0.05$ (significant)

Appendix W: ANOVAs for Post Condition Questionnaire by Gender and Condition

Table W.4 Interference Ratings by Gender and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	0.91	0.91	0.11	0.7417
Subject(Age)	22	179.62	8.16		
Within					
Condition	23	247.73	10.77	16.85	<.0001 *
Age X Condition	23	14.14	0.61	0.96	0.5142
Condition X Subject(Age)	497	317.60	0.64		
TOTAL	566	760.00			

* $p < 0.05$ (significant)

Table W.5 Want Ratings by Gender and Condition

Source	DF	SS	MS	F value	P value
Between					
Age	1	0.11	0.11	0.02	0.9006
Subject(Age)	22	155.24	7.06		
Within					
Condition	23	192.42	8.37	8.51	<.0001 *
Age X Condition	23	23.42	1.02	1.04	0.4178
Condition X Subject(Age)	497	488.80	0.98		
TOTAL	566	860.00			

* $p < 0.05$ (significant)

Appendix X: Content Analysis – Comments Divided by Code

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

<u>Positive Comments:</u>

Pos – good visual icon
- No, I like the flashing sign higher up, I am less distracted
- Good curve direction location.
- The flashing sign was good
- Better location of sign

Pos – liked length of warning
- I liked the time length of the warning
- I did like the sign flashed longer

Pos – change nothing
- No (25 comments)
- no good
- none (4 comments)
- Nothing (2 comments)
- It's a good system change nothing
- No. What I liked about the audio was it told me exactly what to expect
- no suggested change
- No. I liked this one. (2 comments)

Pos – could be used
- Yes. If I knew the road this warning would be sufficient.
- This would be ok, but like #23 [Tone & HDD] better.
- Could be used, it gets your attention, prefer others

Pos – sound is nice
- The sound effect is a lot nicer.

Pos – better or best condition
- Better use of direction arrow
- Better - once you know that the sound means to slow down.
- although in previous tests I heard and saw this better this time.
- The voice is better than beeping
- This was better
- Best set up I've had so far
- No, this was my favorite thus far.
- I liked it the best.

Appendix X: Content Analysis – Comments Divided by Code

Pos – combination more effective
- The combination of the beep and the flashing curve error was more effective than each alone.

Pos – sound conveys urgency
- The sound does raise urgency in my opinion.
- Maybe the sense of urgency.
- I think the beeping sound, although probably more annoying, does raise the sense of urgency.

Pos – not as adverse as before
- Because this was my "second" experience with the beep it was not as adverse as the first experience.

Pos – good warning
- A good warning; second overall; I just like warning tone and low visual the best
- this one is good
- good one

Pos – like being visually and audibly warned
- but I like the idea of being visually and audibly warned

Pos – voice is best
- voice is best

Pos – getting used to
- Once you realize and get use to it I feel you could drive better.

<u>Negative comments:</u>

Neg – not enough information
- A better explanation of the curve, curve speed,
- Its good that it doesn't distract field of vision, but gives no idea how sharp the turn is.
- If I had not been taking the test 9 times would not have know what was going on.
- A little more information about what coming up
- The only thing I would change would be to know what to expect from the warning
- The tire screeching told me nothing about the nature of the warning.
- Let the driver know what speed to take the turn
- Did not convey sense of meaning
- It was too vague. It didn't specify what type of turn or give any suggestions regarding speed. It was also too easy to ignore
- too ambiguous
- Left too many things not answered the speed the direction no good

Appendix X: Content Analysis – Comments Divided by Code

- I liked this warning but it does not tell you what to decelerate to.
- I don't really know. It wouldn't help much unless the driver knew what it was for. If I heard that sound in my car I'd first think it was like the seatbelt or the oil light or something.
- not enough information given
- I needed to know the recommend speed to drive during the curve and also how far ahead curve was located.
- not definite enough
- speed suggestion needed
- Let the driver know what speed he should enter turn in
- too vague
- I was confused about the beeping sound and the flashing image of a curve on the screen. I'm puzzled did the flashing curve image appear before? If so I did not notice it because I was so concentrating on the beep.
- In addition, I would like to know how much time I have to decrease my speed.
- let the driver know how fast he can take the turn
- you need something to identify the message
- In addition, how far ahead the curve is would help.
- Needs some type of warning, sign or some type of warning of curve ahead.
- Add something to recommend a speed
- sound but no directions
- No direction given
- Add direction of curve
- direction of the curve maybe a faster warning time
- No direction of curve given
- Yes. I do not like the screeching sound or lack of curve direction and speed limitation.
- The sound is a bit random
- Give distance or time to the curve.
- You might not realize what the beeping indicated and after several curves it would be annoying.

Neg – change auditory warning

- change the warning sound
- Change the warning sound to something less urgent, maybe a tone similar to what you hear when you leave your keys in the ignition when getting out of your vehicle
- Yes. The sound effect.
- The sound!
- Again w/ the screeching tires
- Replace screech noise with a verbal warning
- Use combination of verbal and visual warning
- Use verbal and visual warnings
- Yes. Change to something other than screeching tires. Beeping sounds OK.

Appendix X: Content Analysis – Comments Divided by Code

- The beeping
- Use a combination of verbal and visual warning
- Replace the beep noise with a verbal warning
- I might change the beep but the reaction time I had was good
- Include verbal warning (2 comments)
- Change audio voice to a warning tone
- Once again, the voice
- I would change the beep to something else, everything in a car already beeps.
- Sound
- Change sound to a tone instead of screeching tires.
- change voice warning to a tone
- make audible warning a tone, not a voice
- Yes, the sound effect
- Use visual and verbal warnings
- Use combination of verbal and visual warnings
- Yes. It would be better to have voice
- Replace this warning with verbal and visual warnings
- Replace irritating beep with verbal and visual warnings
- Change the warning noise to a tone,
- Again, so many things in a car beep
- Change voice to a warning tone
- I think the beeping sound, although probably more annoying, does raise the sense of urgency.
- Change the warning sound
- Change audible warning to a tone

Neg – add visual warning

- Yes. At least have a road sign to indicate direction of turn and speed. Now that I have become used to warning devices I would want them on my car.
- speed prompt with beep would be better
- Yes, the warning I prefer the most is the visual flashing light. I would add that to this warning.
- Prefer sound and signs.
- Add something visual
- Yes, I would add a visual warning.
- Add direction arrow
- I would put the flashing light with it. (the one in the windshield not the one in the dashboard)
- Include visual warning in case background noise would deter clarity of the verbal warning.
- Yes. I would add the light.
- Larger flashing lights.

Appendix X: Content Analysis – Comments Divided by Code

- Add visual like others in lower part of windshield;
- Use visual and verbal warnings
- Use combination of verbal and visual warnings

arrow showing curve direction

- Replace this warning with verbal and visual warnings
- Replace irritating beep with verbal and visual warnings
- Yes, I would add a light warning.
- Yes, the blinking light is more useful than the sound effect (at least this particular sound) in my opinion
- A visual warning or audible tone before the curve
- Include verbal and visual warnings
- Provide verbal and visual warnings
- A visual warning or audible tone before the curve
- Include verbal and visual warnings
- Provide verbal and visual warnings
- Provide visual warning on lower part of windshield;

Neg – remove auditory warning

- It was weird.
- Yes. I do not like the screeching sound or lack of curve direction and speed limitation.
- Do not like the sound - I suppose if I got use to the sound, it may be ok.
- noise not necessary
- Yes, the sound of screeching tires for the sound effect isn't very pleasant
- Take out the sound - use sign
- That stupid noise! It's terrible!
- Yes. Not use the screeching sound. I would like to see the car automatically adjust the speed like cruise control (Go from 55 to 20mph).
- Take out the sound
- I might take away the voice.
- I still don't like the sound effect.
- Yes. Loose the brake screeching sound.
- The flashing sign was good but the noise was not
- Delete the screeching tires (2 comments)
- However, the braking sound is kind of weird.
- This was better but I would still lose the gas pedal lock

Neg – auditory warning is startling

- Again, problem needs to be identified screeching is scary

sounds like an accident outside

- This warning is alarming, reminds me of something wrong with driving, like tires or brakes.
- That tire screeching still freaks me out

Appendix X: Content Analysis – Comments Divided by Code

- The brake noise is kind of unsettling
- This warning scared me and I lost concentration
- The screeching tire noise is sort of nerve racking/frightening
- The noise is terrible. I think I would be more prone to be startled and have an accident that I would be to take all the turns properly because of this device
- sounds like an accident outside
- The "screeching" just about causes me to "jump-out-of-the seat!!"
- screeching of brakes leads to too much panic
- sounded like an outside noise
- that noise makes me think I'm about to be rear-ended
- Well, its just that if you were in a conversation with a passenger or lost in thought, a woman's (or man's, for that matter) voice suddenly telling you to slow down could be really startling.
- the voice, it's a nice voice and very appropriate for its purpose, but I think a voice could startle or interrupt conversation, especially on a curvy road.
- The voice is better than beeping but still kind of startling.

Neg – increase auditory volume
- sound should be louder
- as stated before. Crash sound should be louder
- If you had the radio on or were talking you wouldn't hear just the beeping (2 comments)

Neg – remove haptic warning
- Do not have the accelerator kick back; if I had cruise control on I would not have felt it
- Don't like the accelerator override feedback thing too much, feels like the car is broken.
- Don't have the accelerator kick back, it interferes w/ driving
- Do not like the accelerator feedback, seem like it should just slow the car down for me.
- Yes, my preference would be to not have the change in pedal resistance.
- The gas pedal lock startles me a bit
- Don't mess with the accelerator (2 comments)
- Lose the accelerator modification
- The pedal
- Don't have the accelerator kick back (8 comments)
- Yes, I think I would do away with the pedal resistance, but I can see how others would prefer it.
- I feel like I'm being forced to react w/ the pedal thing but not in a good way
- I would just think that something was wrong with my car, and get freaked out, if my accelerator just got stuck suddenly.
- I didn't like the pedal thing,

Appendix X: Content Analysis – Comments Divided by Code

- Yes, I prefer not having the pedal offer resistance.
- I kind of don't like how it decides to stop accelerating for me, but I do think that that is an effective way of doing it.
- I'm not sure how I feel about the pedal since my first reaction was to see if I could push it down.
- not modify accelerator
- drop the accelerator alteration.
- I would loose the pedal warning
- I don't like how it stops accelerating

Neg – excessive / overload
- It was kind of overdramatic.
- Yes, there may have been too many warnings at once. I don't know if that is something that wouldn't bother someone once they had gotten used to it.
- Too many indicators.
- Too much going on (blinking sign on windshield and woman talking)
- 3 types of warning for one device seems excessive –
- Screeching tires AND gas lock? It seems excessive
- Yes. Overkill on the alarm.

Neg – add auditory warning
- Have an audible tone similar to the one that has been used (not the screeching tires)
- Missed the verbal portion
- Include verbal warning
- Not as good as audio or the beep plus the flashing curve sign.
- Include verbal warning
- Need verbal warning to supplement visual warning
- I missed having the sound effect, not the sound.
- no verbal warning
- Yes. Also a voice warning helps.
- Voice warning would be good addition.

Neg – don't use entire condition
- Don't use it (3 comments)
- use a different warning
- All together I wouldn't use it.

Neg – change the location of the visual icon
- I don't like it on the windshield
- Yes, I would change the position of the warning light.
- Yes. The arrow showing curve direction should be on the side of the curve direction not on left side of right hand turn.
- Lower the visual

Appendix X: Content Analysis – Comments Divided by Code

- color, location, driver feedback
- Placement of graphic on side of turn
- I thought the blinking light should have been in the windshield.
- Make visual warning more obvious
- Yes, I would change the position of the visual warning to the dash.
- location and intensity of graphic
- position of visual was distracting
- Put it on the screen above
- I like the flashing sign on the actual screen better
- Yes. Put the curve warning on the side of the curve direction.
- Don't put on the windshield
- Put the visual warning lower; out of the way of where you need to see to navigate the turn
- Yes, I liked the position of the light better on the dash than on the windshield.
- Don't put it on the windshield
- Don't put it in the middle of the windshield
- Yes, the position of the visual warning to the dash.
- Put the visual lower on the windshield; it distracts.
- Lower the visual (4 comments)
- Yes, I'd change the position of the light.
- The curve warning should be on the same side as the curve.

Neg – change aesthetic characteristics of the visual icon

- Change the color to a brighter color.
- color, location, driver feedback
- The graphic that flashes could be better to portray info
- Change the color of flashing signal to a brighter color.
- I would make the speed that you should go bigger. It's distracting trying to squint at a tiny number in the corner of your screen.
- color, and graphic
- Make the following signal a brighter color.
- It was small and hard to read. I would want it in darker and large numbers
- Make the flashing signal brighter in color.
- you have better signals to use than this
- Change color of warning signal.
- warning sign needs to be more obvious
- Make the color brighter.
- Change the color.
- Increase the size of the mph recommendation
- signage needs to be more apparent
- Change the color.
- Change the color to a brighter color. Orange/yellow

Appendix X: Content Analysis – Comments Divided by Code

- Make it brighter
- use the flashing sign with a brighter color (2 comments).
- The color of the graphic, and design,
- graphic
- location and intensity of graphic

Neg – took a second to notice visual
- Yes, it took me a second to recognize the flashing light was present,
- Yes. It took me a few driving feet to see the warning device -

Neg – visual blocks roadway view
- Not have it in the way of the road I'm trying to drive on.
- recommended speed is hard to read if paying attention to the road
- Watching both screens for first time made it worse to drive.
- I'm trying to look to the right at the curve but the flashing was very distracting and in my line of view
- It sort of blocked my field on the road
- had to take focus off the road to look at it
- It was in my line of sight
- arrow got in line of vision
- Put the visual lower on the windshield; it distracts.

Neg – remove/change visual flashing
- no flashing (7 comments)
- not such fast flashes
- dizzying, better if it didn't flash
- The device was disorienting to me, made it hard to focus.
- slow down flashing
- Yellow flashing light was distracting.
- flashing speed limit is annoying
- distracting and disorienting
- not such fast flashing
- The flashing on this was too much
- Did not like the flashing (2 comments)
- no flashing - it's distracting

Neg – warning timing too early
- the timing of the warning. I felt like I had too much time –

Neg – condition seems dangerous
- That just seems dangerous

Appendix X: Content Analysis – Comments Divided by Code

Neg – prefer other conditions

- Could get use to the sounds, but prefer other alerts.
- I now have become more conditioned to the flashing curve sign. I still do not like it as well as other curve warning devices.
- I like the signs and other warnings. It is more safe.
- I'm not sure this is as effective as the audio.
- This would be ok, but like #23 [Tone & HDD] better.
- Could be used, it gets your attention, prefer others

Neg – did not notice a warning

Baseline condition (expected response)

- Give a warning
- Yes, since no alarm went off I kept waiting for one, I guess drivers could become dependent on an alarm like this.
- Well, there wasn't a warning at all, so that should be changed.
- After having warnings I didn't like not having one
- no warning
- I didn't actually notice a warning at all.
- I did not detect any warning device.
- still no warning showed.
- not obvious warning

Non-Baseline condition (unexpected response)

- no definite warning
- I did not detect any warning! I believe I was "set-up." I crashed. But my expectation was from the previous presentation I would receive some kind of a warning.
- I did not detect any warning device.
- Did not see any warning device.
- Did not notice a warning at all, plus I don't drive like this.
- could not detect a warning
- No warning given.
- did not see a warning
- Once again, no warning at all. If there were anything obstructing my view of the curve, I would've probably wrecked.
- I did not detect any warning and I was more prepared this time for a "curve ball."
- anticipation got me!
- No warning at all that I noticed.
- I missed it and am unsure why.

Neg – may become / is annoying

- You might not realize what the beeping indicated and after several curves it would be annoying.
- Well, the beeping noise would get really frustrating on a road with a lot of curves.

Appendix X: Content Analysis – Comments Divided by Code

- Yes, the voice was nice, but she says a lot of information, which I can imagine getting annoying after a while.
- This would get very old in normal driving conditions.
- Plus, on a really curvy road, that could get really annoying
- Again voice and sign are enough and pedal is still annoying
- The resistance on the pedal can get annoying

Neg – have warning appear sooner
- I would have it appear sooner
- Give warning sooner
- I would start it sooner - not enough reaction time
- Maybe give the warning a little sooner
- Give more lead time before reaching the curve.
- Maybe a little sooner? Not sure
- Same comments concerning distance warning.
- Warning should be sooner.

Neg – voice is too calm
- If you had the radio on or were talking you might not pay attention to what she was saying.
- The voice is too calm. It almost negates the urgency inflicted by the flashing light.
- Woman's voice still too calm,.

Neg – change length (time) of warning
- Yes, I'd probably change the length of audio message, maybe to: "curve ahead, slow to 20mph"

Neg – barely noticed haptic warning
- I feel like you might not notice a warning - isn't specific/obvious enough
- Don't know what the warning was, the pedal?
- the pedal I barely noticed (2 comments)

Appendix Y: Content Analysis Frequency Count Summary

Table Y.1 Frequency Count Summary by Warning Condition

	Baseline	Icon	Icon & HDD	Icon & HDD & Accel.el.	Icon & HUD	Icon & HUD & Accel.	Icon & Accel.	Tone	Tone & HDD	Tone & HDD & Accel.el.	Tone & HUD	Tone & HUD & Accel.	Tone & Accel.	Speech	Speech & HDD	Speech & HDD & Accel.	Speech & HUD	Speech & HUD & Accel.	Speech & Accel.	HDD	HDD & Accel.	HUD	HUD & Accel.	Accel.
neg - Not enough information	1	4	1				4	7			1		9	2					2	1	1			2
neg - Change auditory warning		2	6	1	2	1	4	3	2	1	2	1	2		1	2	2	1	1					
neg - add visual warning	3	2					1	4					4	6					1					3
neg - remove auditory warning		3	3	2	4	4																		
neg - auditory warning is startling		3			2	6	2							1	1			1						
neg - increase auditory volume		1			1			1					1											
neg - remove haptic warning				2		1	1			3		3	2			5		3	1		3		3	2
neg - excessive / overload				3		1				2						1		1						
neg - add auditory warning	2																			3	1	4	2	1
neg - don't use entire condition		1	1	1				2																
neg - change the location of the visual icon			1		1	4			1		3	3			1		3	2		2	2	3	2	
neg - change aesthetic characteristics of the visual icon	1				1	2			2	1	2	2			2	2	2	1		3	1	1	1	
neg - took a second to notice visual					1																	1		
neg - visual blocks roadway view					2							2				1		1					1	
neg - remove/change visual flashing					1				2	3	2	2			2	3	1			1	1		1	
neg - warning timing too early							1																	
neg - condition seems dangerous							1																	
neg - prefer other conditions					1		1	1		1													1	1
neg - did not notice a warning	9						1													1	1	3	2	5
neg - may become / is annoying				1				1	1				1					1	1				1	
neg - have warning appear sooner									1		1		1	3	1								1	
neg - voice is too calm														1		1	1							
neg - change length (time) of warning																		1						
neg - barely noticed haptic warning																					1		1	2
pos - Good Visual Icon			1		1												1					1		
pos - Liked length of warning				1		1																		
pos - Change Nothing							2	1	1	3	2	2	1	2	4	3	4	4	5	1		1	1	1
pos - Could be used							1	1																
pos - Sound is nice								1																
pos - Better & Best Condition								1	2	1					2									
pos - Combination more effective									1															
pos - sound conveys urgency							1				1					1								
pos - not as adverse as before												1												
pos - good warning														2				1						
pos - like being visually and audibly warned																	1							
pos - voice is best																	1							
pos - getting used to																					1			

Appendix Z: Remaining Chi-Squared Tables for Content Analysis

Table Z.1 Positive Comments Analysis for Gender Main Effect

	Gender		
	Male	Female	Total
Positive	39	27	**66**

DF	Value	p-value
1	2.1818	0.1493

Table Z.2 Negative Comments Analysis for Age X Gender Interaction

		Gender		
Negative		Male	Female	Total
Age	Younger	103	85	188
	Older	73	56	129
	Total	176	141	**317**

DF	Value	p-value
1	0.1005	0.7520

Appendix AA: ANOVAs for Curve Acceptance Questionnaire

Table AA.1 Useful – Useless Ratings by Age and Gender

Source	DF	SS	MS	F value	P value	
Between						
Age	1	2.04	2.04	4.30	0.0513	
Gender	1	1.04	1.04	2.19	0.1542	
Age X Gender	1	1.04	1.04	2.19	0.1542	
Subject (Age X Gender)	20	9.50	0.48			
TOTAL	23	13.63				

* $p < 0.05$ (significant)

Table AA.2 Pleasant – Unpleasant Ratings by Age and Gender

Source	DF	SS	MS	F value	P value	
Between						
Age	1	2.67	2.67	3.64	0.0710	
Gender	1	0.00	0.00	0.00	1.0000	
Age X Gender	1	0.00	0.00	0.00	1.0000	
Subject (Age X Gender)	20	14.67	0.73			
TOTAL	23	17.33				

* $p < 0.05$ (significant)

Table AA.3 Bad-Good Ratings by Age and Gender

Source	DF	SS	MS	F value	P value	
Between						
Age	1	7.04	7.04	12.25	0.0023	*
Gender	1	1.04	1.04	1.81	0.1934	
Age X Gender	1	0.38	0.38	0.65	0.4288	
Subject (Age X Gender)	20	11.50	0.58			
TOTAL	23	19.9583				

* $p < 0.05$ (significant)

Table AA.4 Nice – Annoying Ratings by Age and Gender

Source	DF	SS	MS	F value	P value	
Between						
Age	1	2.04	2.04	1.74	0.2023	
Gender	1	2.04	2.04	1.74	0.2023	
Age X Gender	1	0.38	0.38	0.32	0.5784	
Subject (Age X Gender)	20	23.50	1.18			
TOTAL	23	27.96				

* $p < 0.05$ (significant)

Appendix AA: ANOVAs for Curve Acceptance Questionnaire

Table AA.5 Effective – Superfluous Ratings by Age and Gender

Source	DF	SS	MS	F value	P value
Between					
Age	1	0.67	0.67	0.78	0.3863
Gender	1	0.17	0.17	0.20	0.6627
Age X Gender	1	0.00	0.00	0.00	1.0000
Subject (Age X Gender)	20	17.00	0.85		
TOTAL	23	17.84			

* $p < 0.05$ (significant)

Table AA.6 Irritating – Likeable Ratings by Age and Gender

Source	DF	SS	MS	F value	P value
Between					
Age	1	4.17	4.17	3.97	0.0602
Gender	1	0.00	0.00	0.00	1.0000
Age X Gender	1	0.17	0.17	0.16	0.6945
Subject (Age X Gender)	20	21.00	1.05		
TOTAL	23	25.33			

* $p < 0.05$ (significant)

Table AA.7 Assisting – Worthless Ratings by Age and Gender

Source	DF	SS	MS	F value	P value
Between					
Age	1	1.50	1.50	2.81	0.1091
Gender	1	0.17	0.17	0.31	0.5824
Age X Gender	1	0.17	0.17	0.31	0.5824
Subject (Age X Gender)	20	10.67	0.53		
TOTAL	23	12.50			

* $p < 0.05$ (significant)

Table AA.8 Undesirable-Desirable Ratings by Age and Gender

Source	DF	SS	MS	F value	P value
Between					
Age	1	6.00	6.00	9.00	0.0071 *
Gender	1	0.00	0.00	0.00	1.0000
Age X Gender	1	0.67	0.67	1.00	0.3293
Subject (Age X Gender)	20	13.33	0.67		
TOTAL	23	20			

* $p < 0.05$ (significant)

Appendix AA: ANOVAs for Curve Acceptance Questionnaire

Table AA.9 Raising Alertness – Sleep-Inducing Ratings by Age and Gender

Source	DF	SS	MS	F value	P value
Between					
Age	1	0.04	0.04	0.11	0.7477
Gender	1	0.04	0.04	0.11	0.7477
Age X Gender	1	0.04	0.04	0.11	0.7477
Subject (Age X Gender)	20	7.83	0.39		
TOTAL	23	7.96			

* $p < 0.05$ (significant)

Appendix AB: Curve Acceptance Comment Summary

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

- The blinking sign on the dashboard w/o any noise. Its visible and not too much overkill.
- Warning tone and visual set low on windshield. It was the most effective and seems to be the one that would work best. It notifies you what speed and direction, and even if you don't hear it you'd still be warned.
- I liked the ones where there was a visual warning on the dash, no added pedal resistance, no car crashing sound effects. This was my favorite combination.
- I liked the one that made a small beeping sound and signaled on the dash - it didn't obstruct my vision, nor was it bad to listen to, but still told the speed I needed to slow to.
- I liked the one with the woman's voice and the blinking HUD. It wasn't annoying or irritating, and it also told which direction the curve was.
- The voice over along with the directional arrow. I did not have to shift focus off the road. Information was clear and forth coming.
- I liked the warning with all three conditions present (sound, flashing sign and pedal movement) because no matter what I am doing in the car or what I am focusing on, something will get my attention,
- When the flashing sign was on the screen, not below it b/c I didn't have to take my eyes off the road. The voice wasn't bad but I can see it getting annoying if it was in your car and you couldn't turn it off.
- I liked almost all of the warnings where the flashing warning was on the windshield. I think it could be accompanied by either the woman speaking or the beeping. Both seem effective.
- I most liked the talking, all the flashing drove me crazy. I think I would pay attention to someone talking to me more.
- The one with only the flashing 20mph sign. I found the noises to be either startling or kind of annoying, and I didn't like it when the throttle just stopped without my control.
- the voice is informative without being alarming.
- The speed and directions of the curves
- I like the verbal warning, gas pedal bump and the curve and speed indication on the curve side. I would like to see speed adjust automatically.
- The audio warning because it did not startle me and immediately identified the condition I was dealing with.
- The warning tones and Heads up Display at top right
- voice + signal
- Verbal was the most desirable because it was easier to discern and less irritating
- Verbal alertness to on-coming curve - adequate time frame to adjust speed - calm verbal cue
- I preferred the visual sign and sound - I felt more comfortable with that one, however most all are effective for safety.

Appendix AB: Curve Acceptance Comment Summary

- The beeping along with the flashing signal. It gives you a heads up that there is a curve coming.
- Verbal warning because you didn't have to take your eyes off road to know or see the symbols
- low visual display with beep or voice - I immediately started to slow down and paid attention to upcoming change in roadway. High visual was distracting; took my attention away from road.
- voice-calming - especially good with speed prompts - which do not to be slowed down

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

- Blinking sign on windshield w/ adjustment to throttle. The both affected my driving negatively.
- The throttle kicking back and the screeching tires noise. Both were annoying and did nothing to notify you of the speed and direction you should be going.
- I liked the first sound effect (tires screeching) the least, since it's not something I like to hear while driving. I like the conditions the least when the pedal offered more resistance. Also, when the visual warning was on the windshield, it was hard
- I'm not sure of the specific scenario, but the ones where the visual cue is covering up part of the road is no good. Also, the one that automatically releases the gas pedal, while effective, is very annoying and I'd never want such a feature on my car.
- I hated all of the screeching alerts. They were very irritating.
- Conditions in which pedal push back was used. Unclear what the car is doing, and distracting. If pedals are going to be adjusted why not just slow the car down for me.
- The sound that sounded like a wreck or car crashing and the one with no warning. The sound of the car crashing was alertful but scary because I really thought a wreck was occurring.
- The gas pedal lock/resistance b/c it seemed dangerous. It was surprising or sudden which gets a reaction that I don't think is beneficial to "curve awareness."
- All of the warnings with the screeching tires were terrible. They threw you into a false panic for something so small as a curve in the road!
- The flashing symbol - very distracting and annoying.
- Probably the one with the flashing sign, throttle stopping, and the beeping (or voice - that one too); it was just too much, and on a road with a lot of curves, that would get really frustrating.
- the screeching brakes sound and the flashing symbol high in the field of vision. The brakes sound makes me think someone's about to hit me and the flashing is too distracting.
- The tire screeching and no warning of direction of curve.
- The screeching sound made me jump and give little value unless the car speed and distance to the curve was in a dangerous condition.

Appendix AB: Curve Acceptance Comment Summary

- The loud screeching as it startled me and interfered with my driving and I did not know what condition I was faced with (i.e. a car coming in the opposite direction in my lane, a lob in the road, etc.)
- The one with the throttle click
- no direction, 2) blinking arrows in path of vision
- The screeching noise was irritating and distracting
- Flashing light with screeching noise - puts on in semi-panic mode (is it the system or the real tires screeching..) - Too many extraneous cues before curve!
- The unexpected, with the pedal feeling - however, if the curve warning was avoidable, it would also serve the purpose. The one that no warning at all, I didn't like that one.
- The screeching tires. This could cause a person to over react and cause a wreck.
- crash sound and beeps (so glad we don't drive like this in real like). Ha!
- Screeching sound usually startled me rather than giving information. Also knowing directionality of curve was important.
- screeching - seemed to lead to mild alarm

Appendix AC: Personal Vita

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Responsible for gathering and analyzing data following Human Factors guidelines and techniques. Also responsible for helping with data reduction, including statistical analysis. Involved in all stages of research, including conducting literature reviews, creating protocols, and writing project reports.

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Publications:

Blanco, M., Hankey, J. M., Neurauter, M. L., and Pashaj, I. (2004). *Performance evaluation of infotainment tasks available while driving on the Lexus GX 470 and Acura MDX*. Blacksburg, VA: Virginia Tech Transportation Institute.

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