Clemson University TigerPrints

All Dissertations

Dissertations

5-2017

Ambient hues and audible cues: An approach to automotive user interface design using multi-modal feedback

Joshua Ime Asukwo Ekandem *Clemson University,* ekandji@gmail.com

Follow this and additional works at: https://tigerprints.clemson.edu/all dissertations

Recommended Citation

Ekandem, Joshua Ime Asukwo, "Ambient hues and audible cues: An approach to automotive user interface design using multi-modal feedback" (2017). *All Dissertations*. 1893. https://tigerprints.clemson.edu/all_dissertations/1893

This Dissertation is brought to you for free and open access by the Dissertations at TigerPrints. It has been accepted for inclusion in All Dissertations by an authorized administrator of TigerPrints. For more information, please contact kokeefe@clemson.edu.

AMBIENT HUES AND AUDIBLE CUES AN APPROACH TO AUTOMOTIVE USER INTERFACE DESIGN USING MULTI-MODAL FEEDBACK

A Dissertation Presented to the Graduate School of Clemson University

In Partial Fulfillment of the Requirements for the Degree Doctor of Philosophy Human Centered Computing

by Joshua Ime Asukwo Ekandem August 2014

Accepted by: Dr. Juan E. Gilbert, Committee Chair Dr. Damon L. Woodard, Committee Co-Chair Dr. Shaundra B. Daily Dr. Sekou L. Remy

ABSTRACT

The use of touchscreen interfaces for in-vehicle information, entertainment, and for the control of comfort settings is proliferating. Moreover, using these interfaces requires the same visual and manual resources needed for safe driving. Guided by much of the prevalent research in the areas of the human visual system, attention, and multimodal redundancy the Hues and Cues design paradigm was developed to make touchscreen automotive user interfaces more suitable to use while driving. This paradigm was applied to a prototype of an automotive user interface and evaluated with respects to driver performance using the dual-task, Lane Change Test (LCT). Each level of the design paradigm was evaluated in light of possible gender differences. The results of the repeated measures experiment suggests that when compared to interfaces without both the Hues and the Cues paradigm applied, the Hues and Cues interface requires less mental effort to operate, is more usable, and is more preferred. However, the results differ in the degradation in driver performance with interfaces that only have visual feedback resulting in better task times and significant gender differences in the driving task with interfaces that only have auditory feedback. Overall, the results reported show that the presentation of multimodal feedback can be useful in design automotive interfaces, but must be flexible enough to account for individual differences.

ii

TABLE OF CONTENTS

TITLE PAGE	i
ABSTRACT	ii
LIST OF TABLES	v
LIST OF FIGURES	vi
LIST OF ABBREVIATIONS	ix

CHAPTER

I.	INTRODUCTION	1
	Background	1
	Statement of Problem	2
	Purpose of Research	3
II.	LITERATURE REVIEW	5
	Automotive Trends	5
	Driver Distraction	7
	Automotive Interface Design	17
III.	INTERFACE DESIGN	25
	Current Interface Design	25
	Design Motivation for Multimodality	
	Hues and Cues Design Paradigm	
	Other Interface Considerations	54
	System Overview	60
IV.	METHODOLOGY	70
	Rationale for Instruments and Procedures	70
	Research Questions	80
	Hypothesis	

V.	EXPERIMENT	
	Participants	
	Experiment Design	
	Procedure	
	Experimental Set-Up	
VI.	ANALYSES AND RESULTS	
	Data Screening	
	Overall Performance Score	
	Analyses of Performance Measures	94
	Analyses of Subjective Assessments	
VII.	DISCUSSION	
	Discussion of Findings	
	Limitations of Present and Future Research	
VII.	CONCLUSION	116
APPEND	DICES	117
A:	Appendix A	
B:	Appendix B	
C:	Appendix C	
D:	Appendix D	
E:	Appendix E	
F:	Appendix F	
G:	Appendix G	
H:	Appendix H	
I:	Appendix I	
J:	Appendix J	
REFERE	NCES	

Page

LIST OF TABLES

Table		Page
1.	Wierwille's Categorization of Driver Distraction	10
2.	Green's Categorization of Visual Distraction	10
3.	Welcome Screen Ranking	43
4.	Temperature Selection Ranking	44
5.	Fan Speed Ranking	44
6.	Variables collected for every task for every subject are listed	73
7.	Correlation matrix of 15 variables	73
8.	The participant groupings by gender	84
9.	The Presentation order of screens based on group	85

LIST OF FIGURES

Figure	Page
1a.	2012 MyFord Touch
1b.	2010 BMW iDrive
2.	Illustration of Wickens Multiple Resource Theory13
3.	Example of City Browser interface
4.	pieTouch Menu System
5a.	Top level menu of Krenn's A New Car UI
5b.	Interface interaction for Krenn's A New Car UI
ба.	Natalie Jeremijenko's Dangling String
6b.	Ambient Devices' Energy Orb
7.	An Illustration of interface interaction
8a.	Label next to button
8b.	Label over the button
9.	New multitouch interaction
11a.	Screen 1 – Home Screen
11b.	Screen 2 – Temperature Screen
12a.	Screen 3 – Fan Screen
12b.	Screen 4 – Mode Screen
15.	Screen 5 – Music Screen
14.	Chevrolet Equinox IVI system
15.	Preliminary Flow Chart of Menu Structure

List of Figures (Continued)

Figure		Page
16.	Preliminary climate interaction with gestural input	58
17.	Preliminary climate interaction without gestural input	59
18.	Preliminary Hues and Cues design	59
19.	Refinement of preliminary Hues and Cues design	60
20.	Block Diagram of automotive interface system	64
21a.	JS Cover Flow	65
21b.	Apple Cover Flow	65
22.	Start screen for Controller interface	67
23.	Controller interface (displaying script for experiment)	68
24.	Monochromatic Background	86
25.	Dynamic Background	87
26a.	Music Screen	88
26b.	Temperature Screen	88
27.	Overview of experimental setup	90
28.	Mean Standard Deviation in Lane Position	95
29.	Gender Interactions in Mean Standard Deviation in Lane Position	96
30.	Mean Task Time	97
31.	Gender Interactions of Mean Task Time	98
32.	Mean Overall Performance Score	99
33.	Gender Interactions of Mean Overall Performance Score	99

List of Figures (Continued)

Figure		Page
34.	Mean Overall Performance Score for Females	100
35.	Mean RSME Score	101
36.	Gender Interactions for Mean RSME Score	101
37.	Mean SUS Score	102
38.	Gender Interactions for Mean SUS Score	103
39.	Forced Choice Ranking of Interface Preference	104

LIST OF ABBREVIATIONS

AUX	Auxiliary Input
CDS	Crashworthiness Data System
CRT	Cathode Ray Tube
DOT	Department of Transportation
GUI	Graphical User Interface
HCI	Human-Computer Interaction
HMI	Human-Machine Interface
HVAC	Heating Ventilation and Air Conditioning
IP	Instrument Panel
IVI	In Vehicle Information
LCD	Liquid Crystal Display
NASS	National Accident Sampling System
NHTSA	National Highway Traffic and Safety Association
OEM	Original Equipment Manufacturer
PDT	Peripheral Detection Task
UI	User Interface
VUI	Voice User Interface

CHAPTER ONE

INTRODUCTION

Background

Automobiles have become more than just and means of transportation from one destination to another. Besides increases in vehicle performance and safety, automobiles have become a place for entertainment, communication and information access. Nowadays automobiles come equipped with advanced and more complex in-vehicle systems. It has become a de facto standard to offer a wide variety of in-vehicle systems such as climate control, navigation and music players through these systems. Currently In-Vehicle Infotainment (IVI) systems allow drivers to adjust the temperature to their desired preference, and even provide directions to a desired destination while simultaneously listening to their favorite song; with some luxury vehicles such as the BMW iDrive that offering over 700 functions. It has been observed for at least a decade that as car manufacturers offer additional features and more advanced controls, the automotive user interface inherently becomes more complex to operate (Eviltwin, 2002). It has also been demonstrated for more than a decade that this complexity increases drivers' susceptibility to cognitive and perceptual information overload (T Ranney, Mazzae, Garrott, & Goodman, 2000). However, in recent years, there has been heightened attention toward these issues and driver distraction has received an increase in media coverage and discussed more frequently in the government and safety organizations. Initially, much of the concern was focused on the use of mobile phones for calls and texting. However, it has been increasingly recognized that there are many more

sources of distraction in-and-outside of a vehicle that impact its the safe operation; making the consequences of in-vehicle interface design more significant. These systems have spurred considerable debate amongst legislators, and more recently drawn the attention of the National Highway Traffic Safety Administration (NHTSA), which to mitigate some of the risks associated with the new wave of interfaces in the car, propose distraction guidelines for automakers that implement these in-vehicle systems.

Statement of Problem

As helpful, informative and enjoyable as the current automotive interface systems may be their usefulness is often diminished by the safety risks involved in using these systems while driving. In the year 2012 alone, an estimated 421,000 people were injured in automobile accidents involving distracted drivers (DOT, 2014), and in 2010 these types of accidents resulted in 17% of the total economic loss; costing the nation over \$46 billion dollars (Blincoe, Miller, Zaloshnja, & Lawrence, 2014). It can be inferred that the presence of IVI's has not decreased the potential risk of these types of accidents. In fact, distraction by a device or control integral to the vehicle was reported in 26,000 crashes (3% of the distraction-related police-reported crashes) in 2010 (NHTSA, 2012b). The potential risk of auto accidents attributed to automotive interfaces is further exacerbated by factors such as increased interface complexity, functionality, and generally poor interface layouts and designs.

Purpose of Research

Policy-makers and researchers alike are raising the issue of the appropriateness of using these IVI's while driving; with many researchers finding the current automotive interfaces extremely visually and cognitively demanding. These problematic interfaces have provided an interesting opportunity for research. As Schmidt et al., succinctly state in their survey on automotive user interfaces, "new means for user interface development and interaction design are required as the number of factors influencing the design space for automotive user interfaces are:

- The ubiquity of technology
- Expectation of connectivity,
- Automotive technology pressures

All of which will be thoroughly discussed in the literature review. Needless to say, interest in the design, evaluation, and incremental improvement in automotive user interfaces are flourishing; especially within the domain of human-computer interaction (Bach, Jæger, Skov, & Thomassen, 2009; Schmidt, Spiessl, & Kern, 2010).Parallel, but not entirely apart of the increased interest in design and evaluation of automotive user interfaces, is a similar fervor towards the implementation of various techniques for interacting with these interfaces. Interestingly enough, much of the research influencing the design of automotive user interfaces is a imed at exploring various input modalities and interaction techniques as a means mitigating distraction. Voice and gesture have gained considerable amount of attention as being less visually demanding options for

interaction, however results have not been as conclusive with respects to their cognitive demand.

Though input is important, much of the research is often too narrowly focused on examining input. Researchers must consider the feedback loop as much of the literature on interface development suggests(Baxter, 2013; Foley, 1980; Donald Norman, 2002; Ritter, 2011). Importance should not only be given to how users interact with the interface, but also to how the interface interacts with the user. Feedback, is just as important as input. Little research has been dedicated to the effective combination of output modalities, techniques and related interactions in the domain of automotive user interfaces.

Therefore it is an aim of this research to evaluate a design paradigm applied to an automotive user interface that employs color and auditory cues as a feedback in the effort of minimizing the demand on visual resources needed for safe driving.

CHAPTER TWO

LITERATURE REVIEW

Automotive Trends

As the demand for IVI and telematics accelerates; it is estimated that by the year 2020 electronics will be the main cost component of the vehicle (Accenture, 2011). The past four decades are a testament to this trend. In 1977 the average cost of vehicle electronics to auto manufactures was \$110 while in 2001 it had increased to \$1,800 (Leen & Heffernan, 2002; Miller, Kaminski, Schoner, & Jahns, 1998) The rise of in-vehicle systems can be traced back to the 1990s when auto manufactures implemented crash notification systems like OnStar to allow quick response to emergencies to improve roadway safety (Russ, 1998). Today, such systems are offered in most models, and the electronics of in-vehicle systems can attribute to over 23 percent of the total manufacturing cost (Accenture, 2011).

The increase in the electronics within many vehicles can be attributed to the fact that automobiles have become more than just a means of transportation and for many people have become a multifunctional living space (Kern & Schmidt, 2009). As a recent Nielsen survey illustrates most Americans spend around 35% of their online time on social networking, emails and instant messaging combined (Nielsen Company, 2010). This emphasis on connective technology has extended to automobiles, with consumers demanding that their automobiles seamlessly integrate with their lifestyles (Deloitte Development LLC, 2011). Automotive systems in the 21st century are complex distributed computer systems with various demands on networking capabilities (Nolte,

Hansson, & Bello, 2005). The automobile industry is undergoing a major transition. Protocols and in-vehicle network technologies are being developed to maintain IVI systems (Leen & Heffernan, 2002; Nolte et al., 2005). There is also a major rush by automotive OEMs, Tier Ones, Telematics service providers and software developers to enrich the offerings of onboard functions to users by integrating smartphone applications into vehicles (Apple, 2014; Chan, 2011). The area of multimedia and infotainment initially targeted interconnection of personal computers with multimedia devices such as cameras, video recorders, etc.; the emphasis now is to provide connective services which is starting to permeate automobiles (Nolte et al., 2005).

As auto manufacturers and their affiliates provide more technological services in automobiles there has also been an increased need to provide different techniques for interacting with this content. It has been commonplace to use LCD displays in automobiles. In a study that examined the design space of automobiles at the Frankfurt Auto Show, Kern and Schmidt recorded that 81 out of 133 car models had built in LCD displays, with roughly half of them being touchscreens (Kern & Schmidt, 2009). However, reliance on such technology without proper consideration of the automobile context has been a disaster for many companies. As one writer points out the MyFord Touch (Figure 1a.) controls are "confusing", and "first-time users might find it impossible to comprehend" (Consumer Reports, 2011). Even automakers that do not rely on touchscreens and use different techniques for interacting with content such as the iDrive (Figure 1b.) have faced particular criticism. In 2001 the BMW Group introduced a HMI system, the iDrive which was designed to cope with the constantly increasing

number of functions in the automobile (Niedermaier, Durach, Eckstein, & Keinath, 2009). However, the introduction of iDrive was arguably one of the biggest corporate disappointments. It was commented that even at trade shows "People would walk up to kiosks where iDrive demo's were set up, try to use it, and get confused" (Day, 2004). Confusion, frustration and distraction are just a few keywords that have been associated with the current complexities of in vehicle systems (Eviltwin, 2002).



Figure 1a. 2012 MyFord Touch



Figure 1b. 2010 BMW iDrive

Driver Distraction

Impact of Driving Distracted

Driving distracted has been acknowledged as a serious problem in today's society, and has been attributed to one of the primary causes of road fatalities and accidents (C. P. Gordon, 2009). In 2006 Virginia Tech Transportation Institute's (VTTI) published the report of a "100 car naturalistic study". This study examined 100 cars that were unobtrusively equipped with sensors and video cameras for 12 - 13 months. VTTI recorded that almost 80% of all crashes and 65% of all near-crashes involved the driver looking away from the forward roadway just prior to the onset of the conflict (Dingus et al., 2006). It is more conservatively estimated that in the United States approximately

25% of vehicle accidents are a result from the driver being distracted (Kristie Young & Regan, 2007). Distracted driving is commonly associated with texting while driving. Some cities have even taken steps to ban the specific action of texting while driving (Bradley, 2010). Pew Research Center's study comprising of interviews with 800 teens across four U.S. cities found that 48% of all teens ages 12-17 said they had been in a car when the driver was texting, and over half of cellphone-owning teens between 16 and 17 admitting to talking on a cell phone while driving (Pew Research Center, 2009). However, to put matters in the proper perspective, Pew Institute's later research found that roughly 50% of adults were participating in the same distracting behavior (Pew Research Center, 2010).

Categorization of Common Distractors

Though the media's coverage of texting while driving, and the findings on cell phone usage and driver distraction is compelling, driver distraction is not limited to just texting while driving. Any task whether cognitively, physically or visually demanding can have a significant influence on driver distraction (Kristie Young & Regan, 2007). In the vein of this research, driver distraction is to be understood more generally as the diversion of attention away from activities critical for safe driving towards a competing activity (K Young, Lee, & Regan, 2008). It has been observed that even brief interaction with in-vehicle technologies can delay a drivers' recognition of pertinent information necessary to safely drive. Additionally, Dingus et al., noted in their study that reaching

for and even looking at objects in the vehicle were actions that represented the highest frequencies of crashes and minor collisions (Dingus et al., 2006).

In 2001, Stutts and others, conducted a descriptive analysis of National Accident Sampling System (NASS) crash records from the Crashworthiness Data System (CDS) gathered between 1995 and 1999; along with narratives for two years for both CDS and data from the state of North Carolina. This study examined the frequency of accidents attributed to distracted driving (8.3%), and more importantly identified the most common sources of the distraction. It was found that distractors outside the vehicle were the main contributors (29.4%) of accidents, and adjusting the entertainment features (radio, cassette or CD) were the second highest distractors (11.4%) (Stutts, J.C., 2001). Unlike studies that focus on one specific in-vehicle distraction Stutts and colleagues secondary research captures the numerous possible distractions that may arise during driving. Stutts et al.'s enumeration of distracting behavior is a great complement to Wierwille's previous discussion of distracted driving behaviors. In an earlier work, Wierwille gives a detailed categorization of various in-vehicle tasks with respect to the drivers observable behavioral resources needed to complete the task (Wierwille, 1993). Wierwille's examination produced five meta-categories (Table 1), which are commonly used to classify the types of distractors in automobiles.

Table 1. Wierwille's Categor	ization of Driver Distraction
------------------------------	-------------------------------

Manual Only	tasks that can be performed by one of the driver's hands without visual reference. <i>i.e.setting the directional signal to make a left turn</i>
Manual Primarily	tasks that can be performed by one of the driver's hands after visually locating and determining the present setting of an object. <i>(i.e. changing the fan speed on the air conditioner)</i>
Visual Only	tasks that require no manual input. <i>i.e.</i> glancing at the speedometer to determine present speed
Visual Primarily	tasks that rely heavily on vision but require a degree of manual input. <i>i.e. accessing a compass display in a navigation system to</i> <i>determine correct direction of travel</i>
Visual-Manual	tasks that are distinguished by their interactive visual and manual demands. (<i>i.e. manually tuning radio to a specified frequency</i>)

Similarly, but more specific to vision, Green categorized tasks according to the amount of visual feedback needed for task completion (Table 2.) (Green, 1999). Green's categorization's serve as the means to describe the type of visual sampling behavior in eyes-off-road situations and serve as the bases for interpretation of many eye-glance metrics used in driver distraction research (Olsen, Lee, & Wierwille, 2005; Smith, Chang, & Glassco, 2005; Sodhi, Reimer, & Llamazares, 2002).

Table 2. Green's Categorization of Visual Distraction

Continuous	vision is used to guide the control movement. <i>i.e. inserting a CD</i>
Periodic	vision guides switch selection, but the control actions are discrete. <i>i.e. selecting the heat mode for a climate control system</i>
Intermittent	vision is not required for every switch action. <i>i.e. dialing a hand-held cell phone</i>

Wierwille and Green's categorization have been used extensively in driver distraction research, but these categories do not account for cognitive or the "mind off the road" aspects of driver distraction. More recently, NHTSA has put forth a simple and straightforward classification for types of driver distraction (NHTSA, 2012a):

Cognitive - taking ones mind off the road (i.e. daydreaming) Manual - taking one's hands off the wheel (i.e. eating or applying cosmetics) Visual - taking one's eyes off the road (i.e. reading a text message)

Theoretical Underpinnings of Distraction

Extending on Wierwille and Green's classifications, NHTSA's more general classifications serve as an acceptable basis for discussion on the resources needed for safe driving. Safe driving requires drivers' to access information from multiple sources. Often these sources of information require a combination of cognitive, visual, and/or manual actions in order to maintain safe vehicle control and guidance. Therefore the extent to which secondary tasks interfere with the primary task of driving will determine the amount of performance degradation for one, or both tasks (C. D. Wickens, 2002). Groups such as the Crash Avoidance Metrics Partnership (CAMP), Adaptive Integrated Drivervehicle Interface (AIDE) and others have used the concept of task interference to evaluate a tasks' potential for distraction. Distraction, a problem arising from the limitations of the human information processing has its theoretical underpinnings in Broadbent's classic bottleneck theory of attention. Broadbent's bottleneck theory proposes that there is a filter between a sensory source and short-term memory.

time by filtering only pertinent information through for further processing. This model is considered to be a single channel theory of attention, postulating that people can only attend to one input at a time, as they have one pool of resources (Broadbent, 1958). Though pinnacle to the research of attention at its time of writing, in many instances Broadbent's simple all-or-nothing single bottleneck theory has failed to be an accurate model of human performance (Kahneman & Treisman, 1984; Treisman, 1969).

For example, the bottleneck theory does not explain the phenomena of a driver being able to maneuver along a curvy two-lane road and also carry on a conversation with the passenger. A more accurate theory, illustrating the multifaceted nature of attention and workload is Wickens's Multiple Resource Theory (MRT). In the MRT individuals are viewed as having several different capacities of resources, these resources are differentiated according to information processing stages (encoding and central processing or responding), perceptual modality (auditory or visual) and processing codes (spatial or verbal) (C. Wickens, 1991). Figure 2. from the paper "Multiple resources and performance prediction"(C. D. Wickens, 2002) is a 3D representation of the structure of multiple resources with fourth dimension (visual processing) nested in the visual resources accurately depict the model.



Figure 2. Illustration of Wickens Multiple Resource Theory (Wickens, 2002)

This approach is not exclusively a theory of attention or of workload, despite its close relation to both. The MRT serves as an exceptional model for understanding the multitasking driver. As driving, (visual and manual) task does not necessarily interfere much with the (vocal-cognitive) task of talking; though interference has been observed in these tasks (Bruyas & Brusque, 2008). However, according to this model visual-manual and auditory-cognitive tasks can usually be considered independent of each other. This model improves upon earlier works (Kahneman, 1973; Moray, 1982; DA Norman, 1968) as it more accurately depicts the human model of information processing with respect to workload. The multiple resource model also explains why different in-vehicle tasks on the same interface may not degrade driver performance equally. For example, researchers have found greater deviations in lane keeping when using an Acura-TL navigation system

in visual-manual mode as compared to using it in speech only mode (Harbluk, Noy, Trbovich, & Eizenman, 2007). As driving is a primarily visual-manual task MRT predicts that there will be a greater interference and subsequent degradation of the driving task, the secondary task, or both using the visual-manual interface. The cognition aspects of driving such as mind off the road are important also. Researchers have noticed that drivers reduced their visual monitoring of the instruments and mirrors when cognitively overloaded. Also, some hands-free devices can cause cognitive distraction (Harbluk et al., 2007). However, as aforementioned, driving is mainly a visual, and manual task and cognitive overload often manifests in visual and manual performance degradations (Maciej & Vollrath, 2009).

Moreover, as the visual modality is the primary information gathering modality involved in driving (Wierwille, 1993); it is reasonable that a considerable amount of attention be given to the visual workload of in-vehicle tasks. In attempting to tackle the issue of distracted driving it is pertinent that the visual load of in-vehicle systems be reduced (Wierwille, 1993), as a common type of driver distraction is caused by the driver using a single visual resource to find a specific vehicle control (Pickering, Burnham, & Richardson, 2007). More specifically, these visual resources discussed by Pickering et al., can be characterized as either focal or ambient. Focal vision is nearly always foveal and is required for detail and pattern recognition, while ambient vision is heavily, but not exclusive peripheral and is used for sensing orientation and ego motion (C. D. Wickens, 2002). In-vehicle tasks that require the discrimination of displayed digits, letters, and symbols utilize large amounts of focal visual resources (Horrey, Wickens, & Consalus,

2006); which are the same visual resources integral to safe driving. Furthermore, studies have demonstrated that visual distraction while controlling in-vehicle systems can also substantially reduce lane-keeping, a quality heavily governed by ambient visual resources (Maciej & Vollrath, 2009).

Visual Distraction and Driver Performance

It is not difficult to find research that discusses the correlation between increased visual demands and driver performance. As Green points out, when visual feedback becomes more central to task completion, the time with eyes off the road also increases (Green, 1999). As the time with eyes of the road increases the variability in lane position usually increases (Peng & Zhiqiang, 2013).

Researchers have used driver eye glance metrics to examine number of glances, duration of glances, and the location of glances made while performing a task. It has been shown that longer off-road fixation durations were observed in secondary in-vehicle task such as radio-tuning (Sodhi et al., 2002). Moreover, Antin, Dingus, Hulse, & Wierwille found using eye-glance behavior that drivers spent 80% of their time looking at the road ahead when not engaged in distracting activities. Distracting events reduced amount of time looking at forward headway (Antin, J. F., et al., 1990). Reducing the amount of time looking at the forward headway has serious safety implications as it has been shown that hazard awareness cannot be entirely supported by ambient vision, and relies primarily on focal vision (Horrey & Wickens, 2004). Therefore, IVI safety recommendations often have a component that aims to reduce the visual load of the

interface by reducing the frequency and the duration of eye-glances from the roadway, as IVI tasks are usually in direct competition for the same focal visual resources. However, when visual workload is not reduced task interference or degraded driving performance can most assuredly be observed (Horrey et al., 2006).

To not give the false impression that visual distraction will absolutely always end in some negative consequence it should be optimistically noted that research has shown that drivers are less likely to engage in distracting behavior when driving task demands are high (Stutts, J.C., 2001), and that on average drivers do not allow their single glance times to exceed 1.6 seconds, even for complex information gathering tasks (Wierwille, 1993). In addition, drivers are often capable of dividing their attention between concurrent tasks without any serious consequences to driving performance or safety, due to the fact that many aspects of the driving task become automated with experience (Kristie Young & Regan, 2007). So tasks that place little demand on drivers may be able to be effectively time-shared with the driving task, resulting in little or no degradation in driving performance.

Notwithstanding, this does not imply that burden of responsibility rests solely on users for mitigating the potential risks associated with operating automotive interfaces while driving. Automakers must be prudent in their interface design and understand that if an automotive user interface is to be accessed while driving it should be designed in such a way as to not require large amounts of focal vision; as the driver needs these resources for forward viewing. However, for this to happen further systematic research of driver distraction and the impact of in-vehicle HMI will be needed to reduce the degree of visual workload of these interfaces (Chan, 2011).

Automotive Interface Design

Approaches to Automotive Interface Design

Safety organizations, policy makers, and researchers have put forth a concerted effort to make interactions with the in-vehicle systems less distracting. However, driver distraction is not just popular in the human factors research community as exemplified in the previous review of literature; it has been a hot topic in user interface community as well. The 2009 creation of the special interest group, Automotive UI serves as evidence to this point. This special interest group is focused on exploring automotive user interfaces and the interactive applications used in vehicles. With respects to driver distraction it has been common for researchers in the HCI community to focus their attention on developing less visually distracting automotive user interfaces; and rightfully so. A popular approach has been to examine the effectiveness, efficiency, and overall user satisfaction (W3C, 2002) of various input modalities. The most discussed modalities are tactile, characterized by interaction involving physical contact with an object usually using ones hands; auditory, characterized by interaction involving the sense of hearing usually using vocal communication; and gestural, characterized by a movement of part of the body, usually ones hand which are intended to express semantic meaning associated with the interface. Within the context of automotive user interfaces the different input modalities equip users with the means to achieve their desired goals and can provide

many benefits in speed, accuracy, and ease of use. However, there is a tradeoff between the benefits and the shortcomings of each modality.

Promising Areas of Interaction

Gestural interaction particularly has gained significant interest among many automotive interface researchers. One advantage of using gestures is that they require little to no visual resources especially one-handed non-contact gestures. Mercedes Benz's DICE concept and Audi both showcased prototypes of this type of gestural interaction (Audi, 2012; Lavrinc, 2012). With mainstream adoption of multi-touch gestures such as those similar to Apple's iPhone, in 2012 Cadillac released support for multi-touch gestures in their in-vehicle system for their XTS and ATS luxury sedans and SRX luxury crossover called the Cadillac CUE (General Motors, 2012). For the sake of brevity, a more exhaustive list of gestural categories discussed by Pickering; ranging from contact hand gestures (a paradigm commonly used in interacting with smartphones and tablets) to head gestures. However, for the purposes of this particular research onehanded, non-contact and multi-touch gestures will be examined. These types of gestures take place in the air away from the user and can either be referential, symbolic or natural (Pickering, C.A. and Burnham, KJ and Richardson, 2007). In 2001 Zobl et al., conducted a study that investigated the feasibility of using gestures to control in-vehicle devices. The authors noted that distractions were substantially reduced when using gestural user input for controlling in vehicle systems (Zobl, Geiger, Bengler, & Lang, 2001). Research has also shown gestural interfaces to be a viable option for secondary tasks (Alpern &

Minardo, 2003), because they have less need for glancing (Bach, Jaeger, Skov, & Thomassen, 2008).

Though gestures have received considerable amount of attention, the auditory modality has also shown promise as an effective in-vehicle modality. Similar to gestures, auditory input and output has often been promoted as a good best method for input because it requires no vision. However, unlike gestures auditory input does not require drivers to take their hands off the steering wheel, and eliminates much of the overall difficulty of manual device interactions (Gruenstein et al., 2009). Tangentially, many researchers have found speech to perform better than other input modalities when inputting text (Ablassmeier et al., 2006; Alvarez et al., 2011; Camilli et al., 2011; Maciej & Vollrath, 2009). Ford motor company has done a considerable amount of work in developing a voice user interface (VUI) for their vehicles (Rana, 2010); receiving considerable praise. Some users of the Ford system have even stated that, "it's the best comprehensive infotainment solution currently available, hands down."(Mick, 2011).

Though new input modalities are making their way into the vehicle, direct touch interaction is the most common and most easily understood method of interaction. From push to start buttons, to dials for climate control; touch interaction has long been the primary mode of interaction within automobiles. In the past mechanical buttons were used that provided haptic feedback e.g. when a button was pressed, it felt pushed in (Kern & Schmidt, 2009). This type of tactical feedback contributes greatly to perceived quality (Burnett & Irune, 2009). Nevertheless, many in-vehicle technologies are minimizing the use of buttons and knobs with a major shift toward the use of touchscreens. Traditional

tactile-only buttons provide either a one-to-one mapping (one button to one function), or one button being overloaded with functions. However, touchscreens provide the ability to have interactive elements that are fully adapted to the context of the interface (Harrison & Hudson, 2009). Furthermore, in a more recent examination of multimodal interaction invehicles it was noted that touch interfaces provided a faster form of input when compared to gesture, and speech (Christiansen et al., 2011). Touching a visual display is easy to learn, and requires minimal hand-eye coordination (Shneidemnan, 1991).

Interaction Discussion

A more focused examination will reveal many trade-offs for a particular method of interaction. For example, in many ways gestures have shown to be advantageous, yet have also received numerous criticisms. One shortcoming is the current paradigm of gestures as pointed out by Malizia and Belluci. Malizia and Belluci argue that gestures are touted as being a natural interaction, however current implementations are far from that forcing users to learn symbolic gestures, or make some non-natural predefined motion (Malizia & Bellucci, 2012). Furthermore, Pickering et al., state that, "if the goal is to get away from learned, pre-defined interaction techniques and create natural and safe interfaces free of visual demand for normal human drivers, then the focus should be on the type of gestures that come naturally to normal humans."(Pickering et al., 2007). To further complicate things, in a study that examined the types of gestures that people perform naturally while interacting with in-vehicle systems; it was noted that many gestures were culture-dependent (Zobl et al., 2001). In light of these findings, multi-

national automakers that create vehicles for consumers throughout the world will face a large obstacle in developing, and maintaining relevant gestures for their customers. There has also been little to no research that has identified the best location of hand gestures for in-vehicle systems that would provide optimum safety, ease of use and user acceptability (Pickering, C.A. and Burnham, KJ and Richardson, 2007).

Speech as an input modality is very effective, however if improperly designed can cause increases in cognitive load. When used as an output modality, Christiansen et al., demonstrated that even though auditory feedback had the fewest eye glances it had the longest completion times, and the authors state that, "listening to audio output while driving causes an increase in the cognitive load of the driver, thereby drawing mental resources away from the task of driving." (Christiansen et al., 2011). Similarly an evaluation of a VUI performed by Electronics Research Lab of Volkswagen Group, conclusively found that though less visually distracting, VUI could be extremely confusing and frustrating. Noting that VUI's usability depended on a myriad of factors (Chang, Lien, Lathrop, & Hees, 2009).

A few of the most salient factors include but are not limited to:

• The ability to build a mental model of the system

- Mental models are needed so that users know how to interact with it.

• The wording of the speech commands

-The commands themselves has a large effect on the usability of the system

• The use of visual cues

-Visual cues should be provided to users to guide the user into the correct order of entry.

It has also been noted that though many auditory alerts are clearly useful when the driver is not looking at an interface additional research will be necessary to ensure that auditory alerts are not masked by other auditory information (Kramer, Cassavaugh, Horrey, Becic, & Mayhugh, 2007).

Lastly, the many advantages of touchscreens are often over shadowed by their disadvantages of being used in the automotive context. The most obvious disadvantage, which has already been discussed in depth, is the visual distraction that touchscreens pose to drivers. This issue is exacerbated by poorly designed graphical user interfaces (GUI) that do not display the appropriate amount of information to the user (Costagliola, Di Martino, Oliviero, Montemurro, & Paliotti, 2005), and using touchscreens that provide minimal touch cues to users (Burnett & Irune, 2009). Most touchscreens' only feedback is of pressing against a solid object. It has been noted that these devices fail to provide cues to drivers that would be considered important in the context of safe driving (Carney, Cher, 1997).

Areas of Opportunities in Interaction

Considering the many shortcomings of a single modality it is difficult to neglect the advantages gained by implementing multimodality into interfaces. Many researchers have taken a cross modal or multimodal approach to examining and developing new types of interaction (Althoff, McGlaun, Lang, & Rigoll, 2004; Amditis,

Polychronopoulos, Andreone, & Bekiaris, 2006; Herfet, Kirste, & Schnaider, 2001). Other researchers have acknowledged that the many disadvantages of a single modality can often be overcome by combining them intelligently (Müller & Weinberg, 2011). One example, is a combination that Carney and Cher propose, using auditory and haptic feedback modalities as imminent warnings when a driver is not alert or distracted (Carney, Cher, 1997). With respects to speech, the City Browser (Figure 3.) is a great example of a touchscreen interface that combines a graphical user interface with a conversational speech interface in an actual automobile (Gruenstein et al., 2009).



Figure 3. Example of City Browser interface

(Gruenstein et al., 2009)

Multi-modality has even been observed to improve gestural interaction. Althoff et al., examined head and hand gestures and concluded that the most feasible option for these gestures would be the combing them with spoken utterances and tactile interactions (Althoff, Lindl, Walchshausl, & Hoch, 2005). Furthermore, an examination of the effectiveness of audible, haptic and visual feedback in touchscreens suggests that users prefer multimodal feedback to visual feedback only (Pitts, Williams, Wellings, & Attridge, 2009). With respects to error mitigation it was found that often when one modality fails it is often beneficial to provide the same function in a different modality. In a study that evaluated the potential of misinterpretations while operating a multimodal user interface it was observed that when the system did not react in case of a second oral command repetition, nearly 70% of the test subjects change the modality and made use of the touchscreen (Althoff, McGlaun, Schuller, Lang, & Rigoll, 2002). As Muller, points out this type of multimodal redundancy also allow users to accomplish interactions using the modality most appropriate to the driving situation (Müller & Weinberg, 2011).

IVI systems are becoming more pervasive, and as more automakers add these systems in their vehicles there is also the potential that possible distractors may increase. Therefore, it is quintessential that not only are IVI interfaces novel, attractive and intuitive, but also have been designed in light of the abundance of human factors research related to human performance while driving. In light of this research it is proposed that a strategy for designing automotive user interfaces be developed to reducing driver distraction. As evidenced in the literature multimodal feedback was very useful in supplementing the shortcomings of a single modality. Therefore by employing multimodal feedback this strategy aims to reduce the need for visual resources; resulting in less degradation in driver performance.

CHAPTER THREE

INTERFACE DESIGN

Current Interface Design

To further facilitate individuals' needs to stay connected, many automotive manufacturers like BMW and Ford have products in the market which Facebook, Twitter or the Pandora music service in the car (BMW GROUP, 2011; Ford Motor Company, 2011). Toyota has started offering a wide variety of in vehicle technology aimed at integrating different services and interactive entertainment that provide customers with an experience similar to their homelike devices such as information retrieval using Microsoft's search engine Bing (Toyota, 2012). Also, Audi has made it possible to search for current data such as opening hours and ratings using the Google point of interest search in their vehicles (Audi, 2012). Even Continental a worldwide German auto and truck parts manufacturing company known for its tires and brakes has recently released AutoLinQ an in-vehicle system which aims at better connecting users lifestyles with their vehicles (Continental, 2012).

Not only have automotive manufactures and their affiliates capitalized on this opportunity to provide services for their users, but also other technological companies have aggressively partnered with automotive companies to claim stake in this emerging market. Nissan has worked with Intel to develop an IVI system that would be able to multitask in addition to sending traffic and navigation information to the driver (Kee, 2012). Ford in cooperation with Microsoft, invented the "Ford Sync" platform, a Windows CE operating system running on an embedded PC (Ghangurde, 2011). In

response to this competition, Garmin, one of the largest producers of personal navigation devices, has partnered with Chrysler to embed their GPS hardware in dashboards that interface with Uconnect, Chrysler's IVI system (Rhey, 2012).

Nokia has also approached many automotive manufacturers with their Mirror Link system, which offers different approach to IVI systems. Instead of having the IVI system merely connect to the phone for data, the IVI system projects their smartphone on the IVI display, and allows the user to access and control the many features of their smartphones via the IVI system (Bose, Brakensiek, & Park, 2010).

New Menu Systems

With poor interface design, displays can easily become cluttered with information and widgets, which may lead to confusion or make tasks more complex; factors that influence driver distraction (Wierwille, 1993; Kristie Young & Regan, 2007). Ecker et al., present another approach for interacting with IVI systems via direct touch gestures called pieTouch (Figure 4). The pieTouch system combines touch gestures with a circular menu, which appears around the touch point when the user taps the screen (Ecker, Broy, Hertzschuch, & Butz, 2010). The pieTouch menu system allows users to touch anywhere on the screen which minimizes the need for focal attention in learned interactions, also the minimalistic design reduces visual clutter (Haslbeck et al., 2011).


Figure 4. pieTouch Menu System

Another approach that aims to minimize the need for focal vision in the area of automotive user interface design is Matthaeus Krenn's "A New Car UI" prototype (Figures 5a & 5b). This prototype aims to solve the problem with automotive touchscreens associated with a lack of tactile feedback. Krenn proposes that the lack of feedback coupled with the small intangible buttons on current automotive touchscreen interfaces, increases the need for drivers' dexterity and attention when in operation. Krenn's "A New Car UI" allows an interface to go into a mode where the screen is cleared of all controls and replaced with a simple infotainment and climate control menu screen, and after selecting a specific a desired menu item, users can touch anywhere on the screen to control the interface. Similar to PieTouch this interface reduces the need focused focal vision by allowing the user to touch anywhere on the interface for control.



Figure 5a. Top level menu of Krenn's A New Car UI

Figure 5b. Interface interaction for Krenn's A New Car UI

Design Motivation for Multimodality

One salient factor in developing this multimodal approach was the technical feasibility of implementing the paradigm within automobiles in the near future. Therefore, after the conceptualization process solutions that did not realistically have the potential to be implemented by automakers in the near future (< 3yrs) were not further considered. To this end, gestural and haptic feedbacks were not considered due to the technical difficulty in implementing these types of feedback within automobiles in the near future. The two feedback modalities that showed promise in their ability to be implemented were visual (the de facto standard for automotive interfaces) and auditory. With respects to the visual modality it was decided to best way to reduce the need for focal vision was to not entirely rely on it. The concept of not relying entirely on focal vision framed the future explorations into techniques for passively conveying

information; with the hope that the techniques found could somehow be applied to automotive user interface.

Examples of the passive techniques are Natalie Jeremijenko's "Dangling String" (Figure 6a.), and Ambient Devices "Energy Orb" (Figure 6b.). "Dangling String" is calming technology that indicates the amount of current network traffic. The 8-foot string is attached to a motor in the ceiling that is connected to a nearby Ethernet cable, when information is transmitted this causes the motor to turn; the more information is transmitted the more wildly the string dangles (Ekman, 2013). Likewise the "Energy Orb" produced by Ambient Devices, gives subtle visual cues that indicate how much strain is on the power grid. The frosted-glass ball glows with various colors to represent peak demand conditions. For example during high demand, the Orb pulses red and when demand is low and the grid is not strained it does not pulse and stays a cool green (CNT, 2013). Both the "Dangling String" and "Ambient Orb" demonstrate techniques for placing information in the periphery. In doing so users are able to attend to many more things than if everything had been at the center of focus. Thus the periphery can be informing without being obtrusive or overburdening.





Figure 6a. Natalie Jeremijenko's Dangling String

Figure 6b. Ambient Devices' Energy Orb

The Energy Orb's use of color led to further explorations in how color could be used to provide a mechanism for an effective interface. As succinctly stated by Shubin Falck & Johansen "Color, like typography and layout, is a useful design tool" (Shubin, Falck, & Johansen, 1996). Salomon's discussion of new uses of color describes how color can be used in interfaces to impart information to the user. More specifically he gives examples of how color can provide users with information not available otherwise, or redundantly reinforce information imparted through another medium (Salomon, 1990). Salomon's discussion has some merit as evidenced in some of the psychological research. It has been found that retrieving information about an object's color activates many of the same visual brain areas that are known to be involved in object recognition; suggesting a connection between perception and memory (Hsu, Frankland, & Thompson-Schill, 2011; Tanaka, Weiskopf, & Williams, 2001). Further studies have examined color combinations for visual identification using LCD and CRT for visual identification tasks, finding that color combinations had a direct correlation visual performance and preference ratings (Shieh & Lin, 2000). More interesting, is the fact that color does not exclusively rely on foveal visual resources, but can be recognized by ambient visual resources. Pioneers in the study of peripheral color vision observed decades ago that contrary to popular belief, the periphery had some level of color vision stating that,

"It is misleading to term the peripheral retina color blind, or even 'color deficient.' The quality of color vision in the periphery depends crucially on stimulus size. If the stimulus is sufficiently large, subjects see a full range of well saturated hues."

(J. Gordon & Abramov, 1977)

Size is not the only factor when considering using color as a mechanism to impart information from the periphery. Appropriate attention also needs to be given to appropriate color combinations. Research has shown that distinguishing certain color combinations are more difficult when presented in the periphery. Noting that the loss of the yellow-blue contrast sensitivity is more gradual as opposed to the steep decline in redgreen contrast as combinations get further from the fovea (Ayama & Sakurai, 2003). Therefore, using appropriate color combinations as identifiers could be a viable way of reinforcing a mental model for users and subsequently aid in the effectiveness of automotive user interfaces.

Nevertheless, research into the use of colored ambient lighting in automobiles is sparse even though ambient illumination has been touted in automobiles to assist drivers. For instance, Ford Motor Company suggests that ambient illumination provides "a new

level of customer convenience" by adding helpful illumination features to assist or warn a driver (Ford Motor Company, 2012). Over the last decade, the number of light sources in the interior of automobiles providing ambient illumination has increased considerably. Some current car models have up to 25 LED's that provide this type of ambient lighting (Caberletti, Elfmann, Kummel, & Schierz, 2010). Moreover, color has been increasingly used in cars to enhance ambient illumination. The 2012 Ford Focus provides up to seven different colors that drivers can choose to illuminate their cup holders, instrument panel and foot-wells (Hemphill, 2011). It has also been found that drivers visual senses could be improved through the use of colored interior lighting (Klinger & Lemmer, 2008). Though studies have shown ambient illumination to be beneficial; it has also been observed that ambient lighting can also create a discomforting glare and distract drivers when misapplied. These disadvantages of ambient lighting can negate the advantages gained by driver's perception of the car interior if not designed properly (Caberletti et al., 2010).

As the benefits and caveats of using color as a feedback have been addressed. The next inquiry is to the appropriate implementation of auditory feedback into a system. A cursory glance of many current IVI systems will show that they provide some type of auditory response when a graphical button is touched, or at least have the option to. This is very useful, as this alerts users that an action has been interpreted by the system. **However, the aim of this design paradigm is not just to make them aware, but also to inform users on the specific action they are performing.** This auditory

conformation could be considered an auditory counterpart of icons. The early work of

Blattner et al., describes such a mechanism in the paper, "Earcons and Icons: Their Structure and Common Design Principles". According to Blattner et al., earcons are audio messages used in the user-computer interface to provide information and feedback to the user about computer entities (Blattner, 1989). Usually represented by brief musical melodies whose attributes reflect the structure of the hierarchy of information, earcons can include messages, functions, as well as states and labels (Brewster, Wright, & Edwards, 1993). Brewster, Raty and Kortekangas demonstrated that after a little over five minutes of training users could identify their location in the menu hierarchy four levels deep by listening to the earcons (Brewster, Raty, & Kortekangas, 1996). However, studies by Vargas and Anderson demonstrated that when earcons preceded speech items (e.g. recorded speech of "defrost off"), there was an increase in time of 18% when performing common in-vehicle tasks on such as climate control or radio control (Vargas & Anderson, 2003). Building on the concept of earcons Walker, Nance and Lindsay developed spearcons that are created by speeding up a spoken phrase until it is not recognized as speech. The researchers found that when compared to earcons and auditory icons (e.g. recording of the sound a printer makes when printing a document to represent a printer) spearcons as well as spoken items (text to speech) resulted in improved auditory menu-based interfaces with respects to speed of completing tasks and accuracy (Walker, Nance, & Lindsay, 2006).

Hues and Cues Design Paradigm

When designing automotive interfaces visual information is needed at all, and when it is needed consideration needs to be given so that users are not overwhelmed. An example of too much information can be found in many navigation systems. As Kun et al, demonstrate auditory-only navigation systems are a feasible way to complete navigation tasks. In their study they found that when a navigation system provided multimodal (both auditory and visual) information, users would look at the display even though they did not need to. In other words, there were no cases of missed directions for any of the navigation aids when used as an auditory-only system (Kun, Paek, Medenica, Memarović, & Palinko, 2009). As evident by Kun et al., if a visual display is in the car there is a high probability it will be gazed upon regardless if it needs to be looked at or not. Though multimodal input and multimodal feedback serve as promising techniques for reducing driver distraction, they only constitute a portion of techniques that can be employed to provide intuitive, less distracting and pleasurable automotive user experiences.

The problem is that all too often desktop and mobile metaphors and paradigms such as file system hierarchy are misapplied to the automotive context resulting in frustration, confusion and distraction at the expense of drivers (K Young et al., 2008).

As Christian Muller, an expert on automotive UI, states standards for the design and presentation of information in the automotive context are few and far between; "best practices" dominate instead (Müller & Weinberg, 2011). Though the major concern in designing automotive interfaces is to design interfaces that focus on the minimization of

driver distraction and the maximization of ease of use; most Human Machine Interface (HMI) innovations are being driven by the consumer electronics industry. As Muller and Weinberg (2011) further state that car makers have," 'feature-itis' in an intensely competitive market" and have "taken an ad-hoc approach toward building in-car interfaces that minimize distraction." Researchers and policy makers alike have observed this ad-hoc approach further explicated in an extensive study conducted by Ranney et al. (2011) to assess the extent to which in-vehicle information systems interfere with driving. Consequently, this provided grounds for the proposed guidelines for in-vehicle electronics from NHTSA (Federal Register, 2013). The guidelines comprise of two phases:

Phase I: Electronic devices installed in vehicles at the time they are manufactured

Phase II: Devices or systems that are not built into the vehicle but are brought into the vehicle and used while driving.

Although, both phases are pertinent for reducing distraction while driving the scope of this dissertation is focused on Phase I. The proposed Phase I distraction guidelines include recommendations to:

- Reduce complexity and task length required by the device
- · Limit device operation to one hand only
- Limit individual off-road glances required by device operation to no more than two seconds
- Limit unnecessary visual information in the driver's field of view
- Limit the amount of manual inputs required for device operation

These guidelines provide a foundation for designers and developers of automotive user interfaces; however, it is not the aim of this study to extend such guidelines. The aim of this research is to develop and test a design paradigm in light of these guidelines and others that make touchscreen automotive user interfaces more suitable to use while driving. To assure that the level of discourse is clearly understood, design in the context of this document is considered to be the arrangement of features in according to aesthetic or functional criteria and paradigm is a pattern, model, or example of something (Oxford English Dictionary Online, 2013). Therefore, design paradigms are usually used to describe a design solution. These paradigms describe in sufficient detail the techniques, forms, functional relationships, and behaviors required of a design solution (Wake, 2000).

Figure 7, illustrates the proposed design paradigm entitled Hues and Cues. Hues and Cues is characterized by color coding top-level menu items or top-level functionality and applying speechcons to each interactive element of the interface



Figure 7. An Illustration of interface interaction

For example, the top-level element 'Climate' has a unique color theme and all elements within 'Climate' menu share the same color theme. 'Fan Speed' is a sub-menu that can take on different levels (i.e. 1- 4) represented by the 'Sub-menu interactive elements'.

This paradigm was developed after taking inventory of the current automotive interfaces on the market, review of literature on interface research, and exploration of the various future facing automotive concepts and prototypes. After considering the various possibilities through brainstorming and synthesis sessions including, but not limited to a "how might we" sessions a number of concepts were developed, then narrowed down, then further refined until the testable Hues and Cues paradigm was implemented.

This conceptualization process resulted in some of the functional requirements of how the interface should feel and perform, but the specifics were not addressed in this phase. When considered holistically, conclusions about the distraction potential for

specific tasks cannot be made without consideration to the interface, modality and specific device being used (T. A. Ranney et al., 2011). Therefore for this endeavor it was important that the interface elements be considered holistically. Foreground elements such as buttons, icons, logos, and text could not be designed independently of one another; likewise they could not have been designed independently of the background as each choice affects another.

To this end, three studies helped guide the style of the design elements used in the final Hues and Cues interface. The first was a walk through of paper prototype versions of an interface designed to address the needs of two distinct demographics; gen-y and baby-boomers. Second was a heuristic evaluation of screen-shots performed by Clemson University students, and lastly was a usability study on an interactive prototype that evaluated interaction paradigms. These preliminary studies were performed to gain insight into how to develop more usable and less distracting multimodal automotive user interfaces. The first interface was developed to address the needs of two distinct demographics; gen-y (ages 17-34) and baby-boomers (ages 47-65). Though this interface did not rely on color as a means of reducing distraction the interface provided insight on user preferences. Also, unlike traditional implementations of GUI's in automobiles, which are formatted for small screens with 4:3 aspect ratios, this implementation had a portrait orientation and is approximately 8" x 12" in size. The next sections are adapted from the paper, "A Novel HMI for Automotive Infotainment using a Short-Throw Projector" and serves to identify the significant findings of the preliminary research conducted. A more detailed account is provided by Venhovens et al. (2011).

The aim of the interface design was to create a user-centric experience that was fun and could be easily scaled fit different screen resolutions. This aim resulted in the following considerations:

1) Consideration of the wants of genY and needs of baby-boomer consumers,

2) Consideration of fgeneral usability guidelines

3) Consideration of code and graphical asset development to be flexible For this reason, close attention was given to the information hierarchy and screen states and transitions. Furthermore the interface design layouts reflected existing features (Appendix A) and the design process addressed the flow of interaction, type of interaction and the resources needed for operation. The preliminary usability study of paper prototypes consisted of 16 licensed drivers consisting of eight baby-boomers (defined as born between 1946 and 1964), with an age range of 45-69 years (M=58.11, SD=8.18) and eight genY (defined as born between 1977 and 1994), with an age range of 20-28 years (M=23.75, SD=3.15). Half of the participants for each age group were male. All participants had at least 2 years of driving experience and spend an average of 11.4 hours per week (range 4 - 20 hours) in their vehicles. Participants provided information regarding their use of technologies and infotainment while driving. Eleven participants use a CD player, 14 listen to the radio, and 11 use an MP3 device. While 14 participants have navigation systems, only 11 actually use it. All participants have a cell phone, and 11 use their cell phones while driving.

The study was composed of three types of tasks for each design component. First, participants completed hypothetical tasks, then they made forced-choice comparisons

between specific design features (such as capitalized font versus mixed case font), and finally rank ordered the four designs from most favorite to least favorite. The four design styles were counterbalanced between participants, however each participant started by first examining the welcome screen. The investigations of the audio (Radio and CD) and climate control were counterbalanced. For the climate, radio and CD designs, participants were instructed to start from the design's welcome screen and then move to the next most appropriate screen based on the question. The hypothetical tasks questions for this study aimed at exposing participants to frequently completed in-vehicle tasks. Participants were asked to think out loud as they completed each task to allow for the documentation of their thought process and expectations.

Overall participants preferred a mixed case font (i.e. Radio) to upper case fonts (i.e. RADIO). With most of the participants wanting the ability to change the size of the font. When participants were questioned about the labeling of controls in addition to a graphic, 75% of participants (63% genY, 88% baby-boomer) preferred labels next to the control (Figure 8a.) to no labels at all. A second question investigated the participant's preference of a label above the button or next to the button. The older participants preferred the label next to the button (88% baby- boomer) (Figure 8a.), whereas the younger participants preferred the label above the button (75% genY) (Figure 8b.)





Figure 8a. Label next to button

Figure 8b. Label over the button

Background Images.

Many of the screens included background images. While many of the participants (94% overall, 88% genY, 100% baby-boomer) did not like the image presented on the welcome screen the participants did want the ability to change the image to a picture of their preference. A new multitouch interaction method (Figure 9.) for the adjustment of both temperature and radio were examined. The display consisted of ovals designed to afford finger placement in adjusting the control. Only 25% of all participants identified the purpose correctly, and 0% of the participants understood how to interact with the design using the paper prototypes. This is very insightful, and reflects the importance for automakers to properly inform users on how to interact with systems using new interaction techniques.



Figure 9. New multitouch interaction

Fan Speed

Most participants' preferred incorporating the fan speed (Figure 10.) and vent location in the same graphic simultaneously as they could quickly get information about the status and strength of the vents and speed all at once.



Figure 10. Fan Speed Interface

Song Duration

Song duration was also a concern of this study as many digital music devices display a song's playback time either as elapsed time (from the beginning to the current point in the song) or remaining time (the time from the current point in the song to the end of the song). The study found that the participants' results varied depending upon age. The majority of the baby-boomers (75%) preferred remaining time, while the majority of the younger participants preferred playback time (63%). However some Apple's iTunes, which is widely used, displays song duration in both formats.

	Rank order	Design 1 (red) 1 knob	Design 2 (green) 4 knobs	Design 3 (yellow) 1 knob	Design 4 (blue) 4 knobs
	1st			2	6
GenV	2nd		-	6	2
Gen	3rd	2	6		
	4th	6	2		
	1st		1	2	5
Boomer	2nd	1	1	4	2
boomer	3rd	3	2	2	1
	4th	4	4		

Table 3.	Welco	me Scree	n Ranking.
----------	-------	----------	------------

					Glimate
		Design 1	Design 2	Design 3	Design 4
	Rank	(red)	(green)	(yellow)	(blue)
	order	1 knob	4 knobs	1 knob	4 knobs
	1st		1	3	4
GonV	2nd	1	2	3	2
Gent	3rd	2	3	1	2
	4th	5	2	1	
	1st		1	2	5
Reeman	2nd	2		4	2
boomer	3rd	2	5	1	
	4th	4	2	1	1

Table 4. Temperature Selection Ranking.

Table 5. Fan Speed Ranking.

		0 8 4 5	·**		Fan
		Design 1	Design 2	Design 3	Design 4
	Rank	(red)	(green)	(yellow)	(blue)
	order	1 knob	4 knobs	1 knob	4 knobs
	1st	1	1	2	4
GonV	2nd	1	1	5	1
Genn	3rd	3	2		3
	4th	3	4	1	
	1st		1	2	5
Boomor	2nd	2	-	4	2
boomer	3rd	2	5	1	
	4th	4	2	1	1

Rank Order

The previous tables (Tables 3 - 5) show the rankings for designs that had more than two options. In these cases, participants were asked to rank their preferences. Regardless of age, the top choice for the Welcome screen, temperature selection, and fan speed were Design 4 (blue) 4-knob design. This design was simpler and relied on familiar in-vehicle metaphors.

In summary, it was observed from users comments that there was a strong preference for large buttons, and one-to-one mapping. This study also gave insight into which type of font to use. However, the major limitation of this study is that the paper prototypes did not provide the opportunity to test the inherent strengths of user interaction and animations or the usability of the interface in a driving scenario.

The next usability evaluation as part of this iterative design process involved 15 Clemson University students in an undergraduate Human Factors Psychology class. The class performed a heuristic evaluation of the next iteration of the aforementioned interface in an effort to identify possible usability issues. This iteration differed from the previous iteration in that this was an actual working prototype, and it did not use the show throw projection technology but was implemented on a portrait oriented 16:9 aspect ratio touchscreen monitor. Therefore this implementation did not include the adjustable center knob. However it did allow for the customization of label color, font style and font color. The students watched a pre-recorded video demonstrating the functionality of each screen so they understood the desired interaction. The students were also provided with screenshots of each screen to be evaluated. They then gave feedback on the usability of

the interface with respects to two persona's (Generation-Y and Baby Boomer) and offered suggestions based on Wickens, et. al (2012), "An Introduction to Human Factors Engineering". The key usability factors of interest were: legibility, contrast, and size of each graphic element. This resulted in a rating of 1 - 5 of text, icons and buttons across various dimensions.

Text: Contrast, Size, Readability

Icons: Understandable (in the absence of text), Size, Contrast, Simple

Buttons: Shape, Size, Location

The persona's that the students used to evaluate each of the 5 screens were:

Generation-Ypersona:

Jeff is a 22-year-old recent college graduate. He has just entered the work field doing work doing programming for a social networking company. Jeff does wear glasses for seeing far away objects (near-sighted). Jeff drives a compact, ecofriendly car. While he owns a car out of necessity, he gets very bored sitting in traffic on his 30-minute commute to his new job. Jeff loves music. He primarily listens to small-indie bands. He would even describe himself as "indie" or "hipster."

Baby Boomer persona:

Cindy is a 54-year-old mother of 2. She stayed home with the kids for the last 18 or so years. While she thinks technology is "cool" and "fun," she isn't particularly tech savvy, however she thinks she is very tech-savvy. She primarily

uses Facebook, email and other photo sharing websites. Her biggest technology challenge is learning a new system. Once she is more comfortable is adequately able to navigate, but it takes a while. She likes her "cute" little sporty convertible. She has a short 10-minute commute to her new part-time job that she got to kill time now that the kids are out of the house. She has transition, bifocal lenses (near-sighted prescription on top that fades into bifocals at the bottom).

The Results

The overall score for both personas were above average with the average score for the Gen-Y persona being 3.77 (SD=1.25) and Baby Boomer 3.47 (SD=1.28). Further many of the metrics seemed to mirror each other. For example, when a certain feature (i.e. button size) performed poorly for the Gen-Y persona it usually performed poorly for Baby Boomer persona and vice versa when a metric performed well it usually performed well for both demographics. Therefore many of the recommendations were not demographic specific, but if implemented could benefit both the Gen-Y and Baby Boomer demographic.



Figure 11a. Screen 1 – Home Screen

Figure 11b. Screen 2 – Temperature Screen

For Screen 1 (Figure 11a.) the general consensus was that button size was the best feature. However the readability of the text could be greatly improved. Although the script font added a level of user customization it was hard to read and the recommendation is that script fonts not be included as an option, but that the fonts included be a standard font such as Arial or Helvetica. Similarly to Screen 1, it was recommended that font size be increased on Screen 2 (Figure 11b). Screen 2 strengths were the feedback that mapped to the visual display for temperature.



Figure 12a. Screen 3 – Fan Screen

Figure 12b. Screen 4 – Mode Screen

It was recommended that the size of the font be increased for both screens for both Gen-Y and Baby Boomers. For Screen 3(Figure 12a.) it was recommended that the different colors were useful, but the contrast of an orange bubble around white text could make the fan text hard to read for Baby Boomers. It was also recommended for screen 3 that some type of feedback other than visual be added so that users know when a button was pressed. For Screen 4 (Figure 12b.) a number of recommendations centered around removal of the redundant use of 'mode'. Many observed that Screen 3 could be used for airflow mode, as the arrows seemed to be indicative of airflow.



Figure 13. Screen 5 – Music Screen

The recommendations for both demographics on Screen 5 (Figure 13.) were related to improving the layout. The first concern was the spacing between the track listing (i.e. someone might accidently press the wrong track due to a lack of spacing) and the second was the placement of the home button. The placement of the home button overlapped some of the track listing and this could cause complications of future use. Some type of

spacing between the tracks and shifting of the tracklist could remedy these layout concerns.

The major takeaways from this study were insights into the appropriateness of font size, layout of main menu buttons and the need for feedback that wasn't visual.

The last study gave some insight into user preferences, and tendencies towards the orientation of 2.5D interaction. This became an important vein of study in that many of the previous screens developed had some required some type of gestural interaction in a swipe or a tap. The data collection process also informed the system design of Hues and Cues.

Participants

There were a total of 12 participants in this study. (7 males, 5 females) collectively comprising of 5 different ethnic groups. Participants ranged in ages of 18 -59 with median age range being 25-31. With the addition of a pre-survey & post-survey each participant performed 12 tasks. The tasks were (3) horizontal interaction tasks, (3) vertical interaction tasks, (1) rank order of horizontal & vertical interaction, (4) range interaction tasks, (1) rank order of range interaction.

Procedures

Each participant was administered a pre- experiment survey. The pre-survey gathered basic demographic information and assessed each users technology usage. After the administration of the pre-experiment survey participants were instructed that they were going to be shown a few screens and then asked questions about those screens. They were instructed to talk out loud about how they felt, and what they liked or disliked about

the screens. Participants were then instructed to image that you are in their newly purchased car and that they wanted to hear their favorite song. Although the screen was not connected as a touchscreen they were instructed to select a song and to interact with it as it were. Starting with the horizontal orientation, the participant was instructed to select a song as the experimenter the type, position and direction of the gesture used by the participant. This was repeated, for a total number of two interactions per screen and after each screen the participant was asked questions about their interaction with the screen, about alternative options for the screen, and for any suggestions. This was repeated for all three horizontal screen (5, 10, 15), and vertical screens (5, 10, 15). After all of the screens (horizontal and vertical) were presented to participants the participants were then asked general questions about there preference toward a particular orientation, anticipated problems, and general likes and dislikes. Then participants completed a post-experiment survey of their likes and dislikes.

Results

In this preliminary experiment it was observed that men tended to swipe more frequently than women, which begs the question, "Is this observation a byproduct of stylistic or grooming choices?" Further investigation of this perceived gender difference is necessary and below are a few methods that can be employed to do so:

• Self-reporting (a series of questions that has the participant categorize the length and style of nail)

Lastly, but not ideal, a \$P JavaScript recognizer could be employed to recognize type of gesture during tasks, as well as experimenter categorizing the length and style of nail as well as the manually recording the type of gesture during each task.

Another finding is that a majority of participants preferred a horizontal carousel orientation as opposed to the vertical carousel orientation for the interaction tasks. In a follow-up survey respondents stated that the vertical orientation seemed more cluttered. These statements were made in spite of the fact that the horizontal carousel had the same number of balls. The participants preference appears to be influenced by the proportion of objects to amount of negative space. In the "cluttered" vertical orientation there was a higher ratio of balls occluded (balls to which the number obstructed; hence unrecognizable) to balls visible.

Even though the items that participants interacted with were abstract. Participants indicated that while interacting with the balls they would like to be given various personalization options such as the ability to personalize the layout by adding or subtracting items or customize relevant information (e.g. track, artist, artwork, etc.). Also participants indicated that they would like the interface to adjust its brightness according to the time of day noting that the balls in the back had a lower opacity and at times seemed to "too light", which made it hard to interact with. It was also stated that there needed to be more contrast between the selected ball and the non-selected ball. One of the most interesting findings was that sometime the interaction cues did not change interaction behavior. As it was observed that some people "tapped" or "swiped" regardless of the interaction of the interaction cues.

In summary theses three usability studies provided insight into how to better design the buttons, labels and interactions that would make the Hues and Cues design paradigm more usable. Nevertheless there are other important considerations that relate to automotive user interfaces.

Other Interface Considerations

Ergonomic Considerations

It is important that IVI systems are ergonomically designed to accommodate driver limitations and capabilities (Kristie Young & Regan, 2007). The location of the interaction with the IVI system is a critical factor. For example, reach distance which is an important factor for in-vehicle task performance (Fuller, Tsimhoni, & Reed, 2008). Kramer noted that in-vehicle task performance was far worse when the subject used the screen that was physically farther from the driver, compared with those that were closer (Kramer et al., 2007). Also as the angle between the forward view and the in-car task increases, transition time for the eyes increase. Therefore, it is best to locate the in-car task display high on the instrument panel (IP) (Wierwille, 1993). How I used this in the study

Layout Considerations

Automotive HMI's should also be intuitive and easy to learn. To increase intuitiveness and learnability Niedermaier et al., suggest minimizing the number of interaction paradigms driver's needs to understand across all vehicle functions (Niedermaier et al., 2009). An investigation of the effects of spatial and action-based information on the expectations of interface layout demonstrated that space, familiar graphical semantics (logical meaning) (Green, 1993), and affordances (visually representing actions that can be performed on an object) (Gibson, 1977) are important factors. As these factors play a major role in expectation of objects and visual cues of what to do on VUI's (Terenzi M., 2005). The two previously discussed concepts relate to the overarching idea of building a consistent mental model (explanation of how something works in the real world) (Kieras & Bovair, 1984) with users. The importance of creating an appropriate mental model for users has been expressed within many respects of automotive HMI. When designing a voice user interface (VUI) creating a sense of place or mental model of the layout in pertinent so users would understand where they are (Mynatt, 1997). Also when designing various types of tactical feedback it must be noted that some people may have little experience interpreting or responding to new tactile cues (Kramer et al., 2007).

Furthermore it has been well established that the menu systems are assessed based on how well they map to the mental model of the user interacting with them (Toms, Cummings-Hill, Curry, & Cone, 2001). As aforementioned, building better menu systems partly depends on building better mental models. However many automotive GUI menu systems have been poorly designed As Tom's et al. (2001) states in their commentary on automotive user interfaces:

"The menus for such systems are often designed by engineers who organize them from the perspective of compatibility with electronic and software subsystem

design, rather than in accordance with the end user's understanding of the device's functionality."

(Tom's et al., 2001)

One approach to mitigate these poorly designed menu systems is to cluster similar functions or concepts together. Figure 14, consists of pictures taken during a field study of the current automotive user interfaces. The pictures are of the use of a 2013 Chevrolet Equinox IVI system at Motor Trend's 2013 International Autoshow in Greenville, South Carolina. It can be observed that this interface implements the paradigm of pages to organize content and large "app" buttons most familiar to smartphone and tablet devices. Though using clustering principle it is demonstrated by the "FM Station List" that this system retains some of the menu driven elements.













Tom's et al. (2001) examined a user centric approach to clustering menu items that provided an intuitive menu architecture that corresponded to the users expectations. In thinking about this with respects to Hues and Cues a lot of design thought went into the menu hierarchy as demonstrated in Figure 15. Figure 15 demonstrates the thinking behind how the menu system of Hues and Cues should be implemented. A top level home row or set of buttons and the ability to go back at anytime. One interaction that stood out

the most was some type of tabbed interaction. Although a popular web interaction tabbed navigation or some variation of it deserves some consideration.



Preliminary Flow Chart of Menu Structure

Jakob Nielsen one of the premier authorities on interface usability offered insight in to ways of improving tabbed navigation on websites in a web article entitled "Tabs Used Right" Out of the 13 design guidelines for tab control two (number 5 and number 7) guidelines were adhered to conceptually in the development of the Hues and Cues paradigm (Nielsen, 2007). 5. The current selected tab should be highlighted, just as it would be if we were shuffling several physical index cards that had tabs stuck to them7.Tabs needed to be connected to the content area

One major issue in designing GUIs is to calibrate the appropriate amount of information to present to the user because too little information does not effectively support users in performing the tasks, while too much information leads to a confusing user interface (UI) (Costagliola et al., 2005). Wierville, in his classifications of distraction also called from a reduction in clutter from the visual interface (Wierwille, 1993).

To Nielsen's commentary around the use of tabs and in the spirit of making the interface less confusing it was decided to group similar functions on one page a decision supported by one of the findings of the first usability study. Figures 16 and 17 show the main interaction area and unobtrusive navigation.



Figure 16. Preliminary climate interaction with gestural input

Home				
		Temperature		
		60 °]
Defrost	Μ	lode	Fa	n Speed
***	Ĕ	ir fr	OFF	

Figure 17. Preliminary climate interaction without gestural input

Iterating on the previous designs (Figures 16 and 17) Figures 18 and 19 demonstrate how color could be used to give more information about specific function in use. The colors and their positioning are derived from (Ayama & Sakurai, 2003); the aforementioned paper that examined color in the periphy. Also Figures 18 and 19 improve upon the previous designs (Figures 16 and 17) by making the navigation row buttons larger and locating them vertically and on the left hand side (closer to the driver).

Navigation			
		Temperature	
	60°	70°	80° 90°
Climate			
	Defrost	Mode	Fan Speed
Music Phone		<u> </u>	

Figure 18.

Preliminary Hues and Cues design



Figure 19. Refinement of preliminary Hues and Cues design

System Overview

A considerable amount of attention was directed towards improving the functionality and usability of the interface prototype. Likewise considerable attention was directed to making the process of conducting the experiment and data analysis more efficient. Therefore, a testing platform was developed so that the interface prototype could be integrated into platform; making the experiment and data analysis more efficient. Early in the development process of the interface prototype consideration was given to the integration of this prototype into the testing platform. This is the reason the final interface prototype records the type, duration and distance of each gestural interaction. The subsequent discussion will describe the design and implementation of the platform used to conduct the experiments necessary to evaluate the Hues and Cues design paradigm. The preliminary experiment that examined the various facets of 2.5D interaction proved very useful in providing insight into the desirable characteristics of a system designed for experiments capturing touch interaction. In this experiment, it was observed that the experimenter had to keep track of multiple pieces paper instruments:

- Multipage experiment script
- Pre and post assessments
- Questionnaires administered after each interface interaction,
- Experimental log where the experimenter (by hand) would record the gesture type, and direction of an interaction.
- Visual aids

This type experimental setup posed a number of issues:

- Redundant data entry
- Longer experiment times,
- Increased possibility of systemic error
- Added complexity

In this experiment it was observed that data analysis comprised of unnecessary data reentry; recording results from questionnaires on paper then transferring them to Microsoft excel, then importing them into statistical analysis software. Also, longer experiment times could be attributed to manual rather than automatic recording of gestural interaction requiring more time between tasks. The experimenter manually recorded the type and direction of the gesture performed. Furthermore, this classification of gesture type was based on their judgment of what constituted a swipe, tap, or drag. Though appropriate for initial classifications and as a means to better understand user interaction, this sole observation technique lacks consistent objectivity and accuracy. Another factor decreasing the efficiency of the experiment was the paper shuffling. The juggling of pieces of paper made it difficult for a seamlessness execution of the experiment; the experimenter had to keep track of 18 pieces of paper. This added another level of complexity to the experiment because another system had to be developed to keep track of these pieces of paper (survey instruments and visual aids).

As aforementioned a system was developed to ameliorate the problematic issues of the experiment process. The Hues and Cues experiment platform addresses these issues by:

- Minimizing the number paper survey instruments
- Recording survey data once, in a format easily parsed by statistical analysis software.
- Automating the presentation of secondary task instructions
- Collecting gestural input automatically through the interface prototype.

The system comprises of three components, a participant interface, experimenter interface, and experiment creator tool. The participant interface is an interface that records user's input (gestural and survey data). The controller interface was used by the experimenter to administer tasks and procedures. The template creator is used to create the flow/script that appears on the controller screen for the experiment.
As described by Nam P. Suh in his seminal work entitled "The Principles of Design", "...in good design the independence of functional requirements is maintained" (Suh, 1990). In adhering to this principle, each function that the system performs should be independent of all other functions the system performs (Figure 9). This principle of modularity guided the design of the system so that if at any point in time there needed to be changes in the system (removal of features, functional changes, or additional features/functionality) there would be no need to make multiple changes to the software. In software this principle can demonstrated by:

- Having fewer dependencies
- Increasing the flexibility of the software.
- Promoting loose coupling

To achieve this the mediator design pattern was implemented facilitating the aforementioned features. Often times in software engineering, the behavioral design patterns are used as a template for the communication pattern that should exist between objects. The mediator promotes loose coupling by keeping objects from referring to each other explicitly, and it lets you vary their interaction independently. The module pattern was implemented in JavaScript and the mediator object and modules were also constructed in JavaScript. The JavaScript mediator object was responsible for all of the interconnections; acting as the hub of communication and controlling and coordinating the interactions of its clients. This system is further illustrated in Figure 20.



Figure 20. Block diagram of automotive interface system

Client

The client is comprised of the HTML5 webpages and a JavaScript client listener object that sends all interaction on the webpage to the mediator object and listens to the mediator for any updates. To achieve the desired interaction, HTML5, CSS3, JavaScript and related JavaScript libraries were used to create the interface prototype. To simplify the HTML5 document traversing, event handling, and animation the popular JavaScript library jQuery was employed. jQuery supported the rapid web development and flexibility needed for this project (jQuery Foundation, 2014). In concert with jQuery, a modified JS Cover Flow (Luyten, 2013) was used for the cover flow animation for album selection (Figure 21a). JS Cover Flow is an open source JavaScript component made for the web that allows images to be viewed using the popular coverflow interaction made popular by Apple iTunes (Figure 21b).



Figure 21a. JS Cover Flow (2014)

Figure 21b. Apple's Cover Flow (2007)

JS CoverFlow produces its effect by applying CSS transformations to a list of images displayed on the HTML5 canvas element. Codiqa was used for the development of the survey instruments. Codiqa is a drag and drop mobile UI creator and provided an easy mechanism for creating the tablet-based surveys.

The 7 main functions of Climate, Apps, Phone, Music, Navigation, Car Information and Settings were not arbitrarily chosen. The functions needed to representative of functions currently in IVI systems. To this end, the September 2012 issue of the popular American automotive enthusiast magazine Car and Driver released as special article entitled "New Cars for 2013"; it was from this article that the AutoPacific data on the anticipated 2013 sales volume of car brands in American was taken (except Bugatti and McLauren). This 60-page review detailed each brand's 2013 major models and more importantly provided projected number of units sold in America for all major brands. A general overview with images is included in Appendix A.

Music Player Functional Module

Within the functional modules an audio module was developed to handle the music and audio prompt queuing and playback. This module was implemented using the JavaScript audio functions related to the HTML5 audio tag. This module provided the functionality for loading, playing and viewing track time of the music screen. PHP v4.2 was used to dynamically load the track list stored in a json file, so that when a particular album cover was selected the corresponding tracks would appear. CSS3 was used to implement the modal window that appeared after track selection with the audio module providing the functionality for the controls. The music player module was also responsible for playing the audio prompts. These prompts were static files text to speech files using NeoSpeech's male voice "James"; one of the more understandable voices.

Touch Controller

Not only did the interface have interaction and presentation requirements it also collected touch information. A JavaScript module was developed to capture touch events and then save them in a json format. To establish the correct event on the Microsoft Surface Pro and to simplify the implementation, mouse events, pointer events, and touch events were universally handled (Appendix G). The touch events were captured using a modified version of a proof-of-concept front-end gesture recognizer developed by Joseph

Schooley for iOS and Android devices (Joseph, 2013). The recognizer collects the coordinates of the gesture, the time of the start event (when the user first touches the screen) and end event (when the user's finger leaves the screen). If the user moves more than the threshold (3px) then the recognizer classifies the gesture as a swipe, if the user's finger moves less than the threshold between the start and end event then the gesture is classified as a tap. The threshold was chosen after a few pilot tests of the appropriate tolerance in pixels for a tap gesture.

Controller Interface

Another critical component of the system is the controller interface. The controller interface was also built using HTML5, CSS3, JavaScript and PHP5. The controller interface logs meta-information (group, participant id, test, time) associated with the participant as well as providing a control for the experiment (Figure 22).



Figure 22. Start screen for Controller interface (capturing metadata)

This interface enables the experimenter advance through the survey and various interfaces, keep track of the participant's progress, as well as log the mental effort of the participant. When a new experiment begins the controller interface creates a folder to contain the csv files of the participants survey responses and interactions with the interface. The controller interface also displays instructions for the experimenter (Figure 23). The script and general flow of the experiment for the controller interface comes from a json file that can be altered to the needs of the experimenter.



Figure 23. Controller interface (displaying script for experiment)

WebSockets

All communication between the client, controller interface use WebSockets.

Websockets is a web technology most frequently implemented in HTML5 applications

that provides full-duplex communication channels over a single TCP connection. WebSockets were designed to be implemented in web browsers and web servers, but can be used by any client or server application, facilitating live content and the creation of real-time games (Kaazing Corporation, 2013) Standardized by the IETF as RFC 6455 in 2011, the WebSocket API is currently being standardized by the W3C (Hickson, 2012). With this API, you can send messages to a server and receive event-driven responses without having to poll the server for a reply. The current implementation used WebSockets for the client listener and PHP v4 for the WebSocket server. The WebSocket server receives the client side HTTP to WebSocket upgrade request, and upgrades HTTP protocol/connection to a WebSocket protocol/connection. This allows for the browser-tobrowser communication between the controller interface and the client.

CHAPTER FOUR

METHODOLOGY

Rationale for Instruments and Procedures

The evaluation portion of the Hues and Cues design paradigm aims to assess the effects (if any) of the paradigm on driver performance when applied to a novel automotive user interface prototype. With an abundance of literature on driver performance metrics, testing methods and theories it was essential that sufficient amount of discourse was given to the rationale of the proposed methodology (Fisher, Rizzo, & Caird, 2011). The appropriate metrics and subsequent method of evaluating this paradigm was a trade-off between fidelity, validity, and sensitivity within scope of the research question at hand:

Does the Hues and Cues design paradigm minimize the degradation in driving performance when compared to the same interface without this paradigm applied?

As Hues and Cues have already been defined, the terms that need to be functionally defined are degradation and driver performance. Degradation in the context of this dissertation is a measure of how much the quality of the acceptable standard metric is diminished (i.e. standard deviation in lane change from normative model). More difficult to functionalize is the term driver performance.

Driver performance has been a topic of inquiry for quite a while, and many of the current driver performance metrics can be attributed to the seminal work of Gibson and Crooks entitled, "A theoretical Field-Analysis of Automobile-Driving"(Hochberg, 1994). Gibson and Crooks' concept of the field of safe travel, minimum stopping zone, and the nature of steering are clearly interwoven into the rationale of gap acceptance and steering entropy measurements as viable indicators of multitasking during driving (Östlund et al., 2005;Young & Regan, 2007). Gap acceptance and steering entropy are just a couple of measures that are currently used to quantify driver performance (usually in the presence of a secondary task). Driver performance metrics have evolved to support theories regarding driver motivation, information processing, and perceptual control (TA Ranney, 1994; Vaa, 2007). Therefore, driver performance can comprise of a myriad of metrics.

The Adaptive Integrated Driver-vehicle Interface (AIDE) project evaluated various driving performance assessment methods and metrics, and defined driver performance as, "All aspects involved in mastering a vehicle to achieve a certain goal (e.g. reach a destination), including tracking, regulating, monitoring and targeting." Furthermore, Green characterizes driving as consisting of, "A set of tasks and activities requiring perception, cognition, motor response, planning, and task selection.".

Similarly, Ranney et al. (2000), has characterized driving as the activities involving basic control of the vehicle, such as maintaining appropriate speed, headway, and lane position within surrounding traffic. These expert characterizations of the multifaceted nature of driving performance further illustrate the difficulty that may arise in choosing the appropriate metric(s). Fortunately, the Crash Avoidance Metrics Partnership (CAMP) identified pertinent performance metrics. CAMP, is a partnership established by Ford and GM to undertake joint pre-competitive work in advanced

collision avoidance systems. Such as developing performance metrics and test procedures to assess the visual, manual, and cognitive aspects of driver workload. CAMP's research found that none of the driving performance metrics they tested were able to discriminate high from low-workload tasks for any of the auditory-vocal tasks.However, they found that such metrics as task duration, standard deviation of lane position, speed difference, and selected eyeglance metrics were able to perform this discrimination for type of task (e.g. visual-manual tasks).

In another study, Young and Angell examined 79 secondary manual tasks and demonstrated that the 15 most frequently used measures of driver performance could be separated into three distinct groups using principal components analysis. This study found that three components could account for 83% of the variability in driver performance. The first component, "overall driver demand" accounted for 61% of the total variation and mostly represented driver performance, such as vehicle control. The second principal component, "low-workload-but-high-inattentiveness" accounted for 17% of the total variation and characterized by event detection; represented the phenomena of "mind-off-the road" or mental distraction. The third component, "peripheral insensitivity" accounted for 5% of the total variation and generally encompassed peripheral event detection; associated with visual tunneling (R. Young & Angell, 2003). Table 6 and Table 7 demonstrate the variables that Young and Angell examined and their correlation to the secondary tasks.

Table 6. Variables collected for every task for every subject are listed.

#	Variable	Name
1	Task Completion Time	tasktime
2	Eyes-Off-Road Time	eort
3	Number of Glances to the In-Vehicle System	glances
4	Number of Lane Deviations	lanedev
5	Subjective Workload	workload
6	Subjective Situation Unawareness ⁸	sit_unaw
7	Number of Speed Deviations	speeddev
8	Percent Unsuccessful Task Completion ⁹	per_unsu
9	Percent of Total Visual Events Missed	allmiss
10	Percent of Forward Visual Events Missed	hoodmiss
11	Percent of Side Visual Events Missed	sidemiss
12	Mean Single Glance Time to System	glncedur
13	Time to Respond to Total Visual Events	evnttime
14	Time to Respond to Side Visual Events	sidetime
15	Time to Respond to Forward Visual Events	hoodtime

(R. Young & Angell, 2003)

 Table 7. Correlation matrix of 15 variables

	1 tasktime	2 eort	3 glances	4 lanedev	5 workload	6 sit_unaw	7 speeddev	8 per_unsu	9 allmiss	10 hoodmiss	11 sidemiss	12 glncedur	13 evnttime	14 sidetime	15 hoodtime
1 tasktime	1.000	.984	.989	.923	.931	.910	.914	.876	.576	.521	.462	.521	.393	.312	.281
2 eort	.984	1.000	.989	.920	.917	.895	.875	.882	.564	.508	.464	.583	.369	.289	.273
3 glances	.989	.989	1.000	.922	.935	.911	.885	.866	.566	.499	.462	.535	.352	.276	.247
4 lanedev	.923	.920	.922	1.000	.882	.846	.820	.797	.578	.517	.477	.504	.400	.336	.269
5 workload	.931	.917	.935	.882	1.000	.985	.815	.775	.540	.459	.451	.479	.374	.299	.211
6 sit_unaw	.910	.895	.911	.846	.985	1.000	.799	.742	.509	.439	.417	.470	.367	.294	.200
7 speeddev	.914	.875	.885	.820	.815	.799	1.000	.823	.527	.500	.397	.420	.309	.229	.224
8 per_unsu	.876	.882	.866	.797	.775	.742	.823	1.000	.431	.431	.358	.407	.240	.210	.209
9 allmiss	.576	.564	.566	.578	.540	.509	.527	.431	1.000	.775	.849	.544	.673	.534	.541
10 hoodmiss	.521	.508	.499	.517	.459	.439	.500	.431	.775	1.000	.460	.394	.512	.346	.568
11 sidemiss	.462	.464	.462	.477	.451	.417	.397	.358	.849	.460	1.000	.487	.587	.605	.376
12 glncedur	.521	.583	.535	.504	.479	.470	.420	.407	.544	.394	.487	1.000	.412	.307	.316
13 evnttime	.393	.369	.352	.400	.374	.367	.309	.240	.673	.512	.587	.412	1.000	.812	.734
14 sidetime	.312	.289	.276	.336	.299	.294	.229	.210	.534	.346	.605	.307	.812	1.000	.383
15 hoodtime	.281	.273	.247	.269	.211	.200	.224	.209	.541	.568	.376	.316	.734	.383	1.000

(R. Young & Angell, 2003)

Young and Angell's study provides many useful insights into driver performance metrics. They found that the first component, "overall driver demand" consisted of variables such as: task time, eyes-off-road time, glances, lane and speed deviations, subjective workload, subjective situation unawareness, and unsuccessful task completions. These aforementioned variables encompass both driver visual-manual workload variables as well as event detection variables, and could explain most of the variance in all the tasks studied. Young and Angell's findings along with insights from CAMP's evaluation driver performance metrics establish that with respects to visual manual tasks the indicative variables of degradation in driver performance are:

- Task duration
- Standard deviation of lane position
- Speed deviations
- Eyes-off-road time,
- Frequency of glances

Currently, there is no universally agreed upon set of driving performance measures, however the previous five metrics serve as valid, reliable measures. More so, these metrics have been proven to be sensitive to visual distraction (Young & Regan, 2007). In an attempt to properly ascertain these measurements a number of tests have been developed. It is beyond the scope of this dissertation to provide an extensive review of these tests as extensive reviews of these tests already exist and guide researchers in understanding the implications of using a particular test (Angell et al., 2006; Green, 1995; Lee J. et al., 2008; Östlund et al., 2005). However, it would be negligent not to discuss why certain tests were not used in this study. Though a naturalistic driving assessment is compelling a simulated driving environment was chosen because of its

efficiency, ease of data collection, and overall acceptance as demonstrated by (Horrey et al., 2006) as well as (Caird et al.,2005). Within the scope of simulated driving experiments there are a number of surrogates tasks and tests that have been developed to help assess distraction such as Sternberg memory test, object and event detection tasks, Lange Change Test.

The Sternberg Memory Test involves participants memorizing a number of road signs and then in a simulated driving a road sign will be briefly presented with the participant pressing one pushbutton if the displayed sign was from a set of signs memorized prior to the start of the task, or a second pushbutton if not. This test enables the investigation of task effects on spatial and verbal working memory. At the present time this study is focused on investigating the visual rather than cognitive demand of the interface; therefore, the Sternberg Memory Test was not considered in this testing protocol.

Driver's response to objects and events are a critical part of driving process. As a result object and event detection testing methods are gaining popularity, as a more realistic measure of driver performance. Usually in these tests, reaction time to an event or object presentation is measured while the participants perform a secondary task and the primary task of driving. Commonly used objects are lead vehicle braking or decelerating, center hi-mounted stoplights (CHMSL) and traffic signs. Many experiments have demonstrated the efficacy of using these tests to discriminate multitasking from "just driving" (Chisholm & Caird, 2006; Greenberg et al., 2003; Lee & McGehee, 2002) Aside from the lack of standardized guidelines for using object and event detection in

driving tests the other issues surrounding these types of test are methodological concerns related to the use of repetitive object and event detection methods. For example, surprising events (e.g. deer enters the road unexpectedly) can be employed only a few times before this event stops surprising drivers. As a result, it becomes difficult to collect enough corresponding data points to provide an appropriate and meaningful statistical analysis. Conversely, if a lead vehicle-braking task occurs too often then it runs the risk of becoming predictable. As Victor et al. (2008), point out this frequency affects drivers' expectations, and turns the task into one of vigilance rather than event detection. Furthermore, it has been observed that object and event methods might not be suitable to assess tasks of short duration, since these tasks do not allow sufficient number of object/event presentations to appropriately assess the level of distraction (Angell et al., 2006). In the current study tasks that would frequently occur driving to a destination (e.g. climate and radio control) are of interest. These tasks of shorter duration would not be suitable for the object or event detection events. Though these tasks could be made artificially longer by constant repetition Noy and Lemione point out, visually intensive tasks done repeatedly can artificially elevate a short task's workload measures (Noy & Lemoine, 2001) To this end, the Lane Change Test (LCT) is more suitable for the types of task presented.

During the LCT traffic signs at either the side of the three-lane simulated road indicate the lane the lane to be maneuvered to. Participants are instructed to give priority the main goal of the LCT; changing the lane as quickly as possible and keeping a constant speed of 60 km/h (full acceleration). Participants change lanes while

simultaneously performing a secondary task. As a result, the mean lane deviation from the ideal driving line is a performance measure of how much the secondary task degrades the simulated driving task. As most simulators capture the standard deviation of lane position and speed the LCT also captures these measures. Furthermore, the LCT can be seen as a stimulus response paradigm with complex stimuli (the arrow signs), complex responses (steering maneuver), and a tracking task between two consecutive trials (lane keeping). The LCT was designed to combine the advantages of driving simulator studies and the advantages of probe reaction tasks (Mattes, 2003).

The LCT is not excluded from criticism. One concern of researchers is the level of realism provided by the LCT (Bruyas & Brusque, 2008). However, as Angell et al. point out, the more realistic the scenario, the more difficult and possibly ambiguous data analysis and interpretation can be (Angell et al., 2006). Also when more realistic scenarios are used with object and event detection there is a requirement that measures of longitudinal and lateral performance and other variables be interpreted in the light of the each other. As Angell, known for her work in driver distraction states:

"Changes in lateral performance must be interpreted differently for a driver who decides to reduce speed when they are asked to make an input on a IVI system as compared to a participant who prefers to keep speed constant, as this becomes an artifact of the experiment" (Angell et al., 2006).

To this end, and to avoid the above-mentioned trade-off between lateral and longitudinal control performance, speed is maintained at 60 km/h.

Although not a test measuring driver performance but to eye glance behavior, the Visual Occlusion test is worth mentioning. Since eye-glance frequency and behavior are often difficult to capture and require expensive equipment and time intensive data analysis the Visual Occlusion test has been seen as an appropriate surrogate. The Visual Occlusion Test, which was adopted as a tool for designers and evaluators to gain estimates of visual demand cheaper and faster but still maintaining some level of methodological rigor. In fact, the visual occlusion method was sought out partly in response to dissatisfaction with the "15-second Rule" (the total time it should take to complete a task) (Green, 1999) for its lack of supporting data (Baumann, Keinath, Krems, & Bengler, 2004) and its face validity. In most cases, this bench test (not using a driving simulator) requires the participant to perform tasks on an interface to get the Total Task Time under an unconcluded condition then perform tasks under an occluded condition (using occlusion goggles or blanking screen) for 1.0-1.5 seconds at an interval of 1.0-1.5 seconds until the task is completed. This test has been modeled after extensive research in glance behavior (Olsen et al., 2005; Perez et al., 2013; Smith et al., 2005; Sodhi et al., 2002; Tijerina & Garrott, 2005). The visual occlusion method is more extensively described in the SAE J2364 (Society Of Automotive Engineers, 2004). Furthermore, the publication of ISO Standard 16673 further demonstrates the human factors community's acceptance of the visual occlusion technique as a screening tool for developers of in-vehicle systems (International Standards Organization, 2007). Though the Visual Occlusion Test is highly replicable with cross-validation, very applicable, and consistent across a number of studies. It has been demonstrated that this is not sensitive in

combination with short, auditory, or pure manual tasks. It is also unclear what R measures in terms of safety (Monk & Kidd, 2007). It must be noted that, all in all tests, there is an inherent risk that participants will develop strategies for allocating attention. When compared to a naturalistic driving scenario, and even in "real driving" it has been observed that participants find ways to mitigate distraction while still performing invehicle tasks (International Standards Organization, 2008).

For testing purposes of the Hues and Cues design paradigm on a prototype the LCT proved appropriate (Angell et al., 2006; Federal Register, 2013); the test gives an estimate of how well the design paradigm reduces visual distraction. The LCT measures are interpretable based on the theory that visual distraction induces a visual time sharing between the road and secondary task; as visual feedback becomes more central to task completion, the time with eyes off the road also increases (Green, 1999). During glances to the system, the visual input needed for lateral control is reduced (or entirely inhibited) which temporarily inhibits the driver's steering response, leading to a steering hold (i.e. fixed steering angle). In the LCT, this will likely be observed in lane drifts, which are compensated for by large, and disruptive steering maneuvers when the gaze returns to the road (Östlund et al., 2005; Victor et al., 2005); resulting in greater deviation from the normative driving model. These tracking effects are more frequently quantified by lane keeping variation metrics (e.g. standard deviation of lateral position) (Östlund et al., 2005) and specifically captured by the LCT in the form of the Standard Deviation in Lane Position (SDLP) metric.

In conclusion, after considering the nature of the test needed for Hues and Cues interface the LCT proved to be a feasible solution.. Moreover, the LCT is reliable as tests are highly replicable with cross-validation and consistent findings across a number of studies. Insomuch that the International Standards Organization (ISO) has developed a standard for it, enabling researchers to better communicate and validate their findings (International Standards Organization, 2008). Therefore driver performance in the context of this document will be considered as standard deviation in lane position from the normative model in combination with the frequency of erroneous or missed lane changes; measured by the LCT.

Research Questions

The research questions guided the investigation of the Hues and Cues paradigm are: 1. Does the Hues and Cues design paradigm minimize the degradation in driving performance when compared to the same interface without this paradigm applied? 2. Does the Hues and Cues design paradigm reduce the duration of a task when compared to the same interface without this paradigm applied?

3. Does the Hues and Cues design paradigm minimize mental workload performance when compared to the same interface without this paradigm applied?

4. Does the Hues and Cues design paradigm improve the usability when compared to the same interface without this paradigm applied?

5. Do participants prefer interfaces that implement Hues and Cues design paradigm?

Hypotheses

Hypothesis 1 - There will be less deviation from the normative model when using Hues and Cues interface during the LCT scenarios than with other (monochromatic, audible only, color only) interfaces.

 H_0 : On average, the participants in this study will have the same or greater variation in lane position using the multimodal interface (hue and audible cue), than using monochromatic or primarily chromatic interfaces.

 H_A : On average, the participants in this study will have less variation in lane position using the multimodal interface (hue and audible cue), than using monochromatic or primarily chromatic interfaces.

Hypothesis 2 - There will be fewer missed or erroneous lane changes when using Hues and Cues interface during the LCT scenarios than with other (monochromatic, audible only, color only) interfaces

 H_0 : On average, the participants in this study will have at least the same number or more (missed or erroneous) lane changes using the multimodal interface (hue and audible cue), than using monochromatic or primarily chromatic interfaces.

 H_A : On average, the participants in this study will have fewer (missed or erroneous) lane changes using the multimodal interface (hue and audible cue), than using monochromatic or primarily chromatic interfaces.

Hypothesis 3 - Mean task completion time will be shorter for Hues and Cues interface under LCT task than for other (monochromatic, audible only, color only) interfaces

 H_0 : On average, the participants in this study will have the same or greater mean task completion times using the multimodal interface (hue and audible cue), in comparison with the monochromatic or primarily chromatic interfaces.

H_A: On average, the participants in this study will have lower mean task completion times using the multimodal interface (hue and audible cue), in comparison with the monochromatic or primarily chromatic interfaces.

Hypothesis 4 - Mean overall performance will be lower for Hues and Cues interface

under LCT task than for other (monochromatic, audible only, color only) interfaces.

 H_0 : On average, the participants in this study will have the same or greater overall performance scores using the multimodal interface (hue and audible cue), in comparison with the monochromatic or primarily chromatic interfaces.

H_A: On average, the participants in this study will have lower overall performance scores using the multimodal interface (hue and audible cue), in comparison with the monochromatic or primarily chromatic interfaces.

Hypothesis 5 - On average, participants will have lower mental workload when using Hues and Cues interface during the LCT scenarios compared to other (monochromatic, audible only, color only) interfaces.

 H_0 : On average, the participants will subjectively find the multimodal interface (hue and audible cue) to cause more mental workload than using monochromatic or primarily chromatic interfaces.

 H_A : On average, the participants will subjectively find the multimodal interface (hue and audible cue) to cause less mental workload than using monochromatic or primarily chromatic interfaces.

Hypothesis 6 - On average, participants will find the Hues and Cues interface more usable, compared to other (monochromatic, audible only, color only) interfaces.

H₀: On average, the SUS score will be the lower for the multimodal interface (hue and audible cue) compared to the monochromatic or primarily chromatic interfaces.

H_A: On average, the SUS score will be the higher for the multimodal interface (hue and audible cue) compared to the monochromatic or primarily chromatic interfaces.

Hypothesis 7 - On average, participants will find the visual and audible feedback helpful

 H_0 : The average likert ranking for the combined visual and audible helpfulness will be less than or equal to 3 (likert scale 1 -5).

 H_A The average likert ranking for the combined visual and audible helpfulness will be greater than 3 (likert scale 1 -5).

Hypothesis 8 - On average, participants will rank the Hues and Cues interface higher than the other (monochromatic, audible only, color only) interfaces.

H₀: The average rank for the Hues and Cues interface will be higher than the monochromatic or primarily chromatic interfaces.

H_A: The average rank for the Hues and Cues interface will be lower than the monochromatic or primarily chromatic interfaces.

CHAPTER FIVE

EXPERIMENT

Participants

The participants consisted of 45 licensed drivers living near or in Pickens County South Carolina and were recruited from the campus of Clemson University (Clemson, South Carolina.). The experiment lasted anywhere between 60 minutes - 90 minutes varying by participant and participants were compensated \$10.00 for their time at the end of the experiment.

Although 45 people participated in the study, 1 participant's results were not included in the data analysis due to system malfunction that resulted in unintelligible data. A total of 44 (22 male, 22 female) were included in the data analysis. Participants varied in age from 22 - 47 with a median age was 29, MAD ±3 (Females MD = 29, MAD ±3; Males MD = 29.5, MAD ±3). Each participant of had a valid drivers license with at least two years of driving experience with a median range of 10 to 19 years of experience; 95% of the participants stated that they drove daily, and 5% stated that they drove weekly.

81% of participants were generally unfamiliar with participating in a driving simulation, however 60% of them reported to having experience using an in-vehicle touch screen for functions like radio, climate, etc.

Experiment Design

The overall experiment followed a factorial repeated measures design. This allows for the evaluation of the design paradigm with respects to the effects of the color and auditory feedback by gender. The experimental design consists of 44 participants that were randomly assigned by gender (matched assignment) to the evaluation of the different Hues and Cues interface groups as illustrated by Table 8.

Hues and Cues Interface							
Gender	Group	Gender	Group				
Male	G1	Female	G1				
Male	G2	Female	G2				
Male	G3	Female	G3				
Male	G4	Female	G4				
Male	G1	Female	G1				
Male	G2	Female	G2				
M	G	F	G				
M	M G		G				
M	G	F	G				

Table 8. The participant groupings by gender

Participants were asked to interact with screens that either: change in background color based on current function (hues), provide auditory information in the form of a speechcon based on current function (cues), do both (Hues and Cues), or do neither (no hues, no cues) as seen in Table 9. To reduce the magnitude of order effects each participant was assigned to one of four groups (Group 1, Group 2, Group 3, and Group 4) which corresponded to the order in which screens were manipulated. Screens 2, 3, and 4 demonstrate a balanced 4x4 Latin square design with the first and the last screen serving as baseline measures that will be used in observing the learning effects (if any) of using this interface over time.

	Hues and Cues Interface						
	G1	G2	G3	G4			
Screen 1	Р	A	В	С			
Screen 2	А	В	С	Р			
Screen 3	В	С	Р	А			
Screen 4	С	Р	А	В			

Table 9. The presentation order of screens based on group

Groups

G1 = no-hue|no-cue(p), hue|no-cue(a), cue|no-hue(b), hue|cue(c)

G2 = hue|no-cue(a), cue|no-hue(b), hue|cue(c), no-hue|no-cue(p)

G3 = cue|no-hue(b), hue|cue(c), no-hue|no-cue(p), hue|no-cue(a)

G4 = hue|cue(c), no-hue|no-cue(p), hue|no-cue(a), cue|no-hue(b)

As previously stated, each participant completed a total of 4 driving scenarios using the automotive user interface prototype (plus an additional baseline drive without tasks drive before and after the driving scenarios). In each driving scenario they were presented with a particular interface design. Though interfaces will have the same layout and interaction methods they will vary in presence of audible and color feedback cues.



Figure 24. Monochromatic Background

The first type of interface (baseline) (Figure 24.) has a monochromatic background that remains the same for all infotainment functions, and has no auditory feedback when interacted with. The second type of interface (sound) has a monochromatic background that remains the same for all infotainment functions, and has auditory feedback when interacted with. The third type of interface (color) (Figure 25.) has background colors that correspond with a unique function, and have no auditory feedback when interacted with. The fourth type of interface (color-sound) has both background colors that correspond with a unique function, and corresponding auditory feedback.



Figure 25. Dynamic Background

Task Instructions

During the driving scenario the participants performed the following tasks on the

interface (Figures 26a and 26b). (Text to speech instructions will be given through the

secondary interface programmed at random intervals of 3-8 seconds after previous task

completion until scenario is completed):

Santana = Please play track number 7, "Maria Maria". On Santana's, Supernatural album.

ACDC = Please play track number 1, "Shoot to Thrill". On AC DC's, Iron Man 2 album.

Luther = Please play track number 10, "A House is not a Home". On Luther Vandross's, Live at Radio City Music album.

Temp = Please change the temperature from 62, to 74.

Mode = Please change the fan speed from Off, to level 3.

Fan = Please change the mode of airflow, from feet, only, to head, only.



Figure 26a. Music Screen

Figure 26b. Temperature Screen

Participants went through 6 trials including two baseline trials. In each trial tasks were presented in a different order. Below is the task order based on trial:

Tasks(Tx) = ACDC(T1), Santana(T2), Luther(T3), Temp(T4), Mode(T5), Fan(T6)

Trial 1 = T2, T3, T1, T4, T0, T6 Trial 2 = T0, T1, T6, T2, T3, T4 Trial 3 = T6, T2, T4, T0, T1, T3 Trial 4 = T3, T0, T4, T1, T6, T2 Trial 5 = T2, T3, T1, T4, T0, T6

Procedure

After being greeted by the experimenter, participants were asked to be seated in the chair facing the screen. The experimenter then verbally confirmed with the participant that they were at least 18 years old, and had a valid drivers license for at least two years. The experimenter then informed the participants that they would be participating in a study that would be investigating how different feedback in an automotive interface effects driver performance. After obtaining consent, the participants were asked to fill out a pre-assessment survey collecting relevant driving information and technology usage (Appendices B-F). After completion of the pre-assessment the participants were then introduced to baseline Hues and Cues interface (monochromatic and no-sound) for training purposes. During this training, participants were instructed to get familiar with this interface. After they indicated they were comfortable with the interface the experimenter recorded a baseline measure of the static task time by asking the participant to perform the six tasks (previously mentioned) while the system recorded the task durations. After the baseline measures for task performance were collected the experimenter then introduced the participant to the Lane Change Test (LCT). The experimenter informed the participant that while driving in the simulation they were to perform necessary lane changes as indicated by designated traffic signs as soon as possible. After two practice scenarios, the participant completed one baseline scenario without a secondary task. After the baseline scenario was completed the experimenter instructed the participant that subsequent scenarios were to be performed while simultaneously interacting with the interface with their right hand only. Participants were also instructed that priority should be given to the main goal of changing lanes as quickly as possible while maintaining a constant speed of 60 km/h-37mph. For each scenario, lane change instructions were presented in a random order, *(i.e. Scenario 1 = left, right, is a random order) middle, etc. Scenario 2 = right, middle, left, etc.)* resulting in five different presentation orders of lane change instructions for the experiment. The specific order of Hues and Cues interface presentation varied depending on the gender and group of the participant (see Table 5. and Table 6.). However after each test participants were asked to fill out a

System Usability Scale survey (Appendix C), subjective mental effort assessment (Appendix E), and helpfulness of the sound and color cues (Appendix D). At the end of the experiment (after all 5 scenarios and surveys have been completed) participants were asked to rank the interfaces (1- 4) their favorite (1) to least favorite (4) (Appendix F).



Experimental Set-Up

Figure 27. Overview of experimental setup

With the participant seated at least 60cm away from the display (eye-to-display) the LCT tasks were performed using a force-feedback Logitech G27 Racing Wheel, comprising of a brake and an accelerator (Figure 27). The display is 42" 1080p Toshiba television with a 60 Hz refresh rate. The desktop computer running the LCT software program is a Dell OptiPlex 780 with Intel Core 2 Duo processor and Windows Vista operating system. The LCT 1.2 software and analysis was provided by DaimlerChrysler AG, Research and Technology. The Lane Change Test required participants to drive at a constant, system-

controlled speed of 60 km/h- 37mph along a simulated straight 3-lane road (3000 m) displayed on the screen. Participants were instructed in which of the lanes to drive by signs that appear at regular intervals on both sides of the road. The lane change signs are always visible but blank until the lane indications on the signs appear (i.e. pop up) at a distance of 40 m before the signs. The mean distance from sign to sign is 150 m (a minimum of 140 m plus an exponentially distributed random variable with a mean of 10 m), so that the mean duration between two lane changes is about 9 s and total track time of 180 s (at a speed of 60 km/h). The simulator collected the steering wheel position, lateral and longitudinal data at 60 Hz. The interface prototype ran on a Microsoft Surface Pro tablet with a Windows 8 operating system. The Microsoft Surface has 10.6" HD display at a resolution of 1920x1080 pixels 16:9 (widescreen) and Intel Core i5 processor with integrated Intel HD Graphics 4000 and 4GB of RAM. Device

The interface was implemented using web technologies (HTML5, JavaScript and PHP) as previously discussed. The interface recorded touch input and event times. These event times were recorded from the end of instruction until the participant indicated they have completed the task by pressing the done button located in the top left corner of the interface prototype. The event times for the touch initiation and touch release, coordinates for the start and end of the touch events, as well as the gesture type (i.e. swipe or touch) were also recorded.

CHAPTER SIX

ANALYSES AND RESULTS

Data Screening

All analyses were performed using the statistical package JMP Pro 10.0.0. System Usability Score (SUS) and Rating Scale Mental Effort (RSME) as well as all performance measures were analyzed using a repeated measures multivariate analysis of variance (Manova). All other analysis was performed using Pearson chi-squared tests. All inferential analyses were conducted using an alpha level of 0.05 and, as appropriate, Greenhouse-Geisser degrees of freedom adjustments for violations of sphericity assumptions. All significant effects (main and interaction) were followed up with Tukey's HSD post-hoc paired comparisons.

Prior to and as part of conducting inferential analyses, data were examined for statistical outliers. Observations outside of 3 standard deviations of the mean for any of the conditions were removed from analysis for that condition. As such, all remaining data were included in the analyses unmodified. Furthermore, for discussion purposes the data were split into the categories of performance metrics and subjective assessment. The performance measures are the standard deviation in lane position from the normative model, the average task time, and the overall performance score. The subjective assessment measures are the SUS, RSME, helpfulness of feedback, and ranking of interface.

Overall Performance Score

It must be noted that, a cursory glance at the data is not demonstrative of the variance in performance levels observed during participant trials. The trial times and SDEV measures alone, do not give sufficient indication of how well the participant performed on the dual task of driving while interacting with the interface. It was noticed that some participants employed different strategies when performing these tasks. For example, some participants performed better on the driving task than they did the on the secondary task and vice versa. This is further discussed in ISO 26022, which discusses how to interpret the Lane Change Test measures depending on how participants allocate attention between the lane change maneuvers in the lane change task and the secondary task (International Standards Organization, 2008).

The Lane Change Test is a divided attention method, and in order for the measures generated by the LCT (e.g., mean deviation) to be consistently interpretable, an assumption is made that the participant is allocating attention in such a way that if the secondary task demand increases, it will lead to degradations in LCT performance. However, participants may allocate attention differently, even when carefully instructed and if they do, it can lead to results on LCT measures that obscure important differences between the tasks in their demands on participant resources. To this end, it was decided to create a variable that would encompass both the standard deviation in lane position and average task time values.

The overall performance score normalizes the standard deviation in lane position

for each and the average task time for all participants on a scale from 0 - 50; with 0 being the best performance measure and 50 the worst. The formula for calculating the overall performance score is as follows:

$$x_i = Min + \frac{e_i - E_{min} \times (Max - Min)}{E_{max} - E_{min}}$$

Where:

 x_i = Normalized observation Min = Minimum normalized value Max = Maximum normalized value E_i = observation E_{min} = Minimum observation E_{max} = Maximum observation

It was decided to use the scale that would not collapse the data and since 95% of the observed values for the standard deviation in lane position ranged between 0 -1.2 and 95% of the average task times ranged between 0 and 40; 0 - 50 seemed to be a as a suitable range for measure for the normalized values.

Analyses of Performance Measures

Hypothesis 1 - There will be less deviation from the normative model when using Hues and Cues interface during the LCT scenarios than with other (monochromatic, audible only, color only) interfaces.

As Figure 28 shows, there was not a significant main effect of trial F(3,118.4) = 1.04, p=.3779, nor was there a significant effect of gender F(1,39.37) = 0.2568, p

=0.6152 of the standard deviation in lane position. However, this analysis did reveal a significant interaction effect for trial by gender (Figure 29), F(3,118.4) = 4.7091, p =0.0038. Post-hoc comparisons reveal the simple effect of the standard deviation in lane position was higher for females using the cues interface than for females using the mono interface p = 0.0177.



Figure 28. Mean Standard Deviation in Lane Position



Figure 29. Gender Interactions in Mean Standard Deviation in Lane Position

Hypothesis 2 - There will be fewer missed or erroneous lane changes when using Hues and Cues interface during the LCT scenarios than with other (monochromatic, audible only, color only) interfaces.

A majority of the participants made one or fewer erroneous lane changes and missed one or fewer lane changes. Furthermore, there was no significant relationships observed between total lane error (missed or erroneous) and the use of a specific interface $c^{2}(15, N = 176) = 11.639, p < .7061.$

Hypothesis 3 - Mean task completion time will be shorter for Hues and Cues interface under LCT task than for other (monochromatic, audible only, color only) interfaces.

There was a significant main effect of trial (Figure 30.) F(3,114.6) = 5.0381, p=.0026 on average task time for the interfaces. Post-hoc comparisons reveal that the

average task time for cues (p=.0058) and mono (p=.0149) were significantly higher than the hues interface. However, unlike the standard deviation in lane position there was no significant effects of gender F(1,40.02) = 1.0360, p =0.3149 or any significant interactions of trial by gender (Figure 31.) F(3,114.6) = 1.0360, p = 0.5172.



Figure 30. Mean Task Time



Figure 31. Gender Interactions of Mean Task Time

Hypothesis 4 - Mean overall performance will be lower for Hues and Cues interface under LCT task than for other (monochromatic, audible only, color only) interfaces.

As Figure 32 illustrates, There was not a significant main effect of trial F(3,119.9)= 0.8962, p=.4454, nor was there a significant effect of gender F(1,40.1) = 0.1751, p =0.66778 on overall performance scores. However, this analysis did reveal some significance in the interaction effect for trial by gender (Figure 33.), F(3,119.9) = 3.1257, p =0.0284. Post-hoc comparisons did not reveal any significant simple effects even though the average performance scores for males (22.31) and females (29.87) differ by more than 7 points on the cues interface.


Figure 32. Mean Overall Performance Score



Figure 33. Gender Interactions of Mean Overall Performance Score



Figure 34. Mean Overall Performance Score for Females

Analyses of Subjective Assessments

Hypothesis 5 - On average, participants will have lower mental workload when using Hues and Cues interface during the LCT scenarios compared to other (monochromatic, audible only, color only) interfaces.

Figure 35 illustrates the significant main effect of trial F(3,123) = 6.0234, p=.0007 on the Rating Scale Mental Effort survey . Post-hoc contrasts reveal that participants felt that the mono interface required more mental effort to operate than the Hues and Cues interface (p=.0048) and the cues interface (p=.0135). The analysis also revealed that the Hues and Cues interface was significantly better than the hues interface (p=0.0250) However there was no significant effects of gender (Figure 35), F(1,41) =



.4248, p =0.5182 or any significant interactions of trial by gender F(3,123) = 1.1679, p = 0.3249.

Figure 35. Mean RSME Score



Figure 36. Gender Interactions for Mean RSME Score

Hypothesis 6 - On average, participants will find the Hues and Cues interface more usable, compared to other (monochromatic, audible only, color only) interfaces.

There was a significant main effect of trial F(3,126) = 9.9491, p <.0001 on the System Usability Scale scores (Figure 37). Post-hoc contrasts reveal that participants felt that the cues (p<.0001) and Hues and Cues (p=.0002) interfaces were more usable than the mono interface. However there was no significant effects of gender (Figure 38) F(1,42) = .4234, p =0.5188 or any significant interactions of trial by gender F(3,126) =1.5176, p = 0.2132.



Figure 37. Mean SUS Score



Figure 38. Gender Interactions for Mean SUS Score

Hypothesis 7 - On average, participants will find the visual and audible feedback helpful

Participants generally considered the feedback to be helpful. With the average rating for the helpfulness of feedback for the cues interface was 4.34 (SE =.22) and 4.32 (SD= .22) for the Hues and Cues interface. The average rating for the helpfulness of visual feedback was less helpful with an average rating of 3.00 (SE =.25) for the hues interface and 3.15 (SE= .25) for the Hues and Cues interface.

With respect to overall helpfulness of feedback (i.e. participants indicating a 4 or 5), participants felt that the auditory feedback was more helpful than the visual feedback. 81% of the participants felt that the audio cues were helpful on the cues (20 female, 16 male) and likewise on the Hues and Cues (19 female, 17 male) interface $c^2(15, N = 176) = 111.389$, p <.0001. 52% of the participants felt that the color changes were helpful on the hues (14 female, 9 male) and likewise on the Hues and Cues (25 female, 8 male) interface $c^2(15, N = 176) = 65.807$, p <.0001.

Hypothesis 8 - On average, participants will rank the Hues and Cues interface higher than the other (monochromatic, audible only, color only) interfaces.

As demonstrated in Figure 39, with respect to interface preference, Hues and Cues was the most preferred (18 female, 12 male), followed by the cues interface (15 female, 11 male), the hues interface (14 female, 9 male), and then the mono interface (18 female, 13 male). $c^2(9, N = 176) = 143.636$, p <.0001.



Figure 39. Forced Choice Ranking of Interface Preference

CHAPTER SEVEN

DISCUSSION

Discussion of Findings

The purpose of this experiment was to test the effectiveness of multimodal feedback on reducing the degradation in driver performance. To get a more complete picture of how satisfying the interface was, preference, usability, and mental effort were also considered. Furthermore to test the individual effects of the auditory and visual cues a full factorial experiment was conducted testing all combinations of the factors. In general the results align with many of the hypothesized assumptions suggesting that multimodal feedback is usually more preferred by participants. However the performance metrics do not align with preference and results do not support the prior assumptions of multimodal feedback.

As expected, the interface with the design paradigm of both auditory and visual feedback (Hues and Cues) applied was preferred over interfaces that did not have these features. Similarly, participants indicated that they felt the interface without the auditory and visual cues required more mental effort and was overall less user-friendly as indicated by the RSME and SUS scores respectively. These findings are congruent with much of the literature assessing multimodal feedback. For example, Pitt's et al., observed that on average participants preferred multimodal feedback over a single modality (Pitts, Williams, Wellings, & Attridge, 2009), and further substantiating the benefits of multimodal redundancy (Müller & Weinberg, 2011).

In addition, a closer inspection of the subjective assessments show that auditory feedback is more frequently preferred to visual feedback, with participants ranking the cues interface second only to the combined Hues and Cues interface (visual and auditory feedback). Similarly the average mental effort required to perform task on the cues interface was marginally less better using the Hues and Cues interface (cues = 75.09; Hues and Cues = 76.28). However, the cues did marginally outperform the Hues and Cues interface with regard to helpfulness (cues =4.34; Hues and Cues =4.32) and usability (cues = 78.58; Hues and Cues =77.05) as measured by the system usability scores. These results support that auditory feedback by itself is a more compelling feedback mechanism than the color by itself.

Though the subjective results support many of the hypotheses relating to the subjective measures the objective performance measure describe a slightly different effect. With respect to driver performance, it was expected that when applied to automotive user interfaces, this design paradigm would minimize the degradation in driver performance. Contrary to much of the research in multi-modal feedback, and expectations, **one of the most significant findings was that this hypothesis was not supported**. For example, when performing the actual interface task the hues interface was the best (color feedback only) with an average of 16 seconds. The mono and cues interface had an average task time of little over 18 seconds. The 2 second difference is significant in that NHTSA's has stated individual off-road glances required by device operation to be no more than 2 seconds; therefore the 2 second difference could be considered as an additional glance one would have to make while using this interface

(assuming that all other glances took 2 seconds). A possible explanation for this phenomenon is that there exists some sensory delay in interpreting the auditory feedback; resulting in increased task time. If this were the case then it would be expected that interfaces containing all audio feedback would display similar results, however this is not the case. The Hues and Cues interface (combined visual and auditory feedback) also had an average task time of little over 16 seconds. These results further support the claim that a single modality can be improved by combining it with another (Driver & Spence, 2004; Ho & Spence, 2013; Müller & Weinberg, 2011). Regardless of how the modalities were combined the common denominator in the interfaces that had 16-second average task times is the visual feedback component (color changes). In summary, color changes do have significant impact on reducing secondary task time.

By far, the most significant finding in this study was the relationship of gender and auditory feedback. Although the interfaces were semantically the same (not varying in content, structure or interaction mechanism) the presence of auditory cues resulted in significantly degraded lane-keeping scores for female participants. On average, female participants performed their worst on the cues interface with an average deviation in lane position of .9577 this deviation is about 30% more than the .7086 average lane deviation for the mono (no sound, no color) interface. Contrary to this, male participants seemed to have their best performance on the same cues interface with an average standard deviation of .7699 a 22% decrease in lane deviation when compared to female participants using the same interface. These results spark a myriad of questions, which can be summarized by these two questions:

- Why do the objective performance metrics and subjective assessments diametrically oppose each other?
- Why does the presence of auditory feedback degrade driving performance in female participants exclusively?

Possible Explanations for Difference in Subjective and Objective Measures

Nielsen (1994) has addressed the first question in the paper "Measuring usability: Preference vs. Performance", finding that although performance and preference are usually strongly correlated they do not always have to be. He states, "there are still many cases where users prefer systems that are measurably worse for them." This observation suggests there exists a stark distinction between user experience and usability. Usability being how well the interface performs in light of the traditional effectiveness and efficiency metrics, and experience being categorized more by *perception* such as the perceived usability and overall satisfaction of using a product. Raghavan and Perlman (2000) further support this finding in their study on preference versus performance in entity based searching of print and online resources. In this study participants' subjective retrospective assessments (post-surveys) did not match their objective task times or accuracy. This is not to imply that objective measures are absolutely more or less important than subjective metrics, but this study as well as similar findings from Baily (1993), suggest that close consideration needs to be given to the dynamics in the relationship between these subjective and objective measures. For example, just because a person likes an interface doesn't mean that they will perform well with it and vice versa. By recognizing the strengths of a particular (i.e., users tend to gravitate to things that they prefer) of the measures interfaces can be better optimized. For example, instead of spending time trying to improve the *usability* of an interface, time might be more wisely spent trying to understand how to improve the perceived *experience* interface. The results of this study offer commentary on overall user experience. If user experience is the lasting impression left on a person, then objective performance metrics might a strong predictor of purchasing behavior (Raghavan & Perlman, 2000). With regards to the differences in objective and subjective measures in the Hues and Cues study, it is important to note that, in general, participants felt that multimodal feedback was helpful and they preferred interfaces with visual and auditory feedback. These findings, along with the aforementioned research findings, suggest that substantial consideration should be given to preference.

Possible Explanations for Differences in Gender

The next observed phenomenon to be discussed is the effect of auditory-only feedback on female participants. Numerous studies in [enum different areas] have explored the differences manifested in gender (Lee, Nass, & Brave, 2000; Lorigo, Pan, & Hembrooke, 2006). More aligned with the multimodal aspects of the Hues and Cues study is an experiment performed by Park et al., that examined the effects of multimodal feedback and gender on task performance of stylus pen users. It was observed that female participants had slower reaction times than males when using a stylus with tactile feedback cues. In this study, females had their slowest average response times using tactile feedback, while males' average response times were fastest using the tactile feedback. This observation has a strong corollary with the findings of the present Hues and Cues study; offering useful commentary on how gender affects the usefulness of new or multiple modalities in interacting with interfaces.

In the context of the automotive space, Lin and Chen's (2013) study on the usability of navigation systems in automotive interfaces expose gender differences in visual-spatial performance. It was observed in this study that when using 2D and 3D interfaces male participants' operational performance was higher using 3D interface, whereas female participants performed higher using 2D interfaces (Lin & Chen, 2013). Possible reasons for this difference will be further discussed in this section. These studies suggest that one would expect gender differences; however, these studies do not address the possible causes for these differences.

To better understand *why* these gender differences occur the discussion must shift to some of the psychophysical aspects of these differences. There have been numerous observations of the differences in audio processing ability between men and women; namely that females may have an advantage with regards to auditory acuity, while males may have an advantage in the localization of sounds (Sax, 2010). These differences have been further explicated by the differences in neurological structure of men and women. The auditory acuity in women has been attributed to women usually being left hemispheric dominant; the hemisphere responsible for discriminating in rapidly changing acoustic events; such as speech (Schwartz & Tallal, 1980). Further studies suggest that when it comes to auditory stimuli women are more detail oriented and use a more analytic processing strategy, whereas men perceive information more often as global patterns (Kimura, 2000). This global perception allows men to be more responsive to sounds (i.e., when the sound started and where it was located) but not as proficient at determining what the sound was (Wittmann & Szelag, 2003). This concept of detail orientation versus global pattern recognition has been further extended to the visual modality (Roalf, Lowery, & Turetsky, 2006). However with the advantage of increased ability in women to process language has also been attributed to the disadvantage of a decrease of visuo-spatial skills (Levy & Reid, 1978) with studies showing that men have relatively more neurological resources to process visuo-spatial information (Amunts & Armstrong, 2007).

In light of the aforementioned psychophysical research the following discussion is based on the premise that, the cognitive differences in how men and women process auditory information and visuo–spatial ability influence task performance. Furthermore borrowing from Wickens' Multiple Resource Theory, task performance is even more degraded when other objects/tasks compete for the same resource of the task, as exemplified in numerous studies of the multitasking driver.

With respects to the auditory-only 'cues' interface, a psychophysical explanation for the degradation in performance for women can be attributed to how they process audio. If women naturally perceive more detail in auditory cues as a result of how they

tend to process audio information more analytically, then it is likely that this affected the usefulness of the cues was affected. It would follow, then, that the auditory cues required more cognitive resources for women, these cues by themselves were more of a distractor than an aid.

Although the cues interface was distracting, the hues only interface proved helpful to female participants. On average women performed best with lower average task completion times on the hues interface, and with regards to driving performance (standard deviation in lane position) they hues interface was second best behind the mono (no color-no sound) interface. This finding is aligned with much of the literature from various disciplines that women rely more on visual cues than men (Holbrook, 1986; Jones & Healy, 2006; Putrevu, 2001; Witkin, Wapner, & Leventhal, 1952). Further exploration in this area is needed for this assumption to be substantiated, but the results observed in the present Hues and Cues are congruent with women relying more on visual (hues) cues to complete the secondary tasks

Another possible reason for the difference in performance between genders is bias towards the gender of the synthesized speech. Gender stereotyping is deeply ingrained in human psychology, extending even to inanimate machines (Nass, Moon, & Green, 1997). It has been noted that male voices are perceived as better teachers of technology, with females voices being perceived as better for everything else (Potter, 2011). It has also been shown that gender can affect behavior and attitude with males showing preference for male voices while females exhibited preference for female voices (Lee et al., 2000).

With respects to task of web searching Stevens found that task performance using synthesized TTS male voices were more intelligible and led to more accurate search results and females voices resulted in faster search times (Stevens, Lees, Vonwiller, & Burnham, 2005). In light of the abundant literature on synthesized speech it is plausible that the gender of the TTS in the Hues and Cues study affected the task performance of participants. This is very plausible not only in light of the literature on the topic, but also because of the incongruence between voice prompts and audible cues. To distinguish between the audio prompts; that told the participant what task to perform, and the audio cues; that assisted them in navigating the interface, a male voice gave the prompts and a female voice was used for the cues. This incongruence could have also negatively affected the driving performance of the female participants.

Though the finding from the gender interaction of cues does not support the initial hypothesis. The interesting finding that women tend to perform worse with auditory only cues further contributes to the body of work in gender differences. However for this to be substantiated further research needs to be conducted to better understanding why females had greater degradation in driving performance when using the cues (audio-only) interface.

Limitations of Present and Future Research

Furthermore, consideration must be taken when generalizing these results to everyday driving. The present study was conducted in a controlled environment using a driving simulator. Since people drive differently and are more likely to take risk in a

driving simulator future research should extend beyond the LCT. This extension could be into more natural simulated roads with other vehicles as well as controlled naturalistic drives with a real automobile.

In light of the research surrounding the differences in gender this study has notable limitations. Though not in the scope of the present study it is advisable that future work delve more into the nuances in gender that effect task performance. For example it would be plausible for an extension of this study to use some sort of physiological data acquisition such as a Brain Computer Interface (BCI) device could be worn by participants to determine if these differences are more neurological or cultural in nature. Another extension of this study would be similar but test for gender bias when using either female or male voices for the auditory cues.

Considering the result of this study and limitations, a natural extension of this study an examination of the relationship between the gender of TTS voice prompts and task performance in the LCT task. Additionally, one could the Hues and Cues paradigm in dual tasks for contexts beyond automotive interfaces Furthermore it would be advantageous to test the generalizability of the Hues and Cues design paradigm; by testing the Hues and Cues paradigm applied to other interfaces not necessarily automotive, and measure performance during dual task conditions.

A more industry-centered implication of this study is the need for customization in automotive user interfaces. If future studies reveal the same trend, then individual and/or gender difference could triumph the most theoretically usable design. In the case

of Hues and Cues it was thought that the combination of both the auditory and visual cues would result in the best performance. However, audio cues were better for men than women and conversely the visual cues were better for women than men. Therefore a generalization about multimodal feedback being better than a single modality could be misleading. In turn, it is highly recommended that specific customizations be offered in automotive interfaces. Specifically, when multi-modal feedback is offered, there should also be the ability to turn specific feedback on or off. It is also recommended that when interfaces use a cues-like approach there should be an opportunity for the user to select the gender of the voice.

CHAPTER EIGHT

CONCLUSION

As touchscreen interfaces for in-vehicle information becomes more pervasive, research for interacting with the content on the touchscreens is going to be more significant. The present research, guided by insights into the human visual system and attention, extends research in the space of automotive user interfaces to the applicability of a multimodal design pattern. The Hues and Cues design paradigm was developed to reduce the degradation in driver performance. The paradigm aims to accomplish this by mapping visual cues to higher-level functional categories and auditory cues that aid in navigation of these categories. This paradigm was then applied to an automotive user interface prototype and evaluated with respects to driver performance using the dual-task, Lane Change Test (LCT). Many of the results from this study support the hypotheses that perceived usability, helpfulness, and preference would increase for interfaces with the Hues and Cues design paradigm applied. However a more interesting finding is that certain aspects of the paradigm benefit men and women differently; with women performing worse with the 'cues only' interface, and men performing better with the same interface in lane keeping and task times. These findings coupled with biological and societal differences in gender imply the need for customization or at least the ability to turn certain feedback on or off. Overall, the results reported show that the presentation of multimodal feedback can be useful in design automotive interfaces; however, the interface must be flexible enough to account for individual differences.

APPENDICES

Appendix A

Overview of Interface Functions

BRAND	UNITS	IMAGE	FUNCTIONS			
Ford MyTouch Sync	2,084,600	Phone 3:00 Navigation # III 7 Lill Paul's Phone 0.3 mi Do Not Disturb I Michigan Ave. IV9 96.3 HD2 72° 88.7 90.1 90.3 HD2 100.5 HD3 100.1 105.2 Entertairment i 0.9	Phone Navigation Entertainment Climate			
Chevrolet Spark†	1,863,300	 A audio ➡ picture & movie ➡ telephone ➡ smartphone link ➡ settings 	Audio Picture & movie Telephone Smartphone link Settings			
Toyota Entune	1,692,300	Information Map Data Fuel Traffic XIM Apps Consumption Incidents Fuel Prices XM XM Sports Stocks NavWeather	Radio* Media* Seek* Track* Close* Map / Voice* Dest* Info/Apps* Setup*			
Nissan Altima†	1,132,800	 PANDORA - The Alistars Radio NEVA Only in my Dreams One of These Days 2:07 Menu 	Volume* XM* FM/AM* CD/AUX* Seek* Camera* Tune/Scroll/Enter/Audio* BACK* MAP* NAV* MENU*			
Honda Accord†	1,096,100	Source < 1/2 >>	Navigation* FM AM CD HDD USB Ipod USB Climate**			

	1		
			FM/AM XM
			Seek/Track
		2 XM3 12:54 65 F	Media
		8 9 10 1 1 1	Phone
Hda!			Info
Hyundal	823.000		Map Voice
Sonata†		(DSAM) NAME 800-643-2112	Route
		CATEGORY	Dest
			Tune
		Mode List Search Scan Sound	Setup
			Enter
			Climate (and controls)
		My Music	FM/AM
			Sirius
			Media
Kia		Favorites Artists Albums	Phone
UVO	591,200		Jukebox
070			Phone
		Genres Song Composers	Setup
			Seek/ Irack
			Category
			Music Dhana
		EM 4 95 7 HD1 HDRadio	Phone
			Navigation
		* 8:49 am	Cal Media*
¥7 11		HAVANA BROWN FT. PITB WE RUN THE NIGHT	Radio*
Volkswagon	533 100	1 012 FM 2 027 HD2 3 945 FM	Media*
Tourag†	555,100	1 94.3 FM 2 93.7 HUZ 5 94.5 FM	Phone*
		4 957 FM 5 965 FM 6 97.9 FM	Voice*
			Nav*
		Band > Station Presets Extras Tune	Traffic*
			Car*
			Menu*
		68° 10:10 54° out.	
		5177	
			D
		Gauges 2 120 mph	Radio
		Engine 580 nm	Player
Dodge	511.000	Destioner	Climate
Uconnect	511,000	(4)	Nav
			Phone
			& Apps
			<u>-</u>
		Radio Player Controls Climate Nav Phone & Apps	
			Voice Activation
		AM FM SAT	Telephone
		1 530	Radio
		550 1	Media
Jeep	431 800	2 600	Menu
Uconnect	101,000	I DIRECT	Load
			Audio
		3CAN 866688	My Files
		1:53 Ht RESETS	
1			Climaterr

†Denotes model name of automobile *Denotes dedicated physical controls **Denotes dedicated physical controls as well as touchscreen controls

Appendix B

Screenshot of Pre-Assessment Survey

iender:	Male	Femal	e			
/hat year were you born:	YYYY					
Driving Information	n					
ave you participated in a riving simulator study?	Yes	No				
low many years of driving xperience do you have?	2 - 5 ye	ears 6	6 - 9 years	10 - 13 years	14 - 17 years	more than 17 yea
low frequently do you rive?	Daily	Weekl	y Montl	hly Never		
o you have a touchscreen isplav in the vehicle vou	Yes	No				
nost frequently drive						
o you have experience sing a touchscreen display	Yes	No				
or in-vehicle functions adio, climate control,						

When it comes to technology, what statement do you agree with the most?

I normally get a new technology or device the day it comes out
I normally get a new technology or device the first week it comes out
I normally get a new technology or device within the first few weeks of its release
I normally get a new technology or device within a few months of its release
I normally wait to get a new technology or device until after a second version is released
I normally do not get a new technology or device until I feel that I need it
Previous

How often do you	use this	type of c	omputer	?
Apple Computer	Daily	Weekly	Monthly	Never
Windows Computer	Daily	Weekly	Monthly	Never
Linux Computer	Daily	Weekly	Monthly	Never
Other Type of Computer	Daily	Weekly	Monthly	Never
Previous				

How often do you use this type of tablet device?

Apple Ipad	Daily	Weekly	Monthly	Never
Android Tablet (not amazon kindle)	Daily	Weekly	Monthly	Never
Amazon Kindle -OR- Amazon Kindle Fire	Daily	Weekly	Monthly	Never
Other tablet device	Daily	Weekly	Monthly	Never
Previous				

How often do you use this type of cellphone?

Apple Iphone	Daily	Weekly	Monthly	Never
Android Phone	Daily	Weekly	Monthly	Never
Blackberry Phone	Daily	Weekly	Monthly	Never
Windows Phone	Daily	Weekly	Monthly	Never
Other type of smartphone	Daily	Weekly	Monthly	Never
Non-Smartphone (no internet capabilities)	Daily	Weekly	Monthly	Never
Previous				

Importance of In-vehicle features								
How important is the presence of visual of	lisplays for an enjoyable driving experien	ce (i.e. clocks, LCD screens, etc)?						
Not Important	1 2 3 4 5	Very Important						
How important is the presence of physica	al controls for an enjoyable driving experi	ence (i.e. knobs, sliders, etc)?						
Not Important	1 2 3 4 5	Very Important						
How important is the of presence voice/a	uditory controls for an enjoyable driving	experience?						
Not Important	1 2 3 4 5	Very Important						
Previous		Submit						

Appendix C

Screenshot of System Usability Scale Questions

Usability of the Interfa	ace									
1. I think that I would like to use this sys	stem freq	uently								
Strongly Disagree	1	2	3	4 5	Strongly Agree					
2. I found the system unnecessarily con	nplex.									
Strongly Disagree	1	2	3	4 5	Strongly Agree					
3. I thought the system was easy to use).									
Strongly Disagree	1	2	3	4 5	Strongly Agree					
4. I think that I would need the support	of a techr	nical pe	erson	to be able	to use this system.					
Strongly Disagree	1	2	3	4 5	Strongly Agree					
5. I found the various functions in this s	system w	ere we	II integ	grated.						
Strongly Disagree	1	2	3	4 5	Strongly Agree					
					Next					
Usability of the Interfa	Usability of the Interface									
6. I thought there was too much incons	istency in	n this s	system	ı.						
6. I thought there was too much incons Strongly Disagree	istency in	n this s 2	system 3	1.	Strongly Agree					
 6. I thought there was too much incons Strongly Disagree 7. I would imagine that most people wood 	1 uld learn	to use	3 system 3 this s	۱. 4 ؛ system ver	; Strongly Agree					
 6. I thought there was too much incons Strongly Disagree 7. I would imagine that most people wood Strongly Disagree 	istency in 1 puld learn 1	to use	3 e this s 3	1. 4 t	s Strongly Agree y quickly. Strongly Agree					
 6. I thought there was too much incoms Strongly Disagree 7. I would imagine that most people wo Strongly Disagree 8. I found the system very cumbersome 	1 1 1 1 1 1 1 e to use.	to use	3 e this s 3	i. 4 ! system ver	s Strongly Agree y quickly. Strongly Agree					
 6. I thought there was too much income Strongly Disagree 7. I would imagine that most people woo Strongly Disagree 8. I found the system very cumbersome Strongly Disagree 	istency in 1 uuld learn 1 e to use. 1	to use	3 e this s 3 3	1. 4 4 system ver 4 4	s Strongly Agree y quickly. S Strongly Agree S Strongly Agree					
 6. I thought there was too much incoms Strongly Disagree 7. I would imagine that most people wood Strongly Disagree 8. I found the system very cumbersome Strongly Disagree 9. I felt very confident using the system 	istency in 1 puld learn 1 e to use. 1 n.	to use 2 2	3 e this s 3 3	4 4 system ver 4 4	Strongly Agree y quickly. Strongly Agree Strongly Agree					
 6. I thought there was too much incoms Strongly Disagree 7. I would imagine that most people wood Strongly Disagree 8. I found the system very cumbersome Strongly Disagree 9. I felt very confident using the system Strongly Disagree 	istency in 1 puld learn 1 e to use. 1 h. 1	2 to use 2 2 2	3 e this s 3 3 3	4 4 system ver 4 4 4 4	Strongly Agree y quickly. Strongly Agree Strongly Agree Strongly Agree Strongly Agree					
 6. I thought there was too much incoms Strongly Disagree 7. I would imagine that most people woo Strongly Disagree 8. I found the system very cumbersome Strongly Disagree 9. I felt very confident using the system Strongly Disagree 10. I needed to learn a lot of things before 	istency in 1 uld learn 1 e to use. 1 n. 1 ore I could	n this s 2 to use 2 2 2 d get g	3 a this s 3 3 3 yoing v	4 4 system ver 4 4 4 4 4 4 4 4 4 4 4 4	Strongly Agree y quickly. Strongly Agree Strongly Agree Strongly Agree Strongly Agree					
 6. I thought there was too much income Strongly Disagree 7. I would imagine that most people woo Strongly Disagree 8. I found the system very cumbersome Strongly Disagree 9. I felt very confident using the system Strongly Disagree 10. I needed to learn a lot of things before Strongly Disagree 	istency in 1 puld learn 1 e to use. 1 n. 1 pre I coulor 1	n this s 2 to use 2 2 2 d get g 2 2	3 b this s 3 3 3 ooing v 3	4 4 ystem ver 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	Strongly Agree y quickly. Strongly Agree Strongly Agree Strongly Agree Strongly Agree Strongly Agree Strongly Agree					

Appendix D

Screenshot of Helpfulness of Feedback Questions

Helpfulness of Feedback								
1. I found the color chnages on the so	creen to be:							
l did not notice oclor changes	Very Unhelpful	1 2	3 4	5	Very Helpful			
2. I found the audio cues on the scree	en to be:							
l did not notice audio cues	Very Unhelpful	1 2	3 4	5	Very Helpful			
					Submit			

Appendix E

Copy of RSME Questionnaire

Rating Scale Mental Effort

Please indicate, by marking the vertical axis below, how much effort it took for you to complete the task you've just finished



Appendix F

Screenshot of Post-Assessment Survey

Please rank each screen from favorite (1) to least favorite (4)

Climate Apps Phone Music Nav Car Bettings	South the factor Control of the factor	No color changes and no sounds	1	2	3	4	
Climato Apps Phone Music Nav Car Settings	Au to the function	Color changes and sounds	1	2	3	4	
Climate Apps Phone Music Nav Car Settings	Sue to hore Sue to hore	No color changes but has sounds	1	2	3	4	
Climate Apps Phone Music Nav Car Settings	A such to have A such as the desired as	Color changes but no sounds	1	2	3	4	
							Submit

Appendix G

Modified Touch Controller JavaScript Code

```
var isTouchSupported = 'ontouchstart' in window;
var startEvent = isTouchSupported ? 'touchstart' : 'mousedown';
var moveEvent = isTouchSupported ? 'touchmove' : 'mousemove';
var endEvent = isTouchSupported ? 'touchend' : 'mouseup';
var touchSensor = (function() {
 var gestureType,oldX,oldY,points=[],threshold,startTime,endTime;
 this.strokes=[];
 function Point(x,y){
      this.X = x;
             this.Y = y;
 };
 function startFunc (e){
  //e.preventDefault();
  points = [];
 if(isTouchSupported){
         var touch = e.touches[0];
                   oldX = touch.pageX;
                   oldY = touch.pageY;
                   startTime = e.timeStamp == undefined ? e.timeStamp : Date.now();
  }
  else{
          oldX = e.pageX;
          oldY = e.pageY;
          startTime = e.timeStamp == undefined ? e.timeStamp : Date.now();
  }
 };
 function moveFunc (e){
  //e.preventDefault();
  if(oldX - e.pageX < threshold && oldX - e.pageX > -threshold) {return;}
  if(oldY - e.pageY < threshold && oldY - e.pageY > -threshold) {return;}
  if(isTouchSupported){
          var touch = e.touches[0];
           oldX = touch.pageX;
                   oldY = touch.pageY;
  }
  else{
          oldX = e.pageX;
          oldY = e.pageY;
  }
  points[points.length] = '{X:'+oldX+',Y:'+oldY+'}'; //new Point(oldX,oldY);
 };
 function endFunc (e){
  //e.preventDefault();
  if(isTouchSupported){
   var touch = e.touches[0];
          endTime = e.timeStamp == undefined ? e.timeStamp : Date.now();
  3
  else{
  endTime = e.timeStamp == undefined ? e.timeStamp : Date.now();
  }
//'expID':sessionStorage.expID,
```

```
window.parent.strokes.push({'order':window.parent.strokes.length,'subtask':sessionStorage.subtask,'startTime':startTime,'endTim
e':endTime,'points':points});
points = [];
ł
return {
  start: function(){
       window.addEventListener(startEvent,startFunc ,false);
       window.addEventListener(moveEvent,moveFunc,false);
       window.addEventListener(endEvent,endFunc,false);
                             console.log("touch started");
      },
  stop: function(){
      window.removeEventListener(startEvent,startFunc ,false);
      window.removeEventListener(moveEvent,moveFunc,false);
      window.removeEventListener(endEvent,endFunc,false);
      oldX=undefined;
      oldY=undefined;
      threshold=undefined;
      startTime=undefined;
      endTime=undefined;
      strokes = [];
      points =[];
      console.log("touch ended");
      },
   strokes:function(){
        return strokes;
  };
})();
```

Appendix H

Descriptive Statistics for Performance Metrics

Table H.1 Mean Standard Deviation in Lane Position for Interface

(Overall		1	Female		Male			
;	SDLP			SDLP		SDLP			
	Mean*	Std. Err		Mean*	Std. Err		Mean*	Std. Err	
Cues	0.8638	0.0495	Cues	0.9577	0.0707	Cues	0.7699	0.0694	
Hues	0.8360	0.0488	Hues	0.7746	0.0696	Hues	0.8973	0.0683	
Hues & Cues	0.8524	0.0483	Hues & Cues	0.8159	0.0683	Hues & Cues	0.8890	0.0683	
Mono	0.7825	0.0492	Mono	0.7086	0.0707	Mono	0.8563	0.0683	
* Least Square Mean			* Least	Square Me	ean	* Least Square Mean			

Table H.2 Mean Task Time for Interface

Overall		Female			Male			
Average Task Time			Average Task Time			Average Task Time		
	Mean*	Std. Err		Mean*	Std. Err		Mean*	Std. Err
Cues	18.3236	0.8124	Cues	19.2266	1.1419	Cues	17.4205	1.1560
Hues	16.0665	0.8168	Hues	17.1780	1.1408	Hues	14.9549	1.1694
Hues & Cues	16.8955	0.8081	Hues & Cues	17.6339	1.1294	Hues & Cues	16.1571	1.1560
Mono	18.1775	0.8316	Mono	18.2917	1.1827	Mono	18.0634	1.1694
* Least Square Mean			* Least Square Mean			* Least Square Mean		

Table H.3 Mean Performance Score for Interface

Overall		Female			Male			
Perfor	Performance Score		Performance Score			Performance Score		
	Mean*	Std. Err		Mean*	Std. Err		Mean*	Std. Err
Cues	26.0891	1.9254	Cues	29.8673	2.7186	Cues	22.3110	2.7273
Hues	23.2745	1.9133	Hues	22.4915	2.6842	Hues	24.0576	2.7273
Hues & Cues	24.1183	1.8980	Hues & Cues	23.0154	2.6842	Hues & Cues	25.2212	2.6842
Mono	24.0981	1.9266	Mono	24.8432	2.6842	Mono	23.3531	2.7645
* Least Square Mean		* Least Square Mean			* Least Square Mean			

Appendix I

Descriptive Statistics for Subjective Metrics

Table I.1 Mean System Usability Scale Score for Interface

Overall			Female			Male		
SUS			SUS			SUS		
	Mean*	Std. Err		Mean*	Std. Err		Mean*	Std. Err
Cues	78.5795	2.9109	Cues	78.1818	4.1166	Cues	78.9773	4.1166
Hues	71.9318	2.9109	Hues	76.0227	4.1166	Hues	67.8409	4.1166
Hues & Cues	77.0455	2.9109	Hues & Cues	80.0000	4.1166	Hues & Cues	74.0909	4.1166
Mono	65.5682	2.9109	Mono	65.2273	4.1166	Mono	65.9091	4.1166
* Least Square Mean			* Least Square Mean			* Least Square Mean		

Table I.2 Mean Mental Effort Rating for Interface

Overall			Female			Male		
RSME			RSME			RSME		
	Mean*	Std. Err		Mean*	Std. Err		Mean*	Std. Err
Cues	76.2825	4.6304	Cues	82.1364	6.4718	Cues	70.4286	6.6241
Hues	85.3626	4.6304	Hues	88.7727	6.4718	Hues	81.9524	6.6241
Hues & Cues	75.0866	4.6304	Hues & Cues	74.3636	6.4718	Hues & Cues	75.8095	6.6241
Mono	87.3236	4.6304	Mono	89.4091	6.4718	Mono	85.2381	6.6241
* Least Square Mean		* Least Square Mean			* Least Square Mean			

Table I.3 Mean Helpfulness of Hues for Interface

Overall		Female			Male			
Helpfulness of Hues			Helpfulness of Hues			Helpfulness of Hues		
	Mean*	Std. Err		Mean*	Std. Err		Mean*	Std. Err
Cues	0.8409	0.2596	Cues	1.0000	0.3671	Cues	0.6818	0.3671
Hues	3.0000	0.2596	Hues	3.2727	0.3671	Hues	2.7272	0.3671
Hues & Cues	3.1590	0.2596	Hues & Cues	3.5000	0.3671	Hues & Cues	2.8181	0.3671
Mono	0.9318	0.2596	Mono	0.6818	0.3671	Mono	1.8181	0.3671
* Least Square Mean		* Least Square Mean			* Least Square Mean			

Table I.4 Mean Helpfulness of Cues for Interface

Overall		Female			Male			
Helpfulness of Cues			Helpfulness of Cues			Helpfulness of Cues		
	Mean*	Std. Err		Mean*	Std. Err		Mean*	Std. Err
Cues	4.3409	0.2209	Cues	4.3636	0.3124	Cues	4.3181	0.3124
Hues	1.2727	0.2209	Hues	1.4090	0.3124	Hues	1.1363	0.3124
Hues & Cues	4.3181	0.2209	Hues & Cues	4.4090	0.3124	Hues & Cues	4.2272	0.3124
Mono	1.0454	0.2209	Mono	1.0454	0.3124	Mono	1.0454	0.3124
* Least Square Mean			* Least Square Mean			* Least Square Mean		

Table I.5 Forced Choice Rankings for Interface

Overall								
Interface Ranking								
1 2 3 4								
Cues	5 (11%)	26 (59%)	10 (23%)	3 (7%)				
Hues	4 (9%)	12 (27%)	23 (52%)	5 (11%)				
Hues and Cues	30 (68%)	4 (9%)	5 (11%)	5 (11%)				
Mono	5 (11%)	2 (5%)	6 (15%)	31 (70%)				

Table I.6 Forced Choice Rankings for Interface

Female Interface Ranking									
	1	2	3	4					
Cues	0 (0%)	15 (68%)	6 (27%)	1 (5%)					
Hues	2 (9%)	5 (23%)	14 (64%)	1 (5%)					
Hues and Cues	18 (82%)	2 (9%)	0 (0%)	2 (9%)					
Mono	2 (9%)	0 (0%)	2 (9%)	18 (82%)					

Table I.7 Forced Choice Rankings for Interface

Male									
Interface Ranking									
1 2 3 4									
Cues	5 (23%)	11 (50%)	4 (18%)	2 (9%)					
Hues	2 (9%)	7 (32%)	9 (41%)	4 (18%)					
Hues and Cues	12 (55%)	2 (9%)	5 (23%)	3 (14%)					
Mono	3 (14%)	2 (9%)	4 (18%)	13 (59%)					

Appendix J

Adaption of LCT Measurements for Individualized Curves

The Lane Change Test was performed using DaimlerChrysler AG, Research and Technology's "Lane Change Test 1.2" software package. This package included the driving simulation and LCT analysis software. The general principle of the analysis software is to load raw data files that belong in a project, define parameters for analysis including but not limited to calculated metrics and lane tolerances, and then run the desired analysis. The analysis for each participant involved generating an individualized reference path instead of using the global reference path. This resulted in participants serving as there own control; minimizing extraneous variables. To calculate this reference path each participated in a two trials baseline trials (*Baseline 1 and Baseline* 2), where they drove with LCT method on a complete track without any added task before (Baseline 1) and after (Baseline 2) the interacting with experimental interfaces. The reference path is calculated by averaging the following measurements from the participants baseline trials: *StartLaneChange*, *LaneChangeLength* and the lateral positions on each lane AdaptedPosXlane1, AdaptedPosXlane2, AdaptedPosXlane3 (Figure J.27). The intermediary calculations are further discussed in the ISO 26022 standard (International Standards Organization, 2008). The result however, is the standard deviation in lane position; with the average of the baselines serving as the point of reference.



Figure J.27 Parameters Used to Calculate Reference Curve.

REFERENECES

- Ablassmeier, M., Poitschke, T., & Rigoll, G. (2006). A new approach of a contextadaptive search agent for automotive environments. In *CHI'06 extended abstracts* on *Human factors in computing systems* (pp. 1613–1618).
- Accenture. (2011). *Perspectives on In-Vehicle Infotainment Systems and Telematics* (pp. 5–10).
- Alpern, M., & Minardo, K. (2003). Developing a car gesture interface for use as a secondary task. In CHI'03 extended abstracts on Human factors in computing systems (pp. 932–933).
- Althoff, F., Lindl, R., Walchshausl, L., & Hoch, S. (2005). Robust multimodal hand-and head gesture recognition for controlling automotive infotainment systems. *VDI BERICHTE*, 1919, 187.
- Althoff, F., McGlaun, G., Lang, M., & Rigoll, G. (2004). Evaluating multimodal interaction patterns in various application scenarios. *Gesture-Based Communication in Human-Computer Interaction*, 479–480.
- Althoff, F., McGlaun, G., Schuller, P., Lang, M., & Rigoll, G. (2002). Evaluating misinterpretations during human-machine communication in automotive environments. *Proceedings of the 6th World Multiconference on Systemics, Cybernetics and Informatics (SCI'02)*, 7, 13–17.
- Alvarez, I., Alnizami, H., Dunbar, J., Andrea, J., & Gilbert, J. E. (2011). Designing Driver-centric Natural Voice User Interfaces. In 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp. 166–169). Salzburg.
- Amditis, A., Polychronopoulos, A., Andreone, L., & Bekiaris, E. (2006). Communication and interaction strategies in automotive adaptive interfaces. *Cognition, Technology* & Work, 8(3), 193–199.

Amunts, K., & Armstrong, E. (2007). Gender-specific left-right asymmetries in human visual cortex. *The Journal of Neuroscience*, 27(6), 1356-64.

Angell, L., Auflick, J., Austria, P., & Kochhar, D. (2006). Driver workload metrics task 2 final report.
- Antin, J. F., Dingus, T. A., Hulse, M. C., & Wierwille, W. W. (1990). An evaluation of the effectiveness and efficiency of an automobile moving-map navigational display. *International Journal of Man-Machine Studies*, 33(5), 581–594.
- Apple. (2014). *Apple CarPlay: The best iPhone experience on four wheels*. Retrieved June 20, 2014 from https://www.apple.com/ios/carplay/
- Audi. (2012). *Audi Online Services*. Retrieved May 18, 2013 from http://www.audiusa.com/us/brand/en/owners/audi_connect.html#source=http://www .audiusa.com/us/brand/en/owners/audi_connect/news.html&container=page
- Ayama, M., & Sakurai, M. (2003). Changes in hue and saturation of chromatic lights presented in the peripheral visual field. *Color Research & Application*, 28(6), 413– 424.
- Bach, K. M., Jaeger, M. G., Skov, M. B., & Thomassen, N. G. (2008). You can touch, but you can't look: interacting with in-vehicle systems. In CHI 08 Proceeding of the twentysixth annual SIGCHI conference on Human factors in computing systems (pp. 1139–1148).
- Bach, K. M., Jæger, M. G., Skov, M. B., & Thomassen, N. G. (2009). Interacting with invehicle systems: understanding, measuring, and evaluating attention. In *Proceedings* of the 23rd British HCI Group Annual Conference on People and Computers: Celebrating People and Technology (pp. 453–462).
- Bailey, R. W. (1993). Performance vs. Preference. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 37(4), 282–286.
- Baumann, M., Keinath, A., Krems, J., & Bengler, K. (2004). Evaluation of in-vehicle HMI using occlusion techniques: experimental results and practical implications. *Applied Ergonomics*.
- Baxter, L. (2013). Mechanism of Actions and Effects: Designing Great Feedback Loops. Smashing Magazine. Retrieved June 15, 2013, from http://uxdesign.smashingmagazine.com/2013/02/15/designing-great-feedback-loops/
- Blattner, M. (1989). Earcons and icons: Their structure and common design principles. *Human–Computer Interaction* 4(1), 11-44.
- Blincoe, L., Miller, T. R., Zaloshnja, E., & Lawrence, B. A. (2014). *The Economic and Societal Impact Of Motor Vehicle Crashes, 2010.*
- BMW GROUP. (2011). BMW offers new interface for extended iPhone connectivity. The special option Apps. Retrieved April 1, 2012 from

https://www.press.bmwgroup.com/pressclub/p/pcgl/pressDetail.html?outputChannel Id=6&id=T0097916EN&left_menu_item=node__2369

- Bose, R., Brakensiek, J., & Park, K. Y. (2010). Terminal mode: transforming mobile devices into automotive application platforms. In *Proceedings of the 2nd International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 148–155).
- Bradley, R. (2010). *Clemson becomes first city to ban texting while driving in state*. Retrieved June 22, 2012 from http://www2.counton2.com/news/2010/feb/16/clemson_becomes_first_city_to_ban_ texting_while_dr-ar-535160/

Brewster, S., Raty, V., & Kortekangas, A. (1996). Earcons as a method of providing navigational cues in a menu hierarchy. *In Proceedings of HCI on People and Computers XI (HCI '96)*, 169-183.

Brewster, S., Wright, P., & Edwards, A. (1993). An evaluation of earcons for use in auditory human-computer interfaces. ... In Proceedings of the INTERACT'93 and CHI'93 Conference on Human Factors in Computings, 222-227.

Broadbent, D. (1958). Perception and communication. Oxford: Pergamon Press

- Bruyas, M. P., Brusque, C., Auriault, A., Tattegrain, H., Aillerie, I., & Duraz, M. (2008, April). Impairment of lane change performance due to distraction: Effect of experimental contexts. In Proceedings of the European conference on human centred design for intelligent transport systems (pp. 89-100).
- Burnett, G., & Irune, A. (2009). Drivers' quality ratings for switches in cars: assessing the role of the vision, hearing and touch senses. In *Proceedings of the 1st International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 107–114).
- Caberletti, L., Elfmann, K., Kummel, M., & Schierz, C. (2010). Influence of ambient lighting in a vehicle interior on the driver's perceptions. *Lighting Research and Technology*, *42*(3), 297–311.
- Caird, J. K., Scialfa, C. T., Ho, G., & Smiley, A. (2005). A Meta-Analysis of Driving Performance and Crash Risk Associated With The Use of Cellular Telephones While Driving. In Proceedings of the Third International Driving Symposium on Human Factors in Driving Assessment, Training, and Vehicle Design (pp. 477–486). Rockport.

- Camilli, M., Dibitonto, M., Vona, A., Grimaldi, R., Di Nocera, F., & Medaglia, C. M. (2011). Searching digital audio broadcasting radio stations: usability and safety issues for in-vehicle devices. In *Proceedings of the 9th ACM SIGCHI Italian Chapter International Conference on Computer-Human Interaction: Facing Complexity* (pp. 143–147).
- Carney, Cher, et al. (1997). Human factors field evaluation of automotive headway maintenance/collision warning devices. *Human Factors*, *39*(2).
- Chan, C. Y. (2011). Connected vehicles in a connected world. In VLSI Design, Automation and Test (VLSI-DAT), 2011 International Symposium on (pp. 1–4).
- Chang, J. C., Lien, A., Lathrop, B., & Hees, H. (2009). Usability evaluation of a Volkswagen Group in-vehicle speech system. In Proceedings of the 1st International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp. 137–144).
- Chisholm, S. L., Caird, J. K., Lockhart, J. A., Teteris, L. E., & Smiley, A. (2006). Novice and experienced driving performance with cell phones. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting(Vol. 50, No. 22, pp. 2354-2358). Sage Publications.
- Christiansen, L., Frederiksen, N., Jensen, B., Ranch, A., Skov, M., & Thiruravichandran, N. (2011). Don't Look at Me, I'm Talking to You: Investigating Input and Output Modalities for In-Vehicle Systems. *Human-Computer Interaction--INTERACT* 2011, 675–691.
- CNT. (2013). Celebrating 35 Years: Real-Time Pricing. Power Smart Pricing. Energy-Smart Pricing Plan. : Center for Neighborhood Technology. Retrieved June 23, 2014, from http://www.cnt.org/2013/07/17/celebrating-35-years-real-time-pricingpower-smart-pricing-energy-smart-pricing-plan/
- Consumer Reports. (2011). Ford's frustrating high-tech controls. *Consumer Reports*, 51. Retrieved August 30, 2012 from http://www.consumerreports.org/cro/magazinearchive/2011/february/cars/suvs/myford-touch/index.htm
- Continental. (2012). AutoLinQ brings everything together: Your Car. Your Home. Your Lifestyle. Your Entertainment. Retrieved April 22, 2012 from http://www.contionline.com/generator/www/de/en/continental/automotive/themes/passenger_cars/int erior/connectivity/autolinq/pi autoling en.html
- Costagliola, G., Di Martino, S., Oliviero, F. F. G., Montemurro, U., & Paliotti, A. (2005). A Multimodal Interface for Automotive Information Systems. In *4th Italian Symposium on Human Computer Interaction* (pp. 13–17).

- Day, J. H. (2004). SUCCESS STORY-Can BMW's iDrive Pass Its Road Test Now? After a catastrophic debut and a major makeover, BMW's iDrive infotainment system is gaining acceptance with critics, competitors, and. *Electronic Design*, *52*(14), 48–55.
- Deloitte Development LLC. (2011). *Third Annual Deloitte Automotive Generation Y Survey- "Gaining speed: Gen Y in the Driver's Seat* (pp. 1–2).
- Dingus, T. A., Klauer, S. G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J. D., ... others. (2006). *The 100-car naturalistic driving study, Phase II-results of the 100-car field experiment.*
- DOT. (2014). *Distracted Driving: Key Facts and Statistics*. Retrieved June 20, 2014, from http://www.distraction.gov/content/get-the-facts/facts-and-statistics.html
- Driver, J., & Spence, C. (2004). Crossmodal spatial attention: Evidence from human performance. Retrieved from http://philpapers.org/rec/DRICSA
- Ecker, R., Broy, V., Hertzschuch, K., & Butz, A. (2010). Visual cues supporting direct touch gesture interaction with in-vehicle information systems. In *Proceedings of the* 2nd International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp. 80–87).
- Ekman, U. (2013). *Throughout: Art and Culture Emerging with Ubiquitous Computing* (p. 626). MIT Press.
- Eviltwin. (2002, April). Reinventing the automotive UI or just another gimmick the BMW 7 Series. Retrieved March 29, 2011 from http://www.kuro5hin.org/story/2002/4/15/21213/1517
- Federal Register. (2013). Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices. *National Highway Traffic Safety Administration*, 78(81), 24857–24859.
- Fisher, D., Rizzo, M., & Caird, J. (2011). Handbook of driving simulation for engineering, medicine, and psychology.
- Foley, J. (1980). The Structure of Interactive Command Languages. In *Proceedings IFIP Workshop on the Methodology of Interactio* (pp. 227–234). North-Holland.
- Ford Motor Company. (2011). *SYNC AppLink: The free software program from Ford that gives SYNC users voice control of smartphone apps*. Retrieved April 10,² 2012 from http://media.ford.com/images/10031/SYNC_AppLink_1210_HR.pdf

- Ford Motor Company. (2012). ALL-NEW FORD FOCUS BRINGS SMARTER AMBIENT LIGHTING, ADDING HELPFUL INNOVATIONS. Retrieved February 05, 2012, from http://media.ford.com/article_display.cfm?article_id=33538
- Fuller, H., Tsimhoni, O., & Reed, M. P. (2008). Effect of in-vehicle touch screen position on driver performance. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 52, pp. 1893–1897).
- General Motors. (2012). *Cadillac CUE Overview: CUE Fact Sheet*. Retrieved January 05, 2012, from http://www.cadillac.com/cadillac_cue.html
- Ghangurde, M., & Business, W. E. (2011). Ford's sync® and microsoft windows embedded automotive make digital lifestyle a reality on the road. SAE International.
- Gibson, J. J. (1977). The concept of affordances. *Perceiving, Acting, and Knowing*, 67–82.
- Gordon, C. P. (2009). The 100-Car Naturalistic Driving Study: A Descriptive Analysis of Light Vehicle-Heavy Vehicle Interactions from the Light Vehicle Driver's Perspective. In Crash Studies of Driver Distraction, in Driver Distraction: Theory, effect and mitigation (pp. 281–304). London: Taylor & Francis Group.
- Gordon, J., & Abramov, I. (1977). Color vision in the peripheral retina. II. Hue and saturation. *JOSA*, *67*(2), 202–207.
- Green, P. (1993). Design and evaluation of symbols for automobile controls and displays. *Automotive Ergonomics*.

Green, P. (1995). Measures and methods used to assess the safety and usability of driver information systems (No. FHWA-RD-94-088). Federal Highway Administration.

- Green, P. (1999). Estimating compliance with the 15-second rule for driver-interface usability and safety. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 43, pp. 987–991).
- Greenberg, J., Tijerina, L., Curry, R., Artz, B., Cathey, L., Kochhar, D., ... & Grant, P. (2003). Driver distraction: Evaluation with event detection paradigm.Transportation Research Record: Journal of the Transportation Research Board, 1843(1), 1-9.
- Gruenstein, A., Orszulak, J., Liu, S., Roberts, S., Zabel, J., Reimer, B., ... Coughlin, J. (2009). City browser: developing a conversational automotive HMI. In *Proceedings* of the 27th international conference extended abstracts on Human factors in computing systems (pp. 4291–4296).

- Harbluk, J. L., Noy, Y. I., Trbovich, P. L., & Eizenman, M. (2007). An on-road assessment of cognitive distraction: Impacts on drivers' visual behavior and braking performance. Accident Analysis & Prevention, 39(2), 372-379.
- Harrison, C., & Hudson, S. E. (2009). Providing dynamically changeable physical buttons on a visual display. In *Proceedings of the 27th international conference on Human factors in computing systems* (pp. 299–308).
- Haslbeck, A., Popova, S., Krause, M., Pecot, K., Mayer, J., & Bengler, K. (2011). Experimental evaluations of touch interaction considering automotive requirements. *Human-Computer Interaction. Interaction Techniques and Environments*, 23–32.
- Hemphill, M. (2011). Do You Need Ambient Lighting? Retrieved February 05, 2012, from http://www.autotrader.com/research/article/new-research/77601/do-you-needambient-lighting.jsp
- Herfet, T., Kirste, T., & Schnaider, M. (2001). EMBASSI multimodal assistance for infotainment and service infrastructures. *Computers & Graphics*, 25(4), 581–592.
- Hickson, I. (2012). *The Websocket API*. Retrieved June 12, 2014 from http://www.w3.org/TR/2012/CR-websockets-20120920/
- Ho, C., & Spence, C. (2013). Affective multisensory driver interface design. International Journal of Vehicle Noise and Vibration, 9(1/3), 61–74.
- Hochberg, J. (1994). JAMES JEROME GIBSON. Biographical Memoirs. 63, 151.
- Holbrook, M. (1986). Aims, concepts, and methods for the representation of individual differences in esthetic responses to design features. *Journal of Consumer Research*.
- Holbrook, M. B. (1986). Aims, concepts, and methods for the representation of individual differences in esthetic responses to design features. *Journal of Consumer Research*, 337-347.
- Horrey, W. J., & Wickens, C. D. (2004). Driving and side task performance: The effects of display clutter, separation, and modality. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 46(4), 611–624.
- Horrey, W. J., Wickens, C. D., & Consalus, K. P. (2006). Modeling drivers' visual attention allocation while interacting with in-vehicle technologies. *Journal of Experimental Psychology: Applied*, *12*(2), 67.
- Hsu, N. S., Frankland, S. M., & Thompson-Schill, S. L. (2012). Chromaticity of color perception and object color knowledge. *Neuropsychologia*, 50(2), 327-333.

- International Standards Organization. ISO 16673 Road Vehicles Ergonomic Aspects of Transport Information and Control Systems-Occlusion Method Assess Visual Demand Due to the Use of In-Vehicle Systems (2007). Switzerland.
- International Standards Organization. ISO 26022 Road vehicles Ergonomic aspects of transport information and control systems Simulated lane change test to assess invehicle secondary task demand (2008).
- Jones, C. M., & Healy, S. D. (2006). Differences in cue use and spatial memory in men and women. *Proceedings of the Royal Society B: Biological Sciences*, 273(1598), 2241-2247.
- Joseph, S. (2013). Mobile-Web-based-Gesture-Recognition. Retrieved from https://github.com/schooley/Mobile-Web-based-Gesture-Recognition
- JQuery Foundation. (2014). jQuery. Retrieved from http://jquery.com/
- Kaazing Corporation. (2013). *All About WebSockets*. Retrieved from http://www.websocket.org/aboutwebsocket.html
- Kahneman, D. (1973). Attention and effort. Englewood Cliffs, NJ: Prentice-Hall.
- Kahneman, D., & Treisman, A. (1984). Changing views of attention and automaticity. *Varieties of Attention*.
- Kee, E. (2012). *Intel Atom systems headed for 2013 Nissan rides*. Retrieved June 04, 2012, from http://www.ubergizmo.com/2012/04/intel-atom-systems-2013-nissan/
- Kern, D., & Schmidt, A. (2009). Design space for driver-based automotive user interfaces. In Proceedings of the 1st International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp. 3–10).
- Kieras, D. E., & Bovair, S. (1984). The role of a mental model in learning to operate a device. *Cognitive Science*, 8(3), 255–273.
- Kimura, D. (2000). Sex and cognition. MIT Press.
- Klinger, K. D., & Lemmer, U. (2008). "The influence of ambient light on the driver. In *Proc. SPIE* (Vol. 7003, p. 700329).
- Kramer, A. F., Cassavaugh, N., Horrey, W. J., Becic, E., & Mayhugh, J. L. (2007). Influence of age and proximity warning devices on collision avoidance in simulated driving. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 49(5), 935–949.

- Kun, A. L., Paek, T., Medenica, Ž., Memarović, N., & Palinko, O. (2009). Glancing at personal navigation devices can affect driving: experimental results and design implications. In *Proceedings of the 1st International Conference on Automotive* User Interfaces and Interactive Vehicular Applications (pp. 129–136). New York, NY, USA
- Lavrinc, D. (2012). Mercedes-Benz DICE Concept Brings Gesture Controls To The Cockpit. Retrieved January 05, 2012, from http://www.autoblog.com/2012/01/12/mercedes-benz-dice-concept-brings-gesturecontrols-to-the-cockpi/
- Lee, E. J., Nass, C., & Brave, S. (2000, April). Can computer-generated speech have gender?: an experimental test of gender stereotype. *In CHI'00 extended abstracts on Human factors in computing systems* (pp. 289-290).
- Lee, J. D., McGehee, D. V., Brown, T. L., & Reyes, M. L. (2002). Collision warning timing, driver distraction, and driver response to imminent rear-end collisions in a high-fidelity driving simulator. Human Factors: *The Journal of the Human Factors* and Ergonomics Society, 44(2), 314-334.
- Lee J., Y. K. R. M. (2008). Driver Distraction: Theory, Effects, and Mitigation. In L. J. Y. K. Reagan M. (Ed.), . CRC Press.
- Leen, G., & Heffernan, D. (2002). Expanding automotive electronic systems. *Computer*, 35(1), 88–93.
- Levy, J., & Reid, M. (1978). Variations in cerebral organization as a function of handedness, hand posture in writing, and sex. *Journal of Experimental Psychology: General*. 107(2) 119.
- Lin, P. C., & Chen, S. I. (2013). The effects of gender differences on the usability of automotive on-board navigation systems–A comparison of 2D and 3D display. *Transportation research part F: traffic psychology and behaviour*, 19, 40-51.
- Lorigo, L., Pan, B., Hembrooke, H., Joachims, T., Granka, L., & Gay, G. (2006). The influence of task and gender on search and evaluation behavior using Google. *Information Processing & Management*, 42(4), 1123-1131.
- Luyten, W. (2013). JS Cover Flow. Retrieved from http://luwes.co/labs/js-cover-flow/
- Maciej, J., & Vollrath, M. (2009). Comparison of manual vs. speech-based interaction with in-vehicle information systems. Accident Analysis & Prevention, 41(5), 924– 930.

- Malizia, A., & Bellucci, A. (2012). The Artificiality of natural User interfaces. *Communications of the ACM*, 55(3), 36–38.
- Mattes, S. (2003). The lane-change-task as a tool for driver distraction evaluation. *Quality of work and products in enterprises of the future*, 57-60.
- Mick, J. (2011). *MyFord Touch Shows Dramatic Improvement in Second Tour*. Retrieved January 05, 2011, from http://www.dailytech.com/MyFord+Touch+Shows+Dramatic+Improvement+in+Sec ond+Tour/article22618.htm
- Miller, J. M., Kaminski, D., Schoner, H. P., & Jahns, T. M. (1998). Making the case for a next generation automotive electrical system. In *International Congress on Transportation Electronics (1998: Dearborn Mich.). Vehicle infotronics: enabling* the integrated mobility experience: proceedings of the 1998 International Congress on Transportation Electronics.
- Monk, C. A., & Kidd, D. G. (2007, July). R we fooling ourselves: does the occlusion technique shortchange R estimates. In *Proceedings for 4th International Symposium* on Human Factors, Driver Assessment, Training, and Vehicle Design, Stevenson, Washington (pp. 2-8).
- Moray, N. (1982). Subjective mental workload. Human Factors: The Journal of the Human Factors and Ergonomics Society, 24(1), 25-40.
- Müller, C., & Weinberg, G. (2011). Multimodal input in the car, today and tomorrow. *Multimedia, IEEE, 18*(1), 98–103.
- Mynatt, E. D. (1997). Transforming graphical interfaces into auditory interfaces for blind users. *Human--Computer Interaction*, 12(1-2), 7–45.
- Nass, C., Moon, Y., & Green, N. (1997). Are Machines Gender Neutral? Gender-Stereotypic Responses to Computers With Voices. *Journal of applied social psychology*, 27(10), 864-876.
- NHTSA. (2012a). *DISTRACTION.GOV: Official US Government Website for Distracted Driving*. Retrieved January 12, 2013 from http://www.distraction.gov/content/get-the-facts/index.html
- NHTSA. (2012b). U.S. Department of Transportation Proposes "Distraction" Guidelines for Automakers: Proposed recommendations would encourage manufacturers to develop "less distracting" in-vehicle electronic devices. Retrieved January 14,2013 from http://www.dot.gov/affairs/2012/nhtsa0212.html

- Niedermaier, B., Durach, S., Eckstein, L., & Keinath, A. (2009). The New BMW iDrive--Applied Processes and Methods to Assure High Usability. *Digital Human Modeling*, 443–452.
- Nielsen Company. (2010). What Americans Do Online: Social Media And Games Dominate Activity. Retrieved March 23, 2011 from http://blog.nielsen.com/nielsenwire/online_mobile/what-americans-do-online-socialmedia-and-games-dominate-activity/
- Nielsen, J. (2007). Jakob Nielsen's Alertbox: Tabs, Used Right, 13 design guidelines for tab controls. Retrieved October 06, 2013, from http://www.nngroup.com/articles/tabs-used-right/,
- Nolte, T., Hansson, H., & Bello, L. L. (2005). Automotive communications-past, current and future. In *Emerging Technologies and Factory Automation, 2005. ETFA 2005. 10th IEEE Conference on* (Vol. 1, p. 8–pp).
- Norman, D. (1968). Toward a theory of memory and attention. *Psychological Review*. 75(6), 522.
- Norman, D. (2002). The Design of Everyday Things. Basic Books.
- Noy, Y. I., & Lemoine, T. (2001). Prospects for Using Occlusion Paradigm to Set ITS Function Accessibility Limits. In Presentation at the Exploring the Occlusion Technique: Progress in Recent Research and Applications Workshop, Torino, Italy.
- Olsen, E. C., Lee, S. E., & Wierwille, W. W. (2005). Eye glance behavior during lane changes and straight-ahead driving. *Transportation Research Record: Journal of the Transportation Research Board*, 1937(1), 44-50.
- Östlund, J., Peters, B., Thorslund, B., Engström, J., Markkula, G., Keinath, A., Horst, D., Mattes, S. Foehl, U. (2005). *Driving performance assessment: Methods and metrics*.
- Oxford English Dictionary Online. (2013). "design, n." Oxford University Press. Retrieved from http://www.oed.com/
- Peng, W., & Zhiqiang, L. (2013, January). The Study of Intelligent Vehicle Anti-collision Forewarning Technology by Multi-Information Detection. In *Proceedings of the* 2013 Third International Conference on Intelligent System Design and Engineering Applications (pp. 1557-1561). I

- Perez, M., Hulse, M., & Angell, L. (2013). Support for NHTSA Visual-Manual Guidelines: Expert Review of the Visual Occlusion Method and How It Compares to Driver Eye-Glance Behavior.
- Pew Research Center. (2009). *Teens and Distracted Driving*. Retrieved October 21, 2012 from http://pewresearch.org/pubs/1411/teens-distracted-driving-texting-cellphoneuse
- Pew Research Center. (2010). Adults Text While Driving Too! Retrieved from October 21, 2012 http://pewresearch.org/pubs/1633/adults-texting-talking-on-cellphonewhile-driving-like-teens
- Pickering, C. A., Burnham, K. J., & Richardson, M. J. (2007). A Research Study of Hand Gesture Recognition Technologies and Applications for Human Vehicle Interaction. In Automotive Electronics, 2007 3rd Institution of Engineering and Technology Conference on (pp. 1–15).
- Pickering, C.A. and Burnham, KJ and Richardson, M. J. (2007). A review of automotive human machine interface technologies and techniques to reduce driver distraction. In *The 2007 2nd Institution of Engineering and Technology International Conference on System Safety* (pp. 223–228). IET.
- Pitts, M. J., Williams, M. A., Wellings, T., & Attridge, A. (2009). Assessing subjective response to haptic feedback in automotive touchscreens. In *Proceedings of the 1st international Conference on Automotive User interfaces and interactive Vehicular Applications* (pp. 11–18).
- Potter, N. (2011). *Why Does Apple's Siri Have a Female Voice? ABC News*. Retrieved July 01, 2014, from http://abcnews.go.com/Technology/apples-siri-female-voice/story?id=14802733

Putrevu, S. (2001). Exploring the origins and information processing differences between men and women: Implications for advertisers. *Academy of Marketing Science Review* 10(1), 1-14.

- Raghavan, S., & Perlman, G. (2000, July). The Difference of Preference versus Performance can Differ for Concurrent versus Retrospective Ratings. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 44, No. 37, pp. 617-620).
- Rana, O. (2010). New SYNC with MyFord Touch allows more than 10,000 voice commands. Retrieved January 05, 2012, from http://www.egmcartech.com/2010/07/15/new-generation-sync-with-myford-touchallows-up-to-10000-voice-commands/

- Ranney, T. (1994). Models of driving behavior: a review of their evolution. *Accident Analysis & Prevention*. 26(6) 733-750.
- Ranney, T. A., Baldwin, G. H., Parmer, E., Domeyer, J., Martin, J., & Mazzae, E. N. (2011). Developing a Test to Measure Distraction Potential of In-Vehicle Information System Tasks in Production Vehicles.
- Ranney, T., & Mazzae, E. (2000). NHTSA driver distraction research: Past, present, and future.
- Ranney, T., Mazzae, E., Garrott, R., & Goodman, M. (2000). NHTSA Driver Distraction Research: Past. Present, and Future. In *Driver Distraction Internet Forum* (Volume
- Rhey, E. (2012). *A GPS maker shifts gears*. Retrieved September 03, 2012, from http://tech.fortune.cnn.com/2012/03/08/garmin-gps-dashboards/
- Ritter, W. (2011). Benefits of subliminal feedback loops in human-computer interaction. *Advances in Human-Computer Interaction*. 2011, 1.
- Roalf, D., Lowery, N., & Turetsky, B. (2006). Behavioral and physiological findings of gender differences in global-local visual processing. *Brain and Cognition*. 60(1), 32-42.
- Russ, C. (1998). *OnStar: What Is It?* Retrieved September 4, 2011 from http://www.theautochannel.com/news/date/19980115/news009219.html
- Salomon, G. (1990). New uses for color. *The Art of Human-Computer Interface Design*, 269–278.
- Sax, L. (2010). Sex Differences in Hearing Implications for best practice in the classroom. *Advances in Gender and Education*. 2, 13-21.
- Schmidt, A., Dey, A. K., Kun, A. L., & Spiessl, W. (2010). Automotive user interfaces: human computer interaction in the car. In *Proceedings of the 28th of the international conference extended abstracts on Human factors in computing systems* (pp. 3177–3180).
- Schmidt, A., Spiessl, W., & Kern, D. (2010). Driving Automotive User Interface Research. *Pervasive Computing, IEEE*, 9(1), 85–88.
- Schwartz, J., & Tallal, P. (1980). Rate of acoustic change may underlie hemispheric specialization for speech perception. *Science*, 207(4437) 1380-1381.

- Shieh, K. K., & Lin, C. C. (2000). Effects of screen type, ambient illumination, and color combination on VDT visual performance and subjective preference. *International Journal of Industrial Ergonomics*, 26(5), 527–536.
- Shneidemnan, B. (1991). Touch Screens Now Offer Compelling Uses. *IEEE Softw.*, 8(2), 93–94,107.
- Shubin, H., Falck, D., & Johansen, A. G. (1996). Exploring color in interface design. *Interactions*, *3*(4), 36–48.
- Smith, D., Chang, J., & Glassco, R. (2005). Methodology for capturing driver eye glance behavior during in-vehicle secondary tasks. Transportation Research Record: *Journal of the Transportation Research Board*, 1937(1), 61-65.
- Society Of Automotive Engineers. Navigation and Route Guidance Function Accessibility While Driving (2004). USA.
- Sodhi, M., Reimer, B., & Llamazares, I. (2002). Glance analysis of driver eye movements to evaluate distraction. *Behavior Research Methods, Instruments, & Computers* 34(4), 529-538.
- Stevens, C., Lees, N., Vonwiller, J., & Burnham, D. (2005). On-line experimental methods to evaluate text-to-speech (TTS) synthesis: effects of voice gender and signal quality on intelligibility, naturalness and preference. *Computer Speech & Language*, 19(2), 129-146
- Stutts, J.C., et al. (2001). *The role of driver distraction in traffic crashes*. AAA Foundation for Traffic Safety Washington, DC.
- Suh, N. (1990). The principles of design. New York: Oxford University Press.
- Tanaka, J., Weiskopf, D., & Williams, P. (2001). The role of color in high-level vision. *Trends in Cognitive Sciences*, 5(5), 211–215.
- Terenzi M., D. N. F. F. F. (2005). Action, not Only Semantics, Underlies Expected Action, not Only Semantics, Underlies Expected Location for Interface Elements. In *4th Italian Symposium on Human Computer Interaction* (pp. 23–27).
- Tijerina, L., & Garrott, W. (2005). Eye glance behavior of van and passenger car drivers during lane change decision phase *Transportation Research Record: Journal of the Transportation Research Board*, 1937(1), 37-43.

- Toms, M. L., Cummings-Hill, M. A., Curry, D. G., & Cone, S. M. (2001). Using cluster analysis for deriving menu structures for automotive mobile multimedia applications. SAE Technical Paper.
- Toyota. (2012). *Entune: Connect with your car*. Retrieved Febuary 12, 2012 from http://www.toyota.com/entune/
- Treisman, A. (1969). Strategies and models of selective attention. *Psychological Review*. 76(3), 282.
- Vaa, T. (2007). Modelling driver behaviour on basis of emotions and feelings: intelligent transport systems and behavioural adaptations. *Modelling Driver Behaviour in Automotive Environments*. 208-232
- Vargas, M., & Anderson, S. (2003). Combining speech and earcons to assist menu navigation. *International Conference on Auditory Display (ICAD2003)*, Boston, USA.
- Venhovens, P., Brooks, J., Pryor, T., Ekandem, J. I., Bubilek, T., Xi, Y., & Creber, B. (2011). A Novel HMI for Automotive Infotainment using a Short-Throw Projector. In 18th Annual Symposium of Vehicle Displays and Interfaces; SID. Dearborn, MI.
- Victor, T., Engström, J., & Harbluk, J. (2008). 10 Distraction Assessment Methods Based on Visual Behavior and Event Detection. *Driver Distraction: Theory, Effects, and Mitigation,* 135.
- Victor, T.W, Harbluk, J.L and Engström, J. A. (2005). Sensitivity of eye-movement measures to in-vehicle task difficulty. *Transportation Research Part F: (8)*, 167–190.
- Wake, W. (2000). Design paradigms: a sourcebook for creative visualization.
- Walker, B., Nance, A., & Lindsay, J. (2006). Spearcons: Speech-based earcons improve navigation performance in auditory menus. In *Proceedings of the International Conference of Auditory Display*, London, UK. 66-68.
- Wickens, C. (1991). Processing resources and attention. *Multiple-Task Performance*.
- Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science*, *3*(2), 159–177.
- Wierwille, W. W. (1993). Visual and manual demands of in-car controls and displays. *Automotive Ergonomics*.

- Witkin, H., Wapner, S., & Leventhal, T. (1952). Sound localization with conflicting visual and auditory cues. *Journal of Experimental psychology*, 43(1).
- Wittmann, M., & Szelag, E. (2003). Sex differences in perception of temporal order. *Perceptual and Motor Skills*. 96(1). 105-112.
- Young, K., Lee, J., & Regan, M. (2008). Driver Distraction Injury Prevention Countermeasures Part3: Vehicle, Technology, and Road Design. In L. Regan, Michael, A., Victor, Trent, A., Lee, John, D., Young, Kristie (Ed.), Driver distraction: Theory, effects, and mitigation (pp. 580–590).
- Young, K., & Regan, M. (2007). Driver distraction : A review of the literature. *Distracted Driving*, 379–405.
- Young, R., & Angell, L. (2003). The dimensions of driver performance during secondary manual tasks. *Driving Assessment*.
- Zobl, M., Geiger, M., Bengler, K., & Lang, M. (2001). A usability study on hand gesture controlled operation of in-car devices. In *Abridged Proceedings, HCI 2001 9th Int. Conference on Human Machine Interaction, New Orleans, Louisiana, USA, August* 5-10, 2001 (pp. 166–168).