University Transportation Research Center - Region 2

Final Report

Deaf and Hard-of-Hearing Drivers: Making Highways Safer for Everyone

Performing Organization: Rochester Institute of Technology (RIT)

December 2019

Sponsor:
University Transportation Research Center - Region 2

University Transportation Research Center - Region 2

The Region 2 University Transportation Research Center (UTRC) is one of ten original University Transportation Centers established in 1987 by the U.S. Congress. These Centers were established with the recognition that transportation plays a key role in the nation's economy and the quality of life of its citizens. University faculty members provide a critical link in resolving our national and regional transportation problems while training the professionals who address our transportation systems and their customers on a daily basis.

The UTRC was established in order to support research, education and the transfer of technology in the field of transportation. The theme of the Center is "Planning and Managing Regional Transportation Systems in a Changing World." Presently, under the direction of Dr. Camille Kamga, the UTRC represents USDOT Region II, including New York, New Jersey, Puerto Rico and the U.S. Virgin Islands. Functioning as a consortium of twelve major Universities throughout the region, UTRC is located at the CUNY Institute for Transportation Systems at The City College of New York, the lead institution of the consortium. The Center, through its consortium, an Agency-Industry Council and its Director and Staff, supports research, education, and technology transfer under its theme. UTRC's three main goals are:

Research

The research program objectives are (1) to develop a theme based transportation research program that is responsive to the needs of regional transportation organizations and stakeholders, and (2) to conduct that program in cooperation with the partners. The program includes both studies that are identified with research partners of projects targeted to the theme, and targeted, short-term projects. The program develops competitive proposals, which are evaluated to insure the mostresponsive UTRC team conducts the work. The research program is responsive to the UTRC theme: "Planning and Managing Regional Transportation Systems in a Changing World." The complex transportation system of transit and infrastructure, and the rapidly changing environment impacts the nation's largest city and metropolitan area. The New York/New Jersey Metropolitan has over 19 million people, 600,000 businesses and 9 million workers. The Region's intermodal and multimodal systems must serve all customers and stakeholders within the region and globally.Under the current grant, the new research projects and the ongoing research projects concentrate the program efforts on the categories of Transportation Systems Performance and Information Infrastructure to provide needed services to the New Jersey Department of Transportation, New York City Department of Transportation, New York Metropolitan Transportation Council , New York State Department of Transportation, and the New York State Energy and Research Development Authorityand others, all while enhancing the center's theme.

Education and Workforce Development

The modern professional must combine the technical skills of engineering and planning with knowledge of economics, environmental science, management, finance, and law as well as negotiation skills, psychology and sociology. And, she/he must be computer literate, wired to the web, and knowledgeable about advances in information technology. UTRC's education and training efforts provide a multidisciplinary program of course work and experiential learning to train students and provide advanced training or retraining of practitioners to plan and manage regional transportation systems. UTRC must meet the need to educate the undergraduate and graduate student with a foundation of transportation fundamentals that allows for solving complex problems in a world much more dynamic than even a decade ago. Simultaneously, the demand for continuing education is growing – either because of professional license requirements or because the workplace demands it – and provides the opportunity to combine State of Practice education with tailored ways of delivering content.

Technology Transfer

UTRC's Technology Transfer Program goes beyond what might be considered "traditional" technology transfer activities. Its main objectives are (1) to increase the awareness and level of information concerning transportation issues facing Region 2; (2) to improve the knowledge base and approach to problem solving of the region's transportation workforce, from those operating the systems to those at the most senior level of managing the system; and by doing so, to improve the overall professional capability of the transportation workforce; (3) to stimulate discussion and debate concerning the integration of new technologies into our culture, our work and our transportation systems; (4) to provide the more traditional but extremely important job of disseminating research and project reports, studies, analysis and use of tools to the education, research and practicing community both nationally and internationally; and (5) to provide unbiased information and testimony to decision-makers concerning regional transportation issues consistent with the UTRC theme.

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Principal Investigator(s):
Martin E. Gordon, PE, DFE
Professor
Dept. of Manufacturing and Mechanical Engineering Technology
RIT National Technical Institute for the Deaf
78 Lomb Memorial Drive
Rochester, NY 14623
Tel: (585) 475-7712
Email: megite@rit.edu

Performing Organization:
Rochester Institute of Technology (RIT)

Sponsor(s):
University Transportation Research Center (UTRC)

To request a hard copy of our final reports, please send us an email at utrc@utrc2.org

Mailing Address:

University Transportation Reserch Center
The City College of New York
Marshak Hall, Suite 910
160 Convent Avenue
New York, NY 10031
Tel: 212-650-8051
Fax: 212-650-8374
Web: www.utrc2.org

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One of the primary goals of USDOT is to make the U.S. transportation system the safest In the world. In order to fulfill this goal, it is important to understand how to improve highway safety for all users – including those users that may have different sensory inputs than the general population. In fact, some highway users belong to groups with special needs that have not been studied previously. The purpose of this research was to initiate collection of knowledge regarding deaf and hard of hearing drivers.

The intention of this research was to better understand the mechanisms and situations that may cause increased risk in the D/HH driving community and then use this information to create technologies and educational programs to mitigate the risk.

The research methodology was to use the creation of a realistic,virtual driving simulation to compare the reactions of deaf drivers to hearing drivers in specific situations where sound might play a critical role in accident avoidance. It also intended to use the simulation to compare the reactions of deaf drivers to hearing drivers in specific situations where vision might play a critical role in traffic avoidance.</td></tr>
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EXECUTIVE SUMMARY

A simple low cost portable driving simulator for subjects with Limited Auditory Perception was built and underwent partial pilot testing. This report describes the simulator, but provides no conclusive driving performance results. The research was determined to be cross-cultural and was perceived by the Deaf community to be extremely controversial. Human subject testing was terminated prior to arriving at any meaningful conclusions. Nonetheless, this report includes the efforts up to the point of termination and may provide a new launching point for a future research.

BACKGROUND

The work completed in this project will provide a tool to initiate a better understanding of driving performance of deaf and hard of hearing (D/HH) drivers. Once the driving performance of the D/HH are better understood, educational programs and access technology may be developed/selected to mitigate any performance risk. Because the D/HH are just one user group of the nation's multi-modal transportation system, it is likely that the driving performance of the D/HH certainly affect other user groups as well. Better understanding of D/HH driver performance will allow the development of technologies to maximize D/HH driving performance.

OBJECTIVES

The following outputs were produced:

1. The creation of a realistic, virtual driving simulation on a simple, low-cost simulator that was used to assess the driving performance of deaf drivers in specific simulated driving situations.

3. The creation of a performance instrument that was used to measure the overall simulated driving performance of deaf and hearing drivers using the previously described driving simulator and simulations.

The work accomplished in this project may lay the framework for other researchers to use in their study of deaf and hard of hearing drivers. It is hoped that this initial effort will eventually lead to more research and a more robust body of knowledge that may subsequently be used to help in policy decisions regarding deaf drivers and lead to the selection and/or creation of technology necessary to mitigate any unique risks.

INTRODUCTION

Driving simulators have long been used to study the issue of distracted driving. Some simulators cost hundreds of thousands of dollars. Expensive simulators typically are contained in a dedicated room and are built on motion platforms to create the most realistic simulated driving experience. Other systems may be built for a fraction of that cost and are simply little more than a computer monitor on a desk with a steering wheel and pedal inputs (Blana, 1996). Past investigators have noted that the overall value of a simulator is based on its technical features and how well the simulator matched the needs of its study participants (Campos et al., 2017).

One objective of this study was to produce a relatively low-cost, portable driving simulator that would be able to meet the needs of future studies involving subjects with unique or limited perceptual abilities. The simulator was designed to have a minimum footprint so that it could be housed in a shared lab space. To allow for a greater range of use, the simulator was designed so that the effect of communication with a front seat passenger or other front-seat distractions could be explored. Finally, the simulator system was designed so that features could be easily added or modified as experimental needs changed.

A pilot study was undertaken to look at the driving performance of a group of experienced drivers. A portion of the study group had a conductive or sensorineural hearing loss of 70 dB or greater that occurred prior to their seventh birthday. The remainder of the study group had no hearing loss.

SUMMARY OF LITERATURE REVIEW

For all the different types of simulators created, none has been purposely built to address the unique research issues involved with people who may have a partial or total hearing loss. Driving has long been known to be a task that requires a significant amount of visual perception – driving has been said to be approximately 90% visual (Sivak, 1998). Therefore, the remaining 10% of the driving task should involve the use of other senses, including hearing.

Few studies have attempted to explore the connection between hearing loss and driving performance. A multitude of previous studies have shown that the deaf population literally sees the world differently (Daphne Bavelier, Dye, & Hauser, 2006; D. Bavelier et al., 2000; Hauthal, Neumann, & Schweinberger, 2012; Hauthal, Sandmann, Debener, & Thorne, 2013; Marschark, Sarchet, & Trani, 2016; Marschark et al., 2015; Mitchell & Maslin, 2007; Shiell, Champoux, & Zatorre, 2014). In addition, studies have shown that perception and attention differs between people with and without hearing loss (Lavie, 2010; Proksch & Bavelier, 2002; van Dijk, Kappers, & Postma, 2013).

In order to focus the study to a needed research area that represented a real, documented highway safety issue, a national database of motor vehicle accidents was reviewed. According to data taken from the Fatality Analysis Reporting System (FARS) ("Fatality Analysis Reporting System," 2017) and the Auto Insurance Center ("Deadly Bad Drivers: What Causes Fatal Crashes Nationwide?,") the most common type of fatal collision in most states, including New York, involves lane departure. Lane departure may result in a sideswipe of a vehicle traveling in the same direction or an offset, head-on collision with a vehicle traveling in the opposite direction. In keeping with the information parsed from the FARS data, the pilot study relied on driving scenarios that evaluated lane keeping ability.

The relatively small amount of research that has been done with deaf or hard of hearing subjects was performed on driving simulators that provided a visual screen-based display of the roadway environment, speakers that projected engine or road noise and a speedometer. At least one previous study mentioned that deaf subjects' speed maintenance was poor when compared to hearing subjects. The study surmised that part of the poor performance was due to the fact that hearing drivers had the advantage of using engine or road noise to modulate their speed (Zodda et al., 2012).

As an aid to deaf or hard of hearing subjects and to avoid those issues that were found in the Zodda study the simulator was designed to have features that drivers with a hearing loss typically rely on in a real driving environment. Namely, vibration that has a frequency proportional to speed and a flow of visual information at the periphery of the drivers frontal view. [need to check for proper language when dealing with the Deaf – check NTID website for reference]

SUMMARY OF WORK PERFORMED

A team made up of graduate and undergraduate students was assembled to construct the simulator. Several of the students on the team were deaf or hard of hearing. At least one student had a parent who was deaf. Based on the experiences of past researchers, it was determined that the simulator should be able to provide vibration proportional to velocity or engine speed and be able to provide as close to 180 degrees of optical flow as possible. To make the simulator useful for studies involving front-seat distraction, including communication with passengers, it was decided that a complete vehicle body forward of the rear seats should be used.

Simulator Design and Construction

The team obtained a 1996 Saturn Sedan from a local junkyard. Because of space and weight limitations, all unnecessary material was removed from the sedan. This included the entire vehicle body aft of the front seats. Powertrain, steering and suspension components were removed and the remaining body clip was equipped with cart wheels so that the simulator could be easily transported. All vehicle glass was kept in place, but mirrors were removed because the selected simulation software automatically generates images of the mirrors for screen projection.

Three well-used classroom projectors were donated by the campus media center and white canvas was stretched around a metal tubular frame to make a front projection screen and two side projection screens. The screens were painted white and when the paint dried, the canvas was shrunk around the tubular frame. The design of the screens allowed them to be easily moved and easily adjusted.

Two floor stands were made to hold the side projectors and an adjustable vehicle-based mount was designed to hold the center projector. Again, all this was done with portability in mind.

A donated set of Fanatec CSR Elite gaming controls, including steering wheel, pedals and associated controls was mounted in the modified Saturn chassis. A set of four Buttkickers bass transducers were installed under the driver and passenger seats to allow for the transmission of engine and road vibration directly to the simulator occupants. Buttkickers may also be used for direct haptic feedback. Finally, the vehicle simulation software package STISIM ("STISIM," 2017) was purchased and was loaded onto a dedicated desktop PC. STISIM served as the central controller of the simulator system and was programmed to display the desired realistic driving scenarios.

The simulated road courses to be used for the two experiments were designed so that they were mirror images of one another. By doing this, each experiment would have the same number of curved and straight sections and the sections would be of identical length. Minimal vehicular traffic was programmed into the scenarios and the traffic was only on-coming. The courses each had a 35 mph section and a 55 mph section. Curves in each section were designed such that the subjects would be able to maintain the posted speed throughout each curve.

Projectors and screens were arranged to allow for maximum reality in the driving scenario while providing visual flow that extended a full 180 degrees from the driver’s eyes. Side-projected images were slightly distorted, but served to produce the necessary 180 degrees of optical flow. Providing images for peripheral vision was done to aid deaf and hard of hearing drivers. Some studies have shown that driver’s with some forms of hearing loss are better able to use their non-central vision (Daphne Bavelier et al., 2006; D. Bavelier et al., 2000).

The completed simulator is shown in Figure 1. The driver’s view from inside the completed simulator is shown in Figure 2.

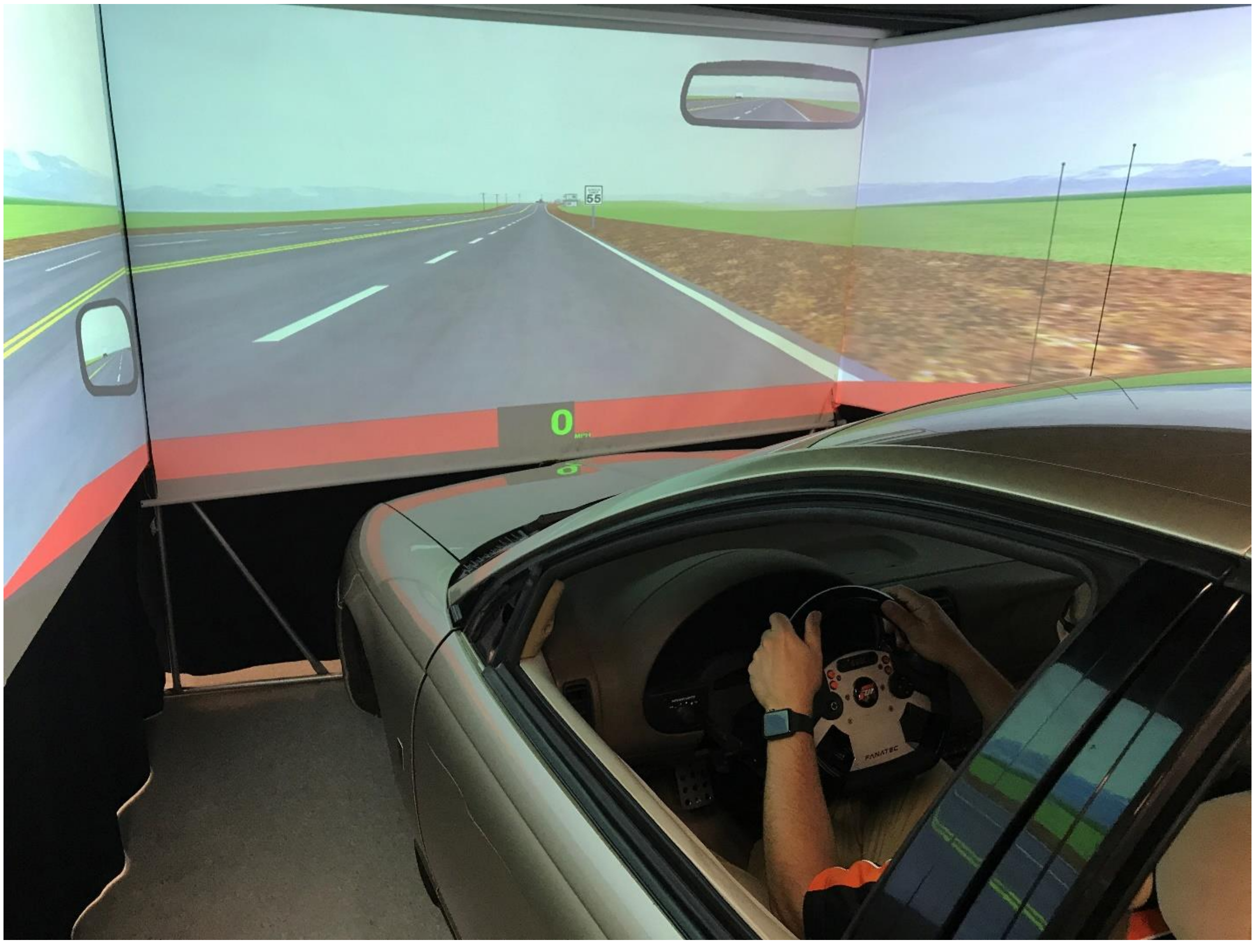

Figure 1 – Completed Low-Cost, Portable Driving Simulator for Subjects with Limited Auditory Perception

Figure 2 – Driver's view from inside the simulator

Pilot Verification Study

Experimental plans were submitted to an Institutional Review Board (IRB) for approval before any human subject testing began. The overall experimental plan is illustrated in Figure 1. Eleven experienced drivers ages 22 to 56 participated in the pilot study. There were five females and six males. The mean driving experience was 22 years and all but one subject owned his or her own car. All but one subject reported that they drove every day of the week. Eight of the subjects reported no hearing loss and three subjects reported a hearing loss of 70 dB or greater that occurred prior to their seventh birthday. Participants that self-identified as Deaf also reported that they used American Sign Language (ASL) as their primary form of communication. All subjects received a $15 gift certificate to a local grocery store.

Subjects were greeted by the principal investigator and were asked to complete a consent form. They were then fitting with a Positive Science eye-tracker. Subjects were shown the vehicle simulator and were guided into the driver's seat. All subjects were joined in the passenger seat by a lab assistant. The eye-trackers were then calibrated and used to collect gaze information while the participants drove. A previous study that investigated the correlation between driving behaviors and fixation patterns (Wang, Walders, Gordon, Pelz, & Farnand, 2018) demonstrated that the eye-tracker was able to supply useable eye-tracking data for the subjects.

The lab assistants educated the subjects regarding the driving simulator and the subjects drove a short practice course. A well-being survey was administered (Balk, Bertola, & Inman, 2013; Kennedy, Lane, Berbaum, & Lilienthal, 1993) to check for excessive simulator sickness. Fresh air was directed onto the faces of the subjects, through the vehicles fresh-air vents in order to minimize the possible onset of simulator sickness. None of the eleven subjects presented with any significant simulator sickness symptoms.

The first driving experiment had the subjects drive along a rural two-lane highway with multiple straight and curved sections. Drivers were instructed to keep their vehicle centered in their lane while maintaining the posted speed limit. Standard deviation of lane position and speed maintenance data was collected during the experiment. At the end of the first experiment, the subjects were again given the well-being survey (Balk et al., 2013; Kennedy et al., 1993). Again, none of the eleven subjects presented with any significant simulator sickness symptoms.

The second driving experiment had the subjects drive along a similar two-lane highway with multiple straight and curved sections. Drivers were again instructed to keep their vehicles centered in their lane and to maintain the posted speed limits. Additionally, drivers were told to answer a set of 42 yes/no questions (Barberettez & Barberettez, 2017) as quickly and accurately as they could. Drivers who identified Deaf were asked the question in ASL. The remaining drivers were asked the questions orally. Standard deviation of lane position and speed maintenance data was collected during the experiment.

After completing both driving experiments, the subjects were asked about their past driving record. Nearly all participants reported that they had been involved in at least one accident and half reported that they had been in a serious accident. A serious accident was defined as an incident involving at least $5000 in property damage and/or serious injury and/or death.

Finally, Useful Field of View (UFOV) testing (Ball & Owsley, 1993) was administered to all subjects. UFOV is used to assess both useful vision and cognition. Processing speed, divided attention and selected attention subtest were administered. The overall experimental plan is illustrated in Figure 3.

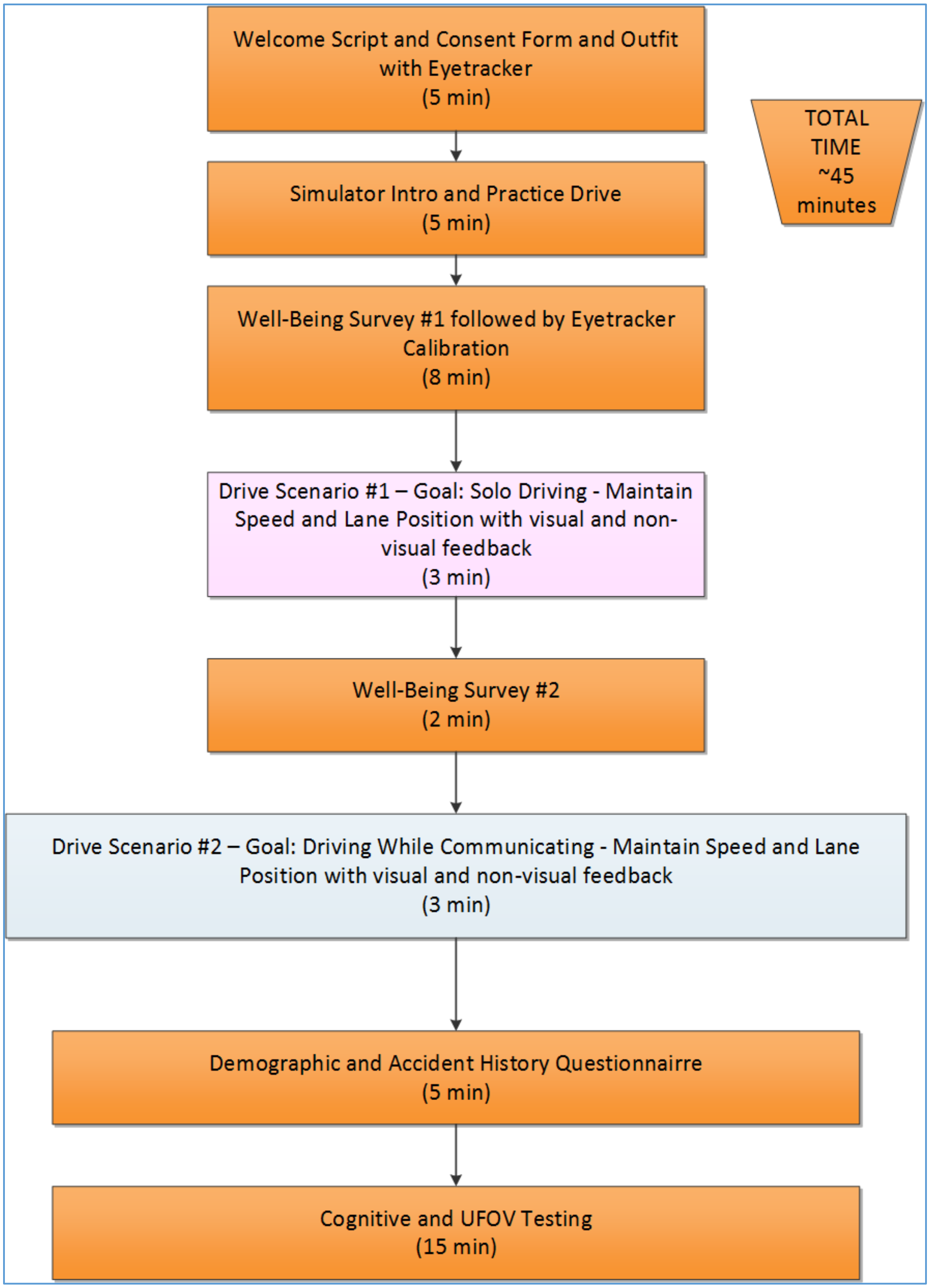

Figure 3 – Experimental Plan

RESULTS

A summary of the human subjects is provided in Table 1. The dataset of human subjects was too small to provide statistically significant results and is provided only as an aid for the initiation of future research. Nonetheless, a summary of the results obtained from human subject testing is provided in Table 2.

	Age	Count	Own Car?	Years Driving	# Days of Driving per week
ALL Mean	39.6	11	10	21.9	6.7
Hearing Mean	43.6	8	88%	26.6	6.8
Deaf Mean	29	3	100%	9.3	6.7

Table 1 – Summary of Human Subjects

	Corrective Lenses	Total Accidents	Serious Accidents	Accidents per year of driving	Accidents per year of driving	(no ques.) Speed Only	(w/ ques.) Speed Only	ODP #1 (no ques.) SDLP Only	ODP #2 (w/ ques.) SDLP Only	UFOV Processing Speed	UFOV Divided Attention	UFOV Selected Attention
ALL Mean	45%	1.1	0.5	0.067	0.036	12.13	11.25	2.78	2.65	15.5	18.0	53.6
Hearing Mean	37%	1.4	0.6	0.084	0.049	12.13	11.52	2.85	2.59	15.8	19.0	59.9
Deaf Mean	66%	0.3	0	0.022	0	12.11	10.18	2.51	2.90	14.9	15.4	36.8

Table 2 – Summary of Results from Human Subjects

ODP – Overall Driving Performance

SDLP – Standard Deviation of Lane Position

UFOV – Useful Field of View

Overall driving performance (ODP) was a manufactured measure of how well a subject was able to both maintain speed and maintain central lane position. Higher values of ODP indicate relatively better driving performance. ODP was created to satisfy Objective #2 - A performance instrument to measure the overall driving performance of deaf and hearing drivers using the previously described driving simulations.

CONCLUSIONS AND RECOMMENDATIONS

Given the controversy that this work caused with the Deaf community – even with members of the community participating as team members, demonstrates the extremely sensitive nature of this research. The Deaf community gained the right to drive rather recently and there continue to be restrictions and lawsuits involving heavy vehicle operation. One must be aware that this research is considered to be cross-cultural and therefore must have an advisory committee and other safeguards in place to protect the Deaf community. Ironically, it was notification of advisory committee members that alerted the National Association for the Deaf to the research and its subsequent protestation with the National Technical Institute for the Deaf on the Rochester Institute of Technology Campus.

On a more positive note, the simulator appeared to be able to provide a useful tool for future research involving deaf and hard of hearing drivers. The results obtained, while not statistically significant, proved that the simulator and the ODP could provide metrics useful in measuring driving performance.

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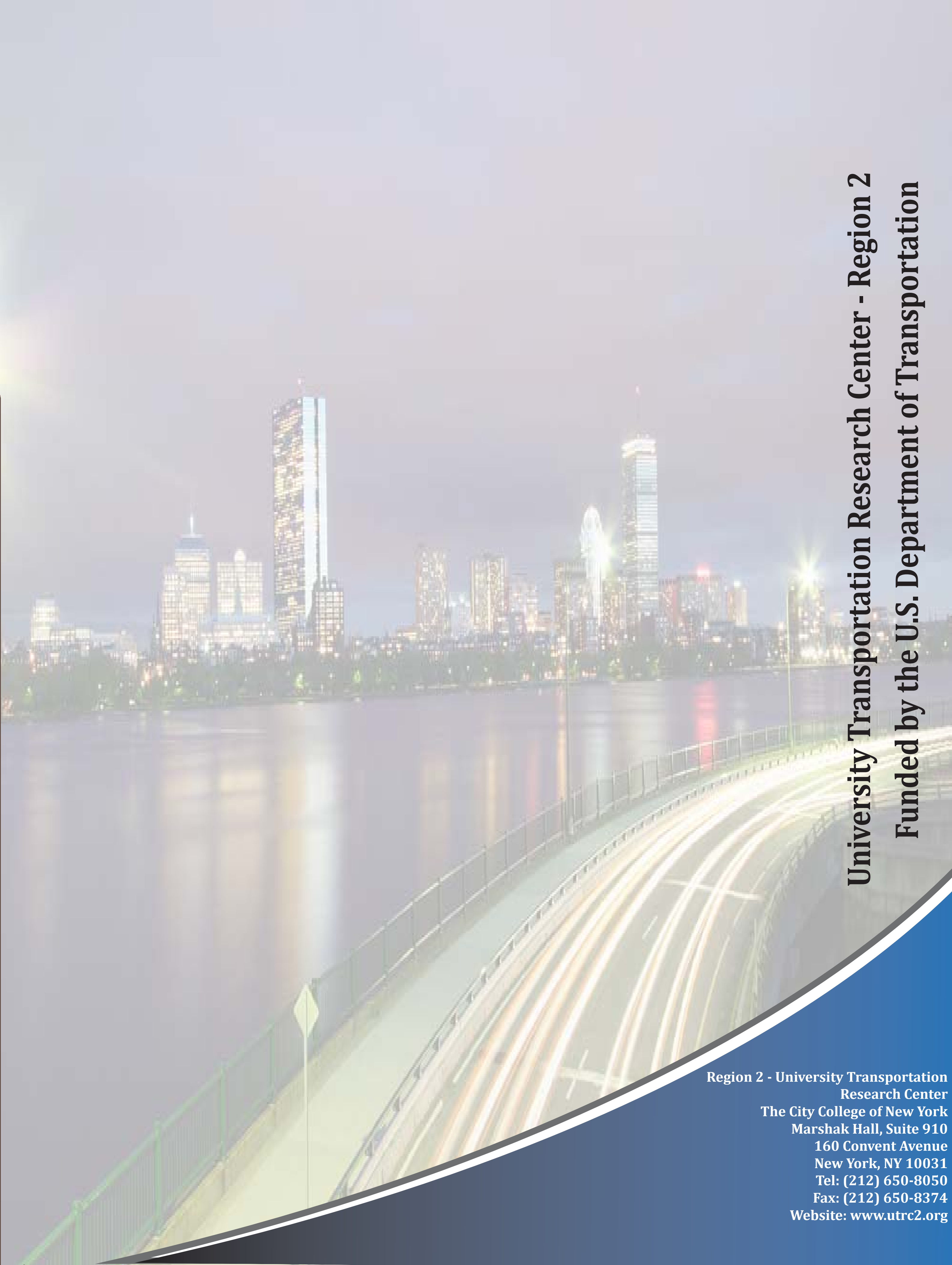

University Transportation Research Center - Region 2
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Region 2 - University Transportation Research Center
The City College of New York
Marshak Hall, Suite 910
160 Convent Avenue
New York, NY 10031
Tel: (212) 650-8050
Fax: (212) 650-8374
Website: www.utrc2.org