New Jersey Commission on Spinal Cord Research

Individual Research Grant

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Retraining Driving Skills after SCI: A VR Approach

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BODY OF REPORT

1. Original Aims of the Project

The primary aim of this project was to utilize virtual reality to develop a new driving simulator to help individuals with traumatic spinal cord injury (SCI) re-learn how to drive following their injury. This original goal was modified and approved by the New Jersey Commission in 2006. Specifically, the revised aims included two studies to pilot test the virtual reality simulator. Study 1 required individuals with traumatic SCI to complete both a simulator evaluation session and a session with the Kessler Institute for Rehabilitation Driving Evaluation program, as well as complete several traditional cognitive and neuropsychological tests. We examined concurrent validity by examining the relationship among driving simulator performance, the results of the cognitive evaluation, and behind the wheel driving performance (as determined by a certified driving instructor).

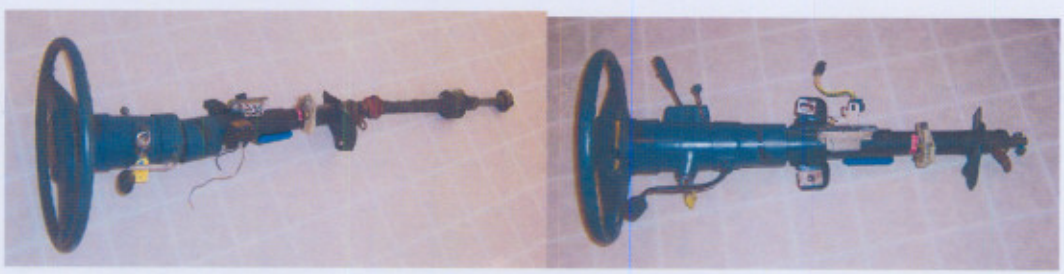
Study 2 was conducted to evaluate the potential for simulator sickness. Specifically, this study compared a traditional head mounted reality simulator display with a 3 panel (big screen) monitor simulator display. Participants were randomly assigned to the two groups and simulator sickness was evaluated and served as the dependent variable of the study.

2. Project Successes

This project has resulted in the development of a state of the art driving simulator with adaptive hand controls for use in the spinal cord injury population. Specifically, project successes include: A. hardware development; B. software development; C. Study 1 results; and D. Study 2 results.

A. Hardware Development: Traditional, commercially available hardware systems for virtual reality driving programs consist of a steering wheel and foot pedals. This type of system is not functional for most individuals with spinal cord injury. Therefore, this study designed a virtual reality simulator that incorporated hand controls for acceleration and deceleration, and adaptive equipment for steering (e.g. spinner knob, tri-pin). Research team members invested significant time and effort ensuring that the hardware set-up is an accurate representation of the adaptive equipment utilized by individuals with SCI.

Figure 1: At left, non-modified steering column. At right, modified steering column with hand controls



The modified steering column (see Figure 1) was attached to a specially designed table that could be optimized to accommodate differences in the height clearance for different models of wheelchairs. This hardware was been combined with three flat-panel display screens and a personal computer to create the simulator pictured below (See Figure 2).

Figure 2. Kessler Foundation Virtual Reality Driving Simulator Hardware

B. Software Development: Digital Media Works (DMW) was contracted to develop the software program for this project. Specifically, DMV designed four different driving zones (residential, school, commercial and highway) within a closed loop environment. Participants go through a fixed route within each of these four driving zones; they are given verbal directions to ensure that they stay on route (see Figure 3). Although each route that a participant completes is fixed, the program can be modified by the examiner to vary both the order of zone presentation and the difficulty level within each zone. Specifically, the program allows for changes in the number of static vehicles (e.g., cars parked in driveways or at the side of the road) or dynamic vehicles (the amount of traffic on the road), and includes 8 challenges (2 in each zone) that can be enabled (e.g., turned on or off) separately. Challenges include a ball that suddenly rolls out into the middle of a street with a child (who is about to follow the ball into the street) masked from view by a parked car (residential zone; see Figure 4) and a car that runs a red light and crosses in front of the participant's car (commercial zone). The combination of start zone selection and options for each zone (e.g. clutter, traffic, and challenges) results in the ability to develop unique simulations for either research or clinical purposes. The software collects information related to driving quality including speed, lane position, use of turn signals, and any adverse events (e.g. collisions, running off the road).

Finally, the program contains two training environments that are simplified versions of the four zones used in the closed loop environment. Specifically, these zones contain short stretches of roadway with grassy areas to the side; the exclude architectural elements or dynamic/static vehicles in these training zones. The training zones merely provide the user

Figure 3: At left, map of driving simulator zones. At right, detailed map of residential and school zones

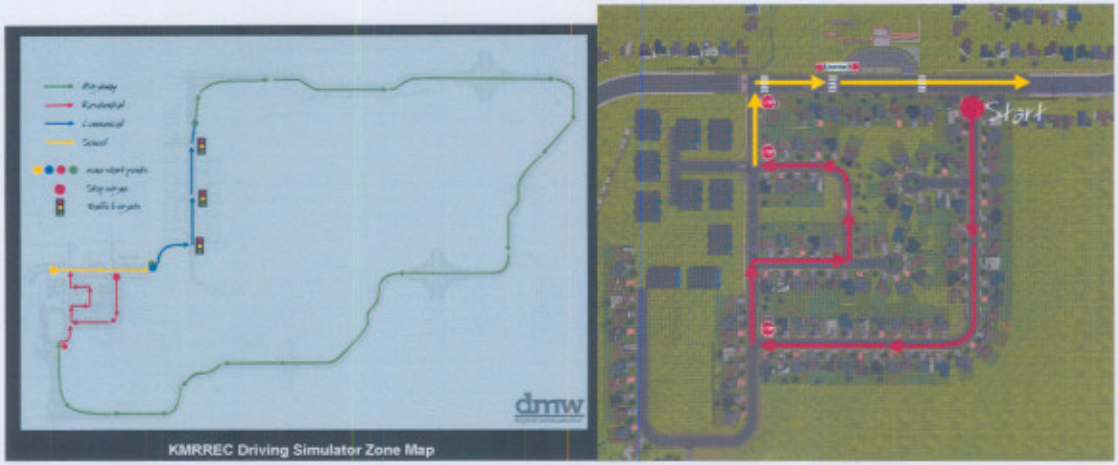


Figure 4: Screenshot of Residential Zone with no options

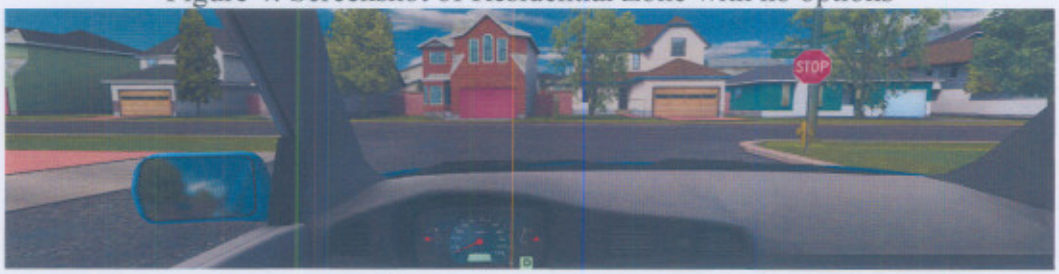


Figure 5: Screenshot of Residential Zone with clutter and challenge enabled (child chasing ball from behind car)

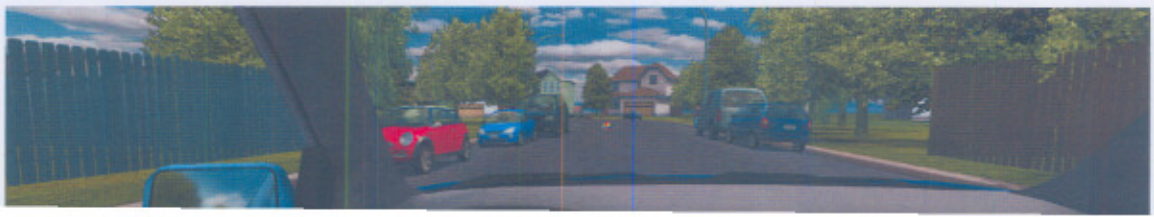
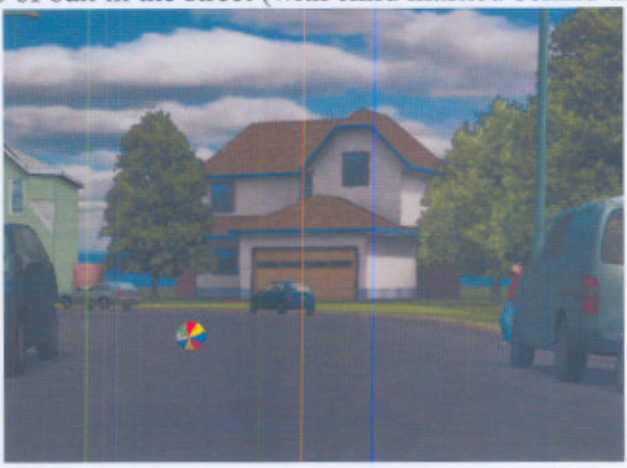


Figure 6: Close-up of ball in the street (with child masked behind the car on the right)



Summary of Hardware and Software Development. In 2006 and 2007, the hardware and software systems were evaluated in both individuals with SCI and healthy participants using several Alpha and Beta tests. Each permutation of zones and challenges were evaluated by at least 5 "test runs." Over 50 individuals participated in this testing and provided cognitive debriefing feedback to help improve our final product highlighting the complexity of both the hardware and the software for this study. The final product is a state-of-the-art software and program system that can be used either clinically or in research studies with individuals with SCI.

C. **Study 1 Results (comparing the results of the virtual reality (VR) simulation to "Behind the Wheel Testing")**. From 2007 through 2009, 30 individuals with were evaluated using the VR simulator, the Kessler "Behind the Wheel" evaluation with a certified driving instructor, and a series of neuropsychological tests. This study was completed as described in the protocol revision outlined in the progress report for this project submitted on May 6, 2006. Primary findings from this study indicate that individuals that have more VR collisions are more likely to fail the behind-the-wheel test, than those with fewer or no collisions. Further, participants who fail the behind-the-wheel test also tend to be more tentative in the VR environment (as evidenced by slower simulator speed), which perhaps reflects insecurity behind-the-wheel.

D. **Study 2 Results (evaluating the prevalence of simulator sickness in individuals with SCI using a headmounted versus a three panel display)**. From 2008 through 2010, 53 individuals with SCI were randomized to one of the two testing conditions (headmounted display or 3 screen display). Three individuals could not complete the study (because of severe simulator sickness). This study was completed as described in the protocol revision outlined in the progress report for this project submitted on May 6, 2006. Primary findings from this study suggest that participants were more likely to experience simulator sickness in the headmounted display condition than in the 3-screen display condition. Further, participants in the headmounted display condition had more collisions and scrapes than those

3. Project challenges.

Following a review of charts of individuals admitted to the KIR driving program during 2004 and 2005, we determined that there were not enough individuals with SCI that met the eligibility requirements of the study (as per the original proposal). Therefore, we revised our proposal to include Study 1 and Study 2 (summarized above) and received approval for this modification in May, 2006.
The development of the hardware and software products took much more time than anticipated (e.g., 3.5 years; see above for a detailed description of the Alpha and Beta testing process). These delays were compounded when the original PI of the study left the Kessler Foundation in 2005. Although these challenges slowed the progress of the study, we have completed the projects aims including the software and hardware development and Study 1 and Study 2 recruitment and analysis.

4. Implications for future research and/or clinical treatment.

Study 1 is one of the first studies to identify parameters in a virtual reality environment that may be predictive of behind-the-wheel driving performance in an SCI population. Specifically, the hardware and software that were developed for use in and SCI population might be used as a clinical tool to assist individuals with driving rehabilitation during their rehabilitation.

Study 2 demonstrates that there are differences in both test performance and simulator sickness using either a headmounted or 3-screen display. In general, findings suggest that performance is better and simulator sickness is less for the 3-screen condition rather than the headmounted display. This may be due to the fact that there are external cues present during the 3-screen display that allow the participant to "ground" his/herself during the testing session. The headmounted display tends to be associated with greater disorientation and simulator sickness, making it a less viable option for driving retraining in this population.

5. Plans to continue this research, including applications submitted to other sources for ongoing support.

The original PI of this study (Maria Schulteis, Ph.D.) has received funding from NCMRR to use a multidisciplinary approach to combine findings from the fields of Neuropsychology and Transportation to develop a VR driving simulator that generates measures that are both clinically relevant and empirically based.

6. **List and include a copy of all publications emerging from this research, including those in preparation.**

Seven presentations have been made at national meetings or locally. Two publications have been completed and 2 manuscripts are currently in progress for publication.

Presentation Given:

Meeting:	American Association of Spinal Cord Injury Psychologists & Social Workers (AASCIPSW) conference
Title:	"Evaluation of Driving Ability Following Spinal Cord Injury- Utility of a Virtual Reality Simulator"
Date:	August, 2008
Authors:	Tulsky, D., Smith, B., Gade, V., Schmidt, M., Komaroff. E., Edwards, T.

Meeting:	Rehabilitation Engineering and Assistive Technology Society of North America. Crystal City, VA.
Title:	"Driving Ability Following Spinal Cord Injury – Initial Comparison of VR Simulator to Behind-the-Wheel Performance"
Date:	July, 2008
Authors:	Gade, V., Smith, B., Moholkar, N., Komaroff, E., Edwards, T., & Tulsky, D. S.

Meeting:	United Spinal Association's Spinal Cord Disability Awareness Day
Title:	"Retraining Driving Skills after SCI: A VR Approach"
Date:	May 30, 2006
Authors:	Schmitt, M., Tulsky, D.S., Schultheis, M, Simone, L., Callahan, L, & Nead, R.

Meeting:	American Association of Spinal Cord Injury Psychologists and Social Workers
Title:	"Retraining Driving Skills after SCI: A VR Approach"
Date:	September 6-8, 2005, Los Vegas, NV
Authors:	Tulsky, D., Schultheis, M., Simone, L.K., Callahan, L., & Need, R.

Meeting:	Rehabilitation Engineering & Assistive Technology Society of North America
Title:	"Development of a Portable Virtual Reality Driving Interface to Retrain Drivers with Spinal Cord Injury"
Date:	June 25-27, 2005; Atlanta, Georgia
Authors:	Simone, L.K., Simone, J.A., Mitura, R., Klimchuk, D., & Schultheis, M.

Meeting:	Annual Meeting of the NJ Commission on SCI Research
Title:	"Retraining Driving Skills after SCI: A VR Approach"
Date:	October 10, 2004
Presenter:	Schultheis, M.

Meeting:	Consumer Spinal Cord Injury Advisory Board
Title:	"Retraining Driving Skills after SCI: A VR Approach"
Date:	September, 21, 2004
Authors:	Schultheis, M., Simone, L.K., Tulsky, D., Callahan, L.

Publications:

Virtual Driving Lessons. Virtual Reality Meets the Road in Kessler Research Project. Orbit: A publication of United Spinal Association, August, 2005.

Retraining Driving Following SCI. Connections, Summer, 2006.

Manuscripts in progress:

Tulsky, D. S., Carlozzi, N. E., & Gade, V. Driving Ability Following Spinal Cord Injury: A comparison of virtual reality simulator performance and behind-the-wheel performance. Manuscript in progress.

Carlozzi, N. E., Tulsky, D. S., & Gade, V. Understanding virtual reality simulator performance in spinal cord injury: Headmounted versus 3-screen display. Manuscript in progress.