PROMOTING SAFE TRANSPORTATION AMONG OLDER DRIVERS: RISK ASSESSMENT VIA DRIVING SIMULATOR TECHNOLOGY

FINAL REPORT

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16. Abstract

Driving simulator technology has potential to safely assess older driver risk. However, to date, there are no standardized, validated simulator scenarios with reliable metrics to assess older driver fitness. The primary objective of this study was to validate driving simulator scenarios. Sixty older adults were screened for inclusion in the study. Roughly 1/3 of the participants either experienced motion sickness or refused to complete the simulated drive. Those who did not experience simulator sickness (n=38) completed a driving simulator assessment (with a National Advanced Driving Simulator MiniSim™) and an on-road evaluation. These participants also completed a thorough clinical assessment of physical, visual, and cognitive performance to evaluate fitness to drive by an occupational therapist. Older drivers' simulator performance was compared to in-clinic assessments and on-road performance, but no significant associations were found. Neither were errors during the simulated drive correlated with in-clinic assessments. Although simulators have face validity, there are not strong associations with older adults' performance. The lack of associations with on road performance in this study may be due to the small sample who all performed safely during the on-road assessment. Scientists are working to derive more sensitive metrics of driving simulator performance indicative of older driver risk.

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EXECUTIVE SUMMARY

Valid methods of identifying older drivers at increased risk for crash involvement are needed to promote safe transportation. Driving simulators are an innovative technological advance with potential to safely assess older driver risk. However, to date, there are no standardized, validated driving simulator scenarios with reliable metrics to assess older driver fitness. Simulation provides a potentially ideal mechanism to gain understanding of driver performance and behavior that is otherwise infeasible, too costly, or unsafe in the real world. With consistency of the simulator and scenarios, comparisons could be made across participants, facilities, and time. However, in order to implement driving simulator assessment in clinical practice, evidence-based assessment protocols are needed. We must first demonstrate that driving simulator performance is a valid indicator of older adults' actual on-road driving performance and safety (as indicated by crash rates and citations). Then, validated assessment scenarios with performance metrics can be implemented to assess driver fitness. However, such validated scenarios with performance metrics are needed for each simulator platform. The primary objective of this study was to validate driving simulator scenarios for older driver assessment using the National Advanced Driving Simulator MiniSim. Older drivers' simulator performance was compared to in-clinic assessments and on-road performance in an attempt to validate a simulated driving scenario for assessment purposes. Sixty older adults were screened for participation. Of the 57 participants who were eligible to participate, 14 (25%) experienced simulator sickness and were unable to complete the study. Four (7%) refused further due to complaints about the simulator. Thus, 31% of the participants were unable to use the simulator for health or personal preference reasons. The total number of errors and critical driving errors during the simulated drive were recorded. Licensed occupational therapists performed in-clinic and on-road evaluations of the study participants using previously validated techniques. Thirty-eight participants completed the clinical assessments, and five were identified as potentially at-risk for adverse driving events due to cognitive performance. Participants further completed an on-road evaluation, but very little variability in performance during the drive was observed. There were no significant associations between driving simulator performance with clinical assessments or on-road evaluations. With regard to the on-road evaluation, this lack of association was due to little variability in the sample. All of the participants were deemed fit to drive except one, and the participants made no critical errors during the on-road drive. In this small study among older drivers without dementia, no associations of simulated driving errors to other validated performance-based assessments of driver fitness were found. The number of driving simulator errors is not a sensitive indicator of performance. Thus, the driving simulator developers plan to further analyze the simulator data to develop impairment detection algorithms. Once these algorithms are derived, we will further examine the driving simulator metrics to on-road driving and safety (i.e., state driving citations and crash involvement). The end goal is to derive reliable metrics of driving simulator performance indicative of older drivers' performance. Much work is still needed toward validating driving simulators for valid clinical assessment of older drivers.

DESCRIPTION OF PROBLEM

Older adults are the fastest growing segment of the population with projections estimating that nearly 20%, or 71.5 million, of the U.S. population will be 65 years of age or older by 2030 (Federal Interagency Forum on Aging-related Statistics, 2004). About one in seven licensed drivers in the U.S. is aged 65 years or older; by 2030 this number will be one in five (Sivak et al., 1995). Overall, rates of motor vehicle crash involvement for U.S. drivers 70 years of age and older have increased 33% since 1975 (Insurance Institute for Highway Safety, 2006). In the U.S., motor vehicle crash deaths per capita increase substantially for males at 75-79 years of age and among females at 60-64 years, with continued increases until 80-84 years of age (Insurance Institute for Highway Safety, 2006). While older drivers may be more susceptible to injuries and fatalities from crashes because of increased fragility (Li, Braver, & Chen, 2003; Meuleners, Harding, Lee, & Legge, 2006; Zhang, Lindsay, Clarke, Robbins, & Mao, 2000), they are also more likely to be determined at-fault when involved in accidents due to age-related changes in driver capacities (McGwin & Brown, 1999). Lyman and colleagues(2002) project that as the U.S. population of older drivers grows, there will be a 178% increase in crashes and a 155% increase in fatal crashes by the year 2030. These trends raise a number of important safety, well-being, and independence concerns for both older adults in particular and society as a whole.

Valid methods of identifying older drivers at increased risk for crash involvement are needed to promote safe transportation. However, existing assessment tools lack adequate sensitivity and specificity (Bedard, Weaver, Darzin, & Porter, 2008; McCarthy & Mann, 2006). On road driving evaluations are often infeasible, too costly, and unsafe in the real world. Driving simulators are an innovative technological advance with potential to safely assess older driver risk. However, there are critical barriers to progress in this field. To date, there are no standardized, validated driving simulator scenarios with reliable metrics to assess older driver fitness. We conducted a systematic literature review on driving simulator assessment among older adults. Results yielded 43 published peer-reviewed journal articles. The majority of published studies merely compared the simulated driving performance of younger and older adults, or correlated sensory/cognitive assessments to simulated driving performance. Only four were validation studies comparing simulated driving performance to *either* on-road driving *or* crash involvement. Three of which had very small samples.

The proposed study built upon work by scientists at the University of Iowa National Driving Simulator to validate the IMPACT driving simulator scenarios for use with the MiniSim™ platform for the purpose of determining older drivers' fitness. No validation studies among older drivers have been completed with this platform, and no previous studies have validated simulator scenario metrics with both on-road and state driving records. The goal of this ongoing work is to produce an end product of validated driving simulator scenarios with reliable metrics for assessing older driver risk. The resulting tools could potentially be adopted by scientists and clinicians to determine older drivers' risk and promote safe driving mobility.

APPROACH AND METHODOLOGY

Research Approach

Participants. Sixty older adult licensed drivers were recruited to participate in the study between September 2014 to May 2015. Inclusion criteria were 55 years of age or older, native English speakers, current licensed driver, and a Montreal Cognitive Assessment (MOCA) score of 20 or higher to exclude probable dementia. Exclusion criteria were stroke, head injury, or prone to motion sickness. After providing informed consent, participants' cognitive status was screened with the MOCA. Three participants were deemed ineligible due to low MOCA scores. Demographic information on age, sex, race, and education was collected. Participants were asked to report if they had "any difficulties with memory" to gauge subjective memory complaints. The eligible 57 participants ranged in age from 65-87 years. These participants included 66% females and most were Caucasian Americans (94%). Education ranged from 12-20 years.

Driving Simulator Assessment. The 57 participants attempted to complete a practice drive in the National Advanced Driving Simulator MiniSim™. Fourteen participants (25%) experienced simulator sickness and were excluded from further testing. Three months into the study we consulted with experts in the field to troubleshoot our high rates of simulator sickness. Although techniques to minimize potential simulator sickness were used (e.g., use of a fan, peppermints, cool room temperatures), we continued to observe higher rates of simulator sickness than expected. Those who completed the practice simulator drive without motion sickness (n=43) further completed the IMPACT driving scenario. The participants' simulated driving performance was assessed by a Research Assistant using the Florida Motor Vehicles Administration on-road evaluation checklist. A licensed Occupational Therapist (OT) experienced performing on-road evaluations for the state trained the Research Assistant on how to code the checklist, which quantifies the number of critical errors as well as the total number of errors.

The MiniSim™ is based on state-of-the-art driving simulation technology developed through decades of research at the National Advanced Driving Simulator and The University of Iowa. Simulation provides a potentially ideal mechanism to gain understanding of driver performance and behavior that is otherwise infeasible, too costly, or unsafe in the real world. With consistency of the simulator and scenarios, comparisons can be made across participants, facilities, and time. This study builds upon work by scientists at the University of Iowa who have explored these driving simulator scenarios among small pilot samples of older drivers and developed impairment detection algorithms. However, older drivers' performance has not yet been validated with on-road driving safety measures. Each scenario consists of critical events, has urban, rural and interstate settings, and lasts about 25 minutes.

Of the 43 participants who did not experience simulator sickness and were enrolled in the study, five (11%) refused further participation after the simulator visit. One cited lack of reimbursement for travel costs to participate as the reason. The other four participants declined further participation due to complaints about use of the driving simulator (that were not related to simulator sickness).

Exploratory Measures. After the simulated drive, participants completed several exploratory measures that we hypothesized may be related to driving performance. This included a hearing assessment to determine pure tone thresholds at 500, 1000, 2000, 4000 and 6000 Hz. Participants also completed the Spatial Navigation Test. This test is a computerized version of the human analogue of the Morris Water Maze. The task is to identify correctly the position of a target (red dot) that is visible briefly before each trial begins. This neuropsychological test captures navigational ability along two main dimensions—allocentric (world-centered and independent of the individual's actual position) and egocentric (body-centered and dependent of the individual's position and the start location). Performance is measured as the distance between the actual and indicated position of the target. Finally, at this visit, subsets of participants completed the questionnaire on everyday navigational ability (QuENA)(Pai et al., 2012). The questionnaire assesses four potential underlying causes of getting lost: landmark and scene agnosia, egocentric disorientation, heading disorientation, and inattention. These pilot data were collected with goal of bolstering our future research on older drivers and to inform grant proposals. We plan to apply this data to obtain funding for two subsequent projects: 1). to examine the association of hearing and driving and 2) to examine predictors of getting lost while driving.

Clinical Assessment. At a second visit, the remaining 38 participants completed a clinical assessment of physical, visual, and cognitive performance by a licensed OT who practices in a driving assessment clinic. According to Fuller's model (2005), driver capability is a function of physical performance, flexibility, and motor coordination; sensory and cognitive capacity; as well as knowledge and skill due to training and experience. While most older drivers have a great deal of knowledge for and experience with driving, their capacity is likely to be impacted by age-related changes in physical performance, vision, and cognition. Accordingly, research has indicated that these abilities, which decline with age, are related to driving performance (e.g., Hu, Trumble, Foley, Eberhard, & Wallace, 1998; Marottoli, Cooney, Wagner, Doucetter, & Tinetti, 1994; Marottoli et al., 1998; Owsley et al., 1998). Thus, the clinic assessment consisted of physical, sensory, and cognitive exams, and an interview of the participant's driving habits.

*Physical Assessment***.** During the physical exam, the participant completed a series of clinical evaluations to assess range of motion, coordination, and gross motor functioning of upper and lower extremities and trunk. Range of motion of cervical region and sensation in hands and feet are also assessed. Strength testing via the Manual Muscle Test of upper and lower extremities is completed. This technique was developed by physical therapists and is a reliable and valid assessment of muscle and nervous system function (Monti, Sinnott, Kunkel, & Greeson, 1999; Motkya & Yanuck, 1999).

*Visual Assessment***.** Participants' vision was tested with use of the Optec 5000P Vision Tester. Binocular and monocular vision was assessed including indices of near and far visual acuity, depth perception, and color perception. Peripheral visual sensitivity was evaluated at 85, 70, and 55 inches temporally and 45 inches nasally. Contrast Sensitivity, which is predictive of driving outcomes (Owsley, Stalvey, Wells, & Sloane, 1999), was tested via the Pelli-Robson Chart.

Cognitive Assessment. Cognitive performance is likely the strongest predictor of older drivers' risk (Ball et al., 2006). Ball and colleagues found that older drivers with poor cognitive function as measured by the Useful Field of View Test (UFOV®), Motor-Free Visual Perception Test (MVPT), or Trails B were more than twice as likely to be involved in an at-fault crash over the subsequent six years (Ball et al., 2006). Similarly, Classen et al.

found that UFOV® and Trails B were indicative of on-road driving performance among older adults (Classen, Wang, Crizzle, Winter, & Lanford, 2013). Thus, during the cognitive exam, the participant completed UFOV®, MVPT, and Trails.

UFOV® (Clay et al., 2009; Edwards et al., 2005). This test measures speed of processing for visual attention tasks across three increasingly difficult subtests. In all subtests, display times are manipulated between 16 and 500 *ms* until the 75% correct threshold is determined. This test is a valid and reliable indicator of older driver safety. *MVPT* (Ball et al., 2006). In this assessment the participant is shown a target figure (geometric drawing) and four partial figures. The participant is asked to identify which of the incomplete figures, if completed, would result in the target figure. The number correct is recorded. *Trails* (Ball et al., 2006; Classen et al., 2013). In Trails A the participant is presented with the numbers 1 to 25 arranged in random order and is required to connect the numbers in sequential order. Trails B is similar to Trails A except that the targets include both numbers and letters. The participant is required to connect the numbers and letters in alternating sequence (1, A, 2, B,…). Time to completion and errors are measured for both.

Driving Behaviors. The *Driving Habits Questionnaire* assesses driving patterns and difficulty. The questionnaire was developed by Owsley and colleagues (1999) and has good test-retest reliability and construct validity. This questionnaire provides useful information regarding driving exposure (measured by miles per week, days per week, and annual mileage) and avoidance. These data have been key for predicting older drivers' crash involvement by providing insight into mobility changes with age. In addition to this questionnaire, state driving records for each participant (which are public record) will be obtained. Crash involvement and citations will be derived from these state records.

On-Road Driving Performance. Previously validated methods (Wood, Lacherez, & Anstey, 2012) of quantifying on-road driving performance were used by the OT to assess on-road performance. Like the simulation scenarios, the on-road exam included urban, rural, and interstate areas. The Florida Motor Vehicles Association on-road checklist was completed. The total number of errors, and the number of critical errors were recorded according to the checklist that was also used in the driving simulator assessment. Performance was categorized on three levels: fit to drive, fit to drive with restrictions, or unfit to drive (Devos, Nieuwboer, Tant, De Weerdt, & Vandenberghe, 2012). Thirty five of the participants completed the on-road driving assessment. Two participants cancelled and were not able to reschedule their assessments before the end of the study period.

Data Analyses. A priori power analyses indicated that a sample size of 50 would be sufficient to detect small to medium effect sizes with 80% power. Our sample was below this target and is thus underpowered to detect anything but large effect sizes.

As planned, the relationship of driving simulator performance to clinical assessments and on-road driving performance was quantified using correlational analyses and regression techniques. Future work will also examine these associations with state-recorded crash and citation records.

According to our memorandum of understanding, the University of Iowa National Advanced Driving Simulator team plans to analyze the simulator data to develop impairment detection algorithms. Common as well as scenario-specific measures may be derived. Common performance measures from scenarios include average speed, deviation of speed, and lane position. Scenario specific performance metrics include gap acceptance, yielding right of way, intersection navigation, left-hand turns, merging onto expressways, lane changing, and reaction to critical events. To give a detailed example, the urban scenario events contain a number of potential hazards in the form of pedestrians and vehicles whose behavior require participants to react to a hazard for collision avoidance. Each of the driving simulator scenarios contains equal numbers of each hazard type. We will work collaboratively with the National Advanced Driving Simulator team to derive and validate metrics of performance that are indicative of older drivers' on road performance, crash involvement, and citation records. The predictive validity of simulator performance metrics to on-road performance as well as crash and citation records will be assessed using logistic regression for categorical outcomes and linear regression for continuously-scaled outcomes.

FINDINGS; CONCLUSIONS; RECOMMENDATIONS

Results

Planned analyses. Characteristics of the 38 study participants who completed the clinical assessments are reported in Table 1. Although our goal was to recruit half of the study participants from the driving assessment clinic, patient flow was not sufficient during the one-year study time frame to accomplish this goal. The vast majority of patients assessed in the clinic during the study period had a dementia diagnosis or had experienced a stroke and were thus ineligible for participation. Future efforts should consider including such individuals in studies of simulator validation. Our participants were primarily recruited from the community, and tended to be highly educated. Eleven percent of the sample scored within the probable mild cognitive impairment range according to the Montreal Cognitive Assessment (scores of 20-26). Five of the participants scored 150 ms or higher on task two of the UFOV, indicating risk for crash involvement. Only one participant scored at 120 seconds or higher on Trails B, indicating risk for crash involvement. Demographics are reported in Table 1.

Table 1. *Demographics and outcomes across participants who completed the clinical assessments*

Measures	*M* (*n*)	*SD* (%)
Demographics		
Age (years)	73.95	5.76
Sex (female)	(37)	(66.10)
Race (Caucasian Americans)	(53)	(94.60)
Education level		
High School degree	(4)	(7.10)
College degree	(17)	(30.4)
Reported subjective memory complaints	(26)	(46.4)
Clinical Assessments		
Montreal Cognitive Assessment (score out of 30)	25.34	2.67
Pure-tone hearing threshold average (dB)	33.46	11.87
Useful Field of View Test (ms)	236.65	149.35
Trail Making Test Part B (s)	157.38	69.31
Motor Free Visual Perception Test (errors out of 16)	1.13	1.04
Timed Up and Go Test (s)	9.07	1.51
Simulator drive		
Total number of errors	6.32	3.26
Number of critical driving errors	0.71	1.10
On-road drive		
Total number of errors	0.31	0.53
Number of critical driving errors	0.00	0.00
Overall outcome rating (fit to drive)	(34)	(97.10)

Driving simulator performance was quantified by number of critical errors as well as total number of errors on the drive. Spearman correlations were performed to examine the association among clinical assessments, errors during the on-road driving assessment, and driving simulator performance, as indicated by critical and total number errors. Results are reported in Table 2.

Performance of the participants in the on-road evaluation lacked variability: 45% of the participants made no errors during the drive. Nine participants made one error, and only one participant made two errors. The OT assessment outcome of the on-road driving evaluation was "fit to drive" for 34 of the 35 participants who completed the evaluation. Thus, none failed the on-road drive. This hampers the ability to examine associations of simulator and on-road driving in this sample. Future work could include more impaired drivers, such as those with dementia, to obtain more variability and assess driving simulator performance.

Table 2. *Magnitude of associations of driving simulator performance with clinical assessments and on-road driving performance*

Variable	Driving Simulator Critical Errors	Driving Simulator Total Errors
Montreal Cognitive Assessment (score)	-.079	.024
Motor Free Visual Perception Test (errors)	.109	-.128
Pure tone hearing average threshold (dB)	.043	-.105
Trails A (s)	.194	.168
Trails B (s)	.173	.142
Timed Up and Go Test (s)	-.147	-.242
Useful Field of View Test (ms)	-.183	.133
Age (years)	.178	.080
On road drive (total number of errors)	-.002	-.010

Note. Correlations with number of critical on road driving errors could not be computed as no errors were recorded. All $ps > .05$.

Logistic regression analyses were performed as planned to examine whether or not simulated drivng predicted the number on road driving performance errors. Neither the number of critical errors or total number of errors were significant predictors of on-road driving performance ($ps > .50$).

Exploratory Analyses

We examined the associations of Spatial Navigation Test performance with the clinical, driving simulator, and on-road assessments. To our knowledge, this is the first study to examine driving outcomes in relation to this assessment, which is sensitive to mild cognitive impairment and longitudinally predicts cognitive decline including dementia (Laczo et al., 2012; Laczo et al., 2009). A significant relationship between allocentric spatial navigation (world-centered and independent of the individual's actual position) and the Motor-Free Visual Perception Test (a known predictor of crashes) was found, $r(24)=.484$, $p=.017$.

Interestingly, the number of driving simulator errors showed a potential relationship with allocentric Spatial Navigation performance, $r(25)=.360$, $p=.065$. We further examined whether the spatial navigation test performance was associated with self-reported navigational abilities as indicated by the QUENA. Of the four QUENA composites (landmark and scene agnosia, egocentric disorientation, heading disorientation, and inattention) only self-reports of getting lost due to inattention were associated with the allocentric and delayed Spatial Navigation performance, $r(25)=-.38$ to $-.52$, $ps < .05$. These exploratory data analyses revealed an interesting and novel finding that performance on the Spatial Navigation Test, a human variant of the Morris Water Maze task, is significantly associated with both cognitive tasks known to predict crashes and driving simulator performance. This finding will be further explored in our future research.

While supported by this grant, the Principal Investigator further explored the association of hearing to indicators of driving performance. Hearing showed significant associations with UFOV performance. This relationship was further explored in a larger data set. Results showed that individuals with moderate or greater hearing impairment performed poorly on the UFOV, indicating increased risk for adverse driving events ($p<.001$). No significant differences were found among older adults with varying levels of hearing impairment for driving mobility ($ps>.05$), including driving cessation rates ($p=.38$), across a three-year time period when adjusted for age, sex, race, hypertension, and stroke. Implications are that although older adults with hearing impairment demonstrated increased driving risk, they were not more likely to modify their driving or cease driving or over time. Our future work will further explore this issue to optimize efforts to improve driving safety and mobility among older adults

Conclusions

In a sample of older adult drivers without dementia, we were not able to show evidence that errors made during a simulated drive were related to other previously-validated, performance-based metrics of older driver fitness. Although there was not a significant association in this study, it is possible that a relationship may exist among more impaired older drivers such as those with stroke or dementia. Future research should examine this. More sensitive metrics of simulated driving performance can be derived from the obtained data. Ongoing work will analyze these data to examine if other indices of simulated driving performance are valid for older driver assessment. Also, it is important to note that driving simulator performance could longitudinally predict driving, despite the lack of strong cross-sectional associations. A problem that plagues older driver research is that much of the validation work for assessments requires longitudinal study. Crashes and citations are rare events. Thus, long periods of time are needed to examine crash and citation rates relative to risk assessments.

These exploratory data analyses revealed an interesting and novel finding that performance on the Spatial Navigation Test, a human variant of the Morris Water Maze task, is significantly associated with both cognitive tasks known to predict crashes and driving simulator performance. This finding will be further explored in our future research.

Recommendations

A larger and more diverse sample is needed to determine whether the driving simulator scenarios may potentially be valid for older driver assessment. Given the 25% rate of simulator sickness observed, in order to achieve an enrolled sample size of 50, an additional twenty-five participants should complete the study battery. Efforts at including more impaired samples of older adults are needed to examine cross-sectional associations with on-road performance. Alternatively, longitudinal follow up across three to five years may reveal that simulated performance is associated with driving safety among older adults without dementia.

Driving simulators are an innovative technological advance with potential to safely assess older driver risk. However, to date, there are no standardized, validated driving simulator scenarios with reliable metrics to assess older driver fitness. Before driving simulation may effectively be used in an evidence-based practice, we must standardize assessments. Simulation provides a potentially ideal mechanism to gain understanding of driver performance and behavior that is otherwise infeasible, too costly, or unsafe in the real world. However, every driving simulator platform is different, and very few driving simulators have scenarios developed and validated for older driver assessment. Only with consistency of the simulator and scenarios, can comparisons be made across participants, facilities, and time. In order to implement driving simulator assessment in clinical practice, evidence-based assessment protocols are needed. We must first demonstrate that driving simulator performance is a valid indicator of older adults' actual on-road driving performance and safety (as indicated by crash rates and citations). Then, validated assessment scenarios with performance metrics can be implemented to assess driver fitness. However, such validated scenarios with performance metrics are needed for each simulator platform.

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APPENDIX

Publications, presentations, posters resulting from this project:

Edwards, J.D., Lister, J.J., Lin, F.R., Andel, R., Brown, L.M., & Wood, J. (in press). Association of hearing impairment and subsequent driving mobility in older adults. *The Gerontologist.*