The Validity of Driving Simulator to Measure On-Road Driving Performance of Older Drivers

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Abstract

Objective: *to validate a laboratory-based driving simulator in measuring on-road driving performance.* ***Method:*** *129 community dwelling older adult drivers were assessed with both the simulator and an on-road tests. The driving performance of the participants was gauged by appropriate and reliable age-specific assessment criteria, which were found to be negatively correlated with age. Using principal component analysis, two performance indices were developed from the criteria to represent the overall performance in simulated driving and the on-road assessment.* ***Results:*** *there was significant positive association between the two indices, with the simulated driving performance index explaining over two-third of the variability of the on-road driving performance index, after adjustment for age and gender of the drivers (R^2 = 0.66).* ***Conclusion:*** *the results supported the validity of the driving simulator and it is a safer and more economical method than the on-road testing to assess the driving performance of older adult drivers.*

Key words: driving assessment; older adult drivers; road safety; diving simulator

INTRODUCTION

Currently about twenty percent of the population in developed nations are aged 60 or older; but one out of three persons will exceed 60 years of age by 2050 (United Nations, 1999). This longer life expectancy suggests that the proportion of older drivers will increase to an even greater extent because there are more young drivers now than two to three decades ago (Waller, 1991).

In Australia, driving has become a symbol of freedom and independence. Losing the driving license may limit older driver's perceived roles in relation to family and fulfilling obligations and expectations from their positions (Crane, 1996; Cobb). Although older drivers have a higher crash involvement on a per vehicle distance travelled basis compared with younger age groups, the majority of older persons can drive safely (Coughin, 1998; Evans, 2000). Some studies of healthy older drivers have demonstrated that they commit fewer errors on standardised road tests than younger drivers (Carr et.al., 1994). However, it has been established that driving ability gradually deteriorates with age (Evans, 1993), prompting concerns on appropriate methods to evaluate the driving ability of the aging population (Reuben, 1993).

Studies have shown that older drivers may be disadvantaged during driving assessments because of their chronological age or their medical conditions (Wiseman & Souder, 1996). Existing licensing procedures for older drivers typically contain certain elements that will screen "age" related deficits. In particular,

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the assessment criteria have a high percentage of psychometric measures requiring good visual acuity and quick reaction time to perform successfully. However, such psychometric measures fail to reflect the actual functional ability of older drivers (Summala, 1988; Carr, Jaskson, Madden, & Cohen, 1994).

Conventional road tests to screen older drivers are not only costly, but also stressful and impractical for routine testing (Waller, 1991; Carr et al., 1994; Carr, 2000). An understanding of the factors that influence older driver's risk of vehicle crashes is important. Nevertheless, epidemiologic studies investigating crashes of older drivers are inconsistent and rather limited in scale (Ray, 1997). The challenge now is to develop appropriate evaluation methods to identify those older drivers at high risk of crash and to provide intervention as early as possible (Foley & Mithell, 1997).

Rapidly evolving electronic and computer technology have made available relatively low-cost, laboratory-based driving simulators (Janke & Eberhand, 1998). It is a safe and economical means of testing driving performance. The driving simulator also allows testing of the driver's unsafe and risky driving behaviour, which can have potentially dangerous consequences (Allen, Rosenthal, & Hogue, 1990; Carsten, Groeger, Blana, & Jamson, 1997). Many studies have concluded that driving simulators can provide accurate observations on drivers' behaviours and functions (Alicandri, 1994; Fraser, Hawken, & Warnes, 1994; Van der Winsum, 1996; Desmond & Matthews, 1997; Ellingrod et al., 1997; Van der Winsum & Brouwer, 1997). Simulators have recently been used to study the driving behaviour of Alzheimer patients (Rizzo, McGehee, Dawson, & Anderson, 2001).

To the best of the author's knowledge, previous studies on older adult drivers have never compared simulated driving performance with actual on-road driving performance. The purpose of this study is to validate a driving simulator using an on-road driving test of a set route.

METHODS

Participants and procedure

A pilot study of twenty participants was conducted to pre-test the assessment procedure. One hundred and twenty nine community-dwelling older adult drivers, aged 60-90, with valid driving license and not having incurred five or more demerit points in the past two years, volunteered to take part in the study. Assessment of each individual took approximately 2.5 hours, which included orientation, a 45-minute simulated driving session, 40 minutes of on-road testing, and a post-assessment questionnaire survey. Participants were reimbursed $10 towards fuel cost and debriefed at the completion of the assessment. Recruitment was accomplished with the assistance of the *Royal Automobile Club of Western Australia* and *Council on the Aging*, and through advertisements in various community-based organisations.

The STISIM Driving Simulator (Allen et al., 1990), shown in Figure 1, was used to study the behaviour of the participants in a simulated driving environment. A laboratory assistant implemented the simulated driving experiment

and followed a set of assessment guidelines designed by the investigator

Figure 1: A participants being assessed by the STISIM Driving imulator(photographed with consent of the participant)

Following the simulated driving session, a set route road test was conducted in each participant's vehicle and by the investigator (Figure 2), who was uninformed of the earlier simulator driving outcome.

Figure 2: A participant being assessed by the investigator on her own car (photographed with consent of the participant)

For orientation purpose, the investigator first drove the participant through the testing route and answered any query from the participant. The testing route, shown in Figure 3, was devised according to the standards for driving test set by the *Transport Department of Western Australia*.

Assessment criteria

It has been established that age-related declines in cognitive, mental and physical ability are associated with an increase in accident risk (Korteling, 1994). In particular, it has been identified that important attributes to automobile crashes included cognitive decrements in memory and visual perceptual skills (Lundberg, Hakamies-Blomqvist, Almkvist, & Johansson, 1998; McGwin Jr, Owsley, & Ball, 1998), visual impairment in acuity and useful field of view deficits (Hu, Trumble, Foley, Eberhard, & Wallace, 1998; McGwin Jr, Chapman, & Owsley, 2000) and difficulty in judging and response to traffic flow (McGwin Jr, Sims, Pulley, & Roseman, 2000). Medical impairments have also been associated with driving difficulties (Lyman, McGwin Jr, & Sims, 2001). Moreover, the behaviour and crash incidents at intersections (Clarke, Forsyth, & Wright, 1998; Preusser, Williams, Ferguson, Ulmer, & Weinstein, 1998), and overtaking road accidents (Clarke, Ward, & Jones, 1998) have been studied with respect to older adult drivers.

Based on a critical review of the literature, two sets of assessment criteria for simulated driving (Table 1) and for on-road test (Table 2) were developed to measure the performance of participants. In formulating the criteria, clinical aspects were also considered after extensive consultations with relevant stakeholders and other researchers. A procedure manual (available upon request), together with specific "on-road assessment scoring sheets" (Appendix A & Appendix B), were adopted to ensure uniformity and consistency in the data collection process.

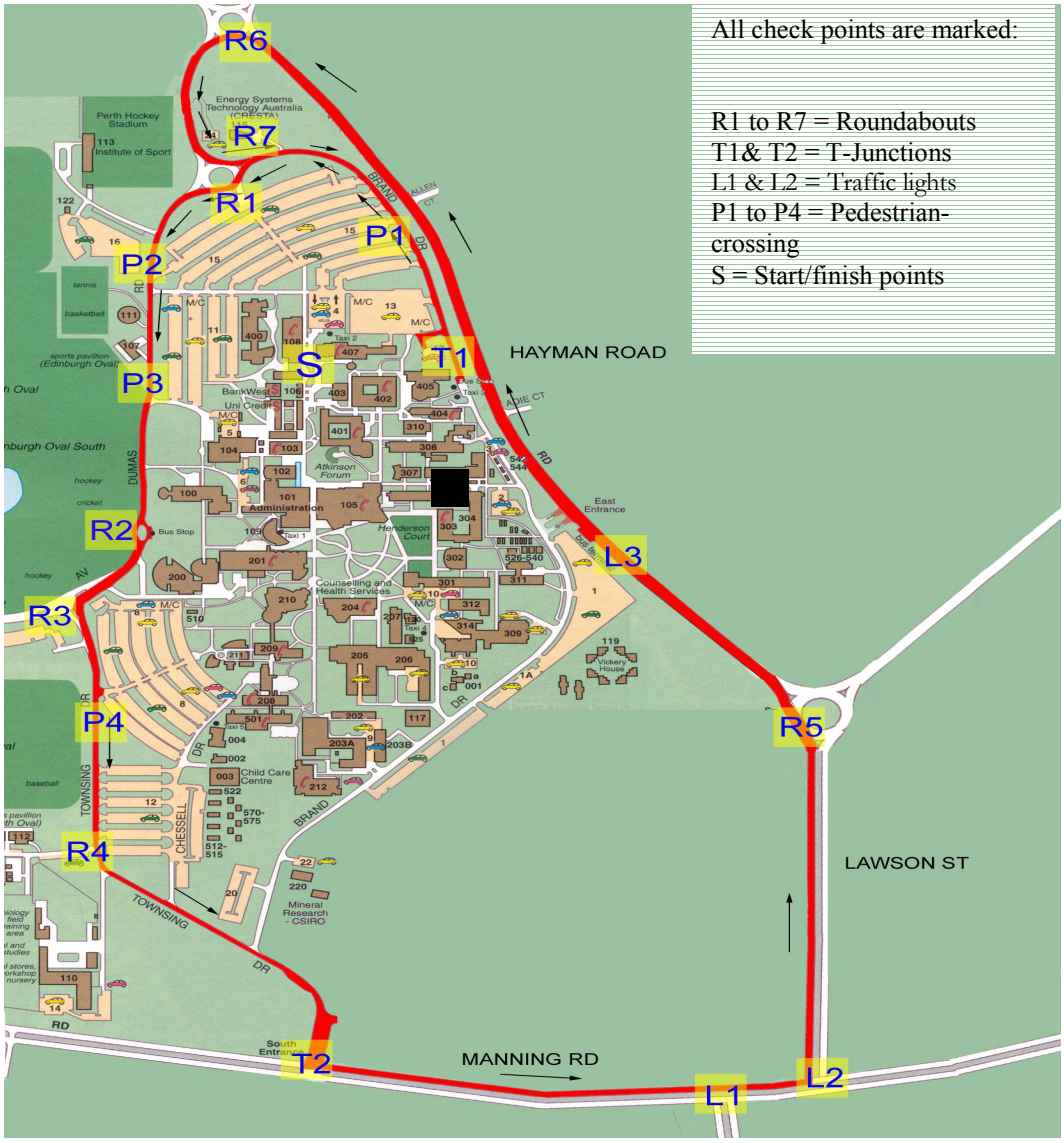

Figure 3: A Map Showing the Road Assessment Route and Various Check Point

Ethical considerations

The study was approved by the Human Research Ethics Committee of the researchers' institution. The assessment procedure was explained to each participant prior to formal testing.

Written consent was sought throughout the process and confidentiality of records was maintained. All participants were informed that they were free to terminate the study at any time without any negative consequences.

Moreover, in the event of inadequate driving skill in the opinion of the principal investigator, counselling and advice would be provided to the subject if deemed necessary.

Statistical analysis

All data were coded and analyzed using SPSS (Norusis, 1999). In addition to descriptive statistics, reliability of the driving performance scales was assessed by Cronbach alpha coefficients. Principal component analysis was then undertaken to develop two overall driving performance indices, owing to the expected correlations among the variables. Relationship between the simulated driving index and the road test index was examined by a regression

Table 1: Assessing Criteria Used in Simulated Driving

Simulated driving criteria	Description of the traffic scenarios and task required to perform by the participants	Measure(score)
Rule Compliance -knowledge & compliance to traffic regulations	Double lanes road, where participant's car was on the right lane. KEEP LEFT signs displayed every 50m to prompt participants to go back to the inner lane. TASK: Lane changing.	Follow "keep to left " rule; voluntarily (2) or with visual prompt (1); Check traffic by head turn (1) or with rear mirror(1) and proper use of indicators(1). Max. possible score = 5
Traffic Sign Compliance -compliance to traffic signs	Driving through STOP, GIVE WAY and pedestrian crossings. TASK: Drive through the scenarios safely	Approach slowly (1); Stop in right place(1);Give way as required(1); Proceed when opportunity comes(1);Correct use of indicators(1) Check mirror before proceed (1). Max. possible score = 6
Driving Speed -speed perception	Double-lanes straight road, 60 km/hr speed limit TASK: Drive 2km along the road according to the designated speed	Speed (2km/ run time of the distance)
Use of Indicatior -crisis response	Road work blocking the road. TASK: Drive around the obstacles and return to the inner lane as soon as possible	Signal to the right and left to change lane (2, one each); Check traffic (1); Voluntarily return to inner lane (1). Max. possible score = 8
Road Use Obligation -obligation of road usage	T-junctions leading to main road with STOP signs. TASK: Observe traffic conditions and drive through safely	Approach with caution and slow down(1);Indicate right or left turn (1); Proceed when has opportunity(1); Check traffic with head turn (1) or rear mirror(1) and Use of indicators(1). Max. possible score = 14
Decision & Judgement - rapid decision, decision under pressure judgement	Pedestrians 25m ahead running across the road hastily, car parking on the road side move out without signalling and car in front suddenly slow down. TASK: Avoid crashing	One mark for each success in avoiding accident when confronted with simulated dangerous driving scenarios. Max. possible score = 15
Working Memory -working memory -organisation of information	Five street names and 5 manoeuvres (turn left or right) marked on a route of road map to a fictitious park. TASK: Remember the names and the manoeuvres in 5 minutes and recall them after 10 minutes' simulated driving	Names and manoeuvres recalled(1 for each correct answer, up to 8) Sequence of manoeuvre (3, in perfect order; 2, 2-3 correct; 1, 1 correct and 0, none). Max. possible score =10
Multi-tasks -time pressure and attend two task simultaneously	Fifteen billboards with "SUBSTRACT" sign were posted along the road. TASK: Starting from 100, take away "5" every time the "SUBSTRACT" billboard comes out	Correct answer (1). Max. possible score = 15
Confidence in High Speed - confidence in driving with appropriate speed	Speed limits (60, 70 and 110 km/hr) vary according traffic conditions. TASK: Observe and maintain a speed close to the speed limits	Number of tokens received when the driving speed is close to the designated speed (± 5 km/hr)
Attention Task - functional reaction time	"Diamond" shapes on the screen change to "triangle" randomly and stay for 10 seconds. TASK: Signal right when the right "diamond" change and left when the left "diamond" change	Correct responses. Max. possible score = 14

Table 2: Assessing Criteria Used in Road Assessment

Road Assessment Criteria - related skills	**Observations of the participants**	**Measures -- (Maximum possible score)**
Road Use Obligation - the obligations of road usage	Driving manoeuvres in roundabout	As in "Roundabout (R1) to (R7)" items of the Scenario Specific Score Sheet(SSSS). Max. possible score = 35
Traffic Sign Compliance - compliance to road sign	Manoeuvres through pedestrian crossing, with a "10 km/hr" speed control sign and a speed bump	As in "Pedestrian crossing (P1) to (P4)" items of SSSS. Max. possible score = 20
Traffic Light - driving through traffic light	Manoeuvres before and through traffic lights	As in "Traffic light (L1) to (L3)" items of SSSS. Max. possible score = 7
T-Junction - drove through T-junctions	Manoeuvres before and through T-junctions	As in "T-junction (T1) to (T2)" items of SSSS. Max. possible score = 12
General Driving Skill - functional driving skills and coordination	The steering and breaking behaviour throughout the assessment	As in items "#2 and #3" of the Driver's General Behaviour Score Sheet(DGBSS) Max. possible score =50
Normal Driving - general skills in normal driving conditions	General driving behaviour throughout the experiment	As in item "#4" in DGBSS. Max. possible score = 10
Error Detection - judgement, information process and attention sharing	Awareness and sensitivity of participants in finding out they had made mistakes	As in item "#5" of DGBSS. Max. possible score =5
Error Recovery - crisis intervention skills in rectifying mistake	Driving behaviours when participants tried to rectify mistakes committed	As in item "#6" of DGBSS. Max. possible score = 5
Use of Indicator - proper use of indicators	The number of correct use of indicators throughout the assessment	One point for each correct use of indicators. Max. possible score = 27
Driving Speed - driving speed	Speed of the car driving through a 500m segment of straight road (70 km/hr)	The distance divided by run time
Working Memory - working memory and concentration	Participants' ability to remember the test route, which is a reverse measurement of number of verbal prompts required to complete the road assessment	One point is deduced if participant ask for directions. Max. possible score = 10

model accounting for age and gender of the driver. A significant association would provide evidence of validity of the simulator with regard to driving assessment for older adult drivers.

RESULTS

Demographic & driving information

The sample age ranged from 60 to 88 (mean = 72.9 years, S.D. = 7.1) and 78% of sample were male. All 129 participants were reasonably healthy with 70% wearing spectacles during the assessment. A quarter of the participants reported they have difficulties seeing objects on the roadside when driving along a straight road and saw a "halo" effect around street lamps. Half of the sample needed some time to adjust their eyes after seeing bright objects. One quarter of the participants reported a hearing deficit, however, over 90% claimed they could hear the indicators of their vehicle while driving. One third of the participants reported that the engine noise did not help them to determine the speed of their vehicle.

Around 12% of the participants were either courier workers, taxi or truck drivers, which required driving a vehicle regularly, prior to retirement. The estimated driving time per week ranged from 1 hour to 35 hours (mean = 11 hrs, S.D. = 8.35). Shopping and attending social gathering are the most common reasons of driving. Eight percent of the participants reported modifications have been made to their vehicle, which included fish-eye mirrors, back support cushions, and enlarged liquid crystal display on dashboard. 90% reported they checked their mirror frequently, however, it was observed that the majority of participants seldom used the rear and side mirrors during the road assessment. Over half of the sample perceived it is safe to drive slowly and would prefer to stay in one lane when on the highway.

One third of the participants understood how to operate the machine immediately after the laboratory assistant had delivered an introduction on the simulator. A post-assessment questionnaire completed at the end of each session indicated that participants felt positive about the simulator and were able to operate the machine without difficulties (survey result omitted for brevity, but available upon request). Several participants (9%) reported a mild degree of dizziness after completing the simulated driving assessment. However, such feeling of dizziness was only last for a short time and did not affect the subsequent on-road test.

All participants agreed to use their own vehicle and were observed to be reasonably confident during the road assessment. The most common mistake committed happened at road junctions. Participants tended to check the traffic conditions on the right side when they approached the T-junctions leading to a main road, but over 95% failed to check the traffic condition on the left side before proceeding. In turning the steering wheel, about 45% of the drivers were observed with hands crossing the mid-line or using one hand to steer.

Table 3: Descriptive Statistics of the Assessment Criteria (n = 129)

Simulated Driving	Mean	S.D.	Max	Min	r*	Road Assessment	Mean	S.D.	Max	Min	r*
Rule Compliance	4.40	1.84	5	0	-0.46	**Error Detection**	3.41	1.46	5	1	-0.58
Decision & Judgement	7.65	1.76	12	1	-0.49	**Error Recovery**	3.27	1.17	5	1	-0.44
Road Use Obligation	9.97	3.38	14	0	-0.51	**General Driving Skill**	40.8	4.16	50	32	-0.47
Working Memory	8.31	2.56	10	0	-0.53	**Normal Driving**	7.41	2.03	10	3	-0.66
Use of Indicator	5.42	2.53	8	0	-0.54	**Road Use Obligation**	21.2	2.59	25	15	-0.66
Multi-tasks	8.48	2.63	14	0	-0.42	**Working Memory**	6.29	2.68	10	1	-0.51
Driving Speed	62.0	13.4	114.1	45.6	-0.49	**Traffic Sign Compliance**	13.9	2.93	20	8	-0.26
Confidence on High Speed	5.29	3.52	17	0	-0.30	**Use of Indicator**	23.2	2.45	27	17	-0.63
Traffic Sign Compliance	2.98	1.61	6	0	-0.60	**Driving Speed**	57.8	8.03	80.6	37.9	-0.25
Attention Task	9.32	3.98	14	0	-0.55	**T-Junction**	5.78	2.27	10	0	-0.53
						Traffic Light	5.17	1.36	7	3	-0.30

* Pearson correlation with age

Analysis of simulated driving and road assessment criteria

Table 3 presents the descriptive statistics of the various assessment criteria. The measurement properties of the assessment criteria were examined by reliability analysis. The Cronbach alpha coefficients were 0.7 and 0.8 for simulated driving and on-road driving variables respectively, confirming the internal consistency of the scales that comprise the two measures of driving performance.

The association between individual criterion and the chronological age of participants was next investigated. As expected, significant negative correlations were found between the assessment scores and age ($-0.6 < r < -0.3$). An inspection of Pearson correlations revealed that the assessment criteria were highly correlated within each setting, with r as high as 0.8 between some variables. Therefore, principal component analysis was undertaken to develop overall driving performance indices for *Simulated Driving Index* and between *Road Assessment Index*. To compensate for different units of measurement of the criteria, the correlation matrix was adopted. The first principal component (whose eigenvalue exceeded 1) was chosen to generate the standardised overall performance index

because it was highly correlated (greater than 0.5) with most assessment criteria and it conveyed about half the variability of its original variables (54.7% for simulator and 48.1% for on-road). It was the most informative and representative among the principal components extracted.

$$\begin{aligned} \textit{Simulated Driving Index} = {} & -0.26\textit{Attention Task} - 0.38\textit{Rule Compliance} - 0.36\textit{Road Use Obligation} - 0.38\textit{Decision \& Judgement} - 0.36\textit{Working Memory} - 0.40\textit{Use of Indicator} - 0.21\textit{Multi-tasks} - 0.18\textit{Driving Speed} - 0.14\textit{Confidence on High Speed} - 0.36\textit{Traffic Sign Compliance} \\ \textit{Road Assessment Index} = {} & 0.28\textit{Error Detection} + 0.15\textit{Error Recovery} + 0.36\textit{General Driving Skill} + 0.3\textit{Normal Driving} + 0.39\textit{Road Use Obligation} + 0.27\textit{Traffic Sign Compliance} + 0.22\textit{Working Memory} + 0.39\textit{Use of Indicator} + 0.31\textit{Driving Speed} + 0.36\textit{T-Junction} + 0.16\textit{Traffic Light} \end{aligned}$$

The performance index of a participant can be viewed as a weighted average score of the assessment criteria. A higher *Simulated Driving Index* or *Road Assessment Index* score indicates a better overall driving performance in the corresponding setting.

Relationship between the performance indices

The scatter plot shows that the simulated driving index was positively associated with the road assessment index, with r = 0.716 (Figure 4)

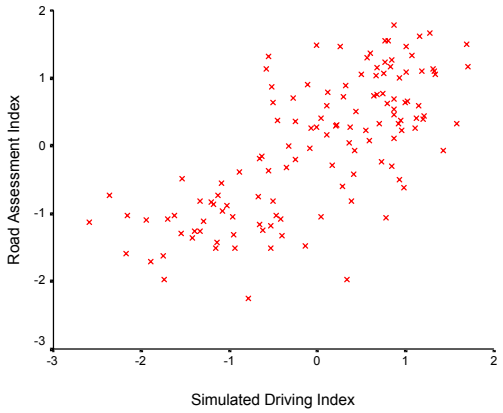

Figure 4: Plots of Road Assessment Index against Simulated Driving Index

A linear regression model was next fitted to further investigate the relationship between *Road Assessment Index* against *Simulated Driving Index*, adjusting for age and gender of the participants. The regression was found to be significant and the result of the model fit is reported in Table 4. The assumptions underlying the regression were checked and no apparent violation was found. Over 66% of the variability in between *Road Assessment Index* can be explained by *Simulated Driving Index,* after accounting for age and gender, though the latter appeared to be non-significant. Interaction terms between the variables were then included, but did not improve the goodness-of-fit of the model.

Table 4: Regression result for Road Assessment Index

	COEFFICIENT	S.E.	P-VALUE
Constant	5.27	0.70	0.00
Simulated Driving Index	0.39	0.07	0.00
AGE	-0.07	0.01	0.00
GENDER	-0.01	0.13	0.91

F (3,125) = 82.75, p-value < 0.001, R^2 = 0.66

DISCUSSION

The present study directly compares simulated driving performance and on-road driving performance for elderly drivers. The high positive relationship between the two overall index measures has validated the development of the driving simulator as a screening tool or as a cost-effective alternative to the on-road driving test. To a certain extent, its success also depends on the acceptability of the machine by the older population. Participants of this study had taken the simulated driving session seriously and endeavoured to improve their skill during the assessment. The post-assessment survey provided further evidence that the majority of participants enjoyed the experience and felt positive about the simulator.

The driving performance of older adult drivers, as assessed by the identified criteria or the overall indices, was confirmed to be negatively associated with age. This finding is consistent with the literature that driving skills deteriorate gradually with age (Dulisse, 1997). Numerous factors can contribute to the deterioration, including lost of visual processing ability on the periphery, deficits due to medical conditions, cognitive decrements and sensory impairment (McCloskey, Koepsell, Wolf, & Buchner, 1994; Rehm & Ross, 1995; Mattes, Weintraub, & Fitten, 1996; Wallace, 1997; Lundberg et al., 1998).

The volunteers participating in this study came from a small sector of the community by invitation and hence non-representative of the elderly drivers population. Self-selection bias is unavoidable in the recruitment of participants; however, random sampling is neither possible nor practical for this type of study. Simulator sickness can affect performance in psychomotor tests (Lerman, Goldberg, Kedem, Peritz, & Pines, 1993). Therefore, it is reasonable to assume the 9% participants who had developed some simulator sickness might not perform well. The *Motion Sickness Susceptibility Questionnaire* that has been used successfully to assess the susceptibility to motion sickness (Reason & Brandt, 1975) may be adapted to screen out susceptible elderly drivers prior to simulator testing.

This study confirmed the high transferability of observations between simulated driving and road assessment. With rapid technological advancement, it is expected that further enhancement of the driving simulator will make simulated driving environment closely resemble to actual on-road environment. The simulator provides a safe, economical and viable alternative to assess driving performance of older adult drivers. Furthermore, it can be used as an initial screening tool whereby recommendation for further driving assessment can be prescribed for those problematic or unsafe older adult drivers.

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REFERENCES

Alicandri, E. (1994). The Highway Driving Simulator (HYSIM): the next best thing to being on the road. *Public Roads, 57*(3), 19-23.

Allen, R. W., Stein, C.A.,Aponso, B.L, Rosenthal, T. J., & Hogue, J. R. (1990). *A Low cost, part task driving simulator based on microcomputer technology.* Paper presented at

the 69th Annual Meeting of the Transportation Research Board, Washington, DC.

Carr, D. (2000). The older adult driver. *American Family Physician, 61*(1), 141.

Carr, D., Jaskson, T. W., Madden, D. J., & Cohen, H. J. (1994). The effect of age on driving skills. *American Geriatric Society, 40*, 567-573.

Carsten, O. M. J., Groeger, J. A., Blana, E., & Jamson, A. H. (1997). *Driver performance in the EPSRC driving simulator: a validation study* (Report No. GR/ K56162). United Kingdom: University of Leeds.

Clarke, D. D., Forsyth, R., & Wright, R. (1998). Junction road accidents during cross-flow turns: a sequence analysis of police case files. *Accident Analysis & Prevention, 31*(1-2), 31-43.

Clarke, D. D., Ward, P. J., & Jones, J. (1998). Overtaking road-accidents: differences in manoeuvre as a function of driver age. *Accident Analysis & Prevention, 30*(4), 455-467.

Cobb, R. W., & Coughin, J. F. (1998). Are elderly drivers a road hazard?: Problem definition and political impact. *Journal of Ageing Studies, 12*(i4), 411-412.

Crane, M. (1996). How to tell patients they are too old to drive. *Medical Economics, 73*(14), 115-118.

Desmond, P. A., & Matthews, G. (1997). Implication of task-induced fatigue effects for in-vehicle countermeaures to driver fatigue. *Accident Analysis and Prevention, 29*(4), 515-523.

Dulisse, B. (1997). Older drivers and risk to other road users. *Accident Analysis and Prevention, 29*(5), 573-582.

Ellingrod, V. L., Perry, P. J., Yates, R. W., Maclnodoe, J. H., Watson, G., Arnalt, S, & Holman, T. L. (1997). The effects of anabolic steroids on driving performance as assessed by the Iowa Driver Simulator. *American Journal of Drug and Alcohol Abuse, 23*(4), 623-637.

Evans, L. (1993). How safe were today's older drivers when they were younger. *American Journal of Epidemiology, 137*, 769-775.

Evans, L. (2000). Risks older drivers face themselves and threats they pose to other road users. *International Journal of Epidemiology, 29*(2), 315-322.

Foley KT, Mithell SJ. The elderly driver: What physician need to know. Cleveland clinic journal of medicine 1997;64:423-428.

Fraser, D. A., Hawken, R. E., & Warnes, A. M. (1994). Effects of extra signals on drivers' distance keeping ----- a simulation study. *IEEE transaction on vehicular technology, 43*(4), 1118 - 1124.

Hu, P. S., Trumble, D. A., Foley, D. J., Eberhard, J. W., & Wallace, R. B. (1998). Crash risks of older drivers: a panel data analysis. *Accident Analysis & Prevention, 30*(5), 569-581.

Janke, M., & Eberhand, J. W. (1998). Assessing medically impaired older drivers in a licensing agency setting. *Accident Analysis and Prevention, 30*(3), 347-361.

Korteling, J. E. (1994). Effects of aging, skill modification, and demand alternation on multiple-task performance. *Human Factors, 36*(1), 27-43.

Lerman, Y. S., G, Goldberg, E., Kedem, E., Peritz, E., & Pines, A. (1993). Correlates of military tank simulator sickness. *Aviation, Space and Environmental Medicine, 64*(7), 619-622.

Lundberg, C., Hakamies-Blomqvist, L., Almkvist, O., & Johansson, K. (1998). Impairment of some cognitive functions are common in crash-involved older drivers. *Accident Analysis and Prevention, 30*(3), 371-377.

Lyman, J. M., McGwin Jr, G., & Sims, R. V. (2001). Factors related to driving difficulty and habits in older drivers. *Accident Analysis & Prevention, 33*(3), 413-421.

Mattes, J. A., Weintraub, M. I., & Fitten, L. J. (1996). Driving and Alzheimer disease. *Journal of the American Medical Association, 275*(3), 182-184.

McCloskey, L. W., Koepsell, T. D., Wolf, M. E., & Buchner, D. M. (1994). Motor vehicle collision injuries and sensory impairment of older drivers. *Age and Ageing, 23*(4), 267 - 274.

McGwin Jr, G., Chapman, V., & Owsley, C. (2000). Visual risk factors for driving difficulty among older drivers. *Accident Analysis & Prevention, 32*(6), 735-744.

McGwin Jr, G., Owsley, C., & Ball, K. (1998). Identifying crash involvement among older drivers: agreement between self-report and state records. *Accident Analysis & Prevention, 30*(6), 781-791.

McGwin Jr, G., Sims, R. V., Pulley, L., & Roseman, J. M. (2000). Relations among chronic medical conditions, medications, and automobile crashes in the elderly: A population-based case-control study. *American Journal of Epidemiology, 152*(5), 424-431.

Norusis, M. J. (1999). *SPSS for Windows, Advance Statistics Release 10.0.*: New York: SPSS Inc.

Preusser, D. F., Williams, A. F., Ferguson, S. A., Ulmer, R. G., & Weinstein, H. B. (1998). Fatal crash risk for older drivers at intersections. *Accident Analysis & Prevention, 30*(2), 151-159.

Ray WA. Safety and mobility of the older driver: A research challenge. Journal of the American Medical Association 1997;278:66-67.

Reason, J. T., & Brandt, J. J. (1975). Motion sickness. London: Academic Press, 181-186.

Rehm, C. G., & Ross, S. E. (1995). Elderly drivers involved in road crashes: A profile. *The American Surgeon, 61*, 435 - 437. .

Reuben, D. B. (1993). Assessment of older drivers. *Clinic in Geriatric Medicine , 9* (2), 449 - 459.

Rizzo, M., McGehee, D. V., Dawson, J. D., & Anderson, S. N. (2001). Simulated car crashes at intersections in drivers with Alzheimer disease. *Alzheimer Disease and Associated Disorders, 15*(1), 10-20.

Summala, H. (1988). Risk control is not risk adjustment: The zero-risk theory of driver behaviour and its implications. *Ergonomics, 31*, 491-506.

United Nations. The world in six billion. New York, New York: Population Division, Department of Economic and Social Affair, United Nations, November 1999:1-63.

Van der Winsum, W. (1996). Speed choice and steering behaviour in curve driving. *Human Factor, 38*(3), 343- 351.

Van der Winsum, W., & Brouwer, W. (1997). Time headway in car following and operational performance during unexpected braking. *Perceptual and Motor Skills, 84*, 1247 -1257.

Wallace, R. B. (1997). Cognitive change, medical illness, and crash risk among older drivers: An epidemiological consideration. *Alzheimer Disease and Associated Disorders, 11*(1), 31-37.

Waller, P. F. (1991). The older driver. *Human Factors, 33*(5), 499-505.

Wiseman, E. J., & Souder, E. (1996). The older driver: a handy tool to assess competence behind the wheel. *Geriatric, 51*(7), 36-38.

Appendix A: Scenario Specific Score Sheet

Scenario Specific Score Sheet	**Time Start:**	**Time finish:**	**The total "No" score of the participant =**
This form should be filled up during the road test. **It is based on accomplishment of certain task in specific spots of a set route indicating by an *On road Assessment Check Points Map*.** **A tick in "Yes" column indicates the task has been accomplished.** **If verbal prompting (VB) or physical Assistance (PA) is required to accomplish the task, mark the corresponding ✧ as well.**		**A tick in "No" column indicates the task has not been accomplished.** **All items should be assessed in this form.** **Put N/A, in case the item is not applicable** **NUMBER OF VERBAL PROMPTING: ❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑❑ ❑ ❑ ❑ ❑ ❑ ❑ ❑❑ ❑ ❑ ❑**	

TASKS										Task				
Before Starting	Yes	No	V/P	P/A		Yes	No	V/P	P/A		A	B	V/P	P/A
Adjust seat properly					**Pedestrian's Crossing (P2)**					**Traffic Light(L1)**				
Adjust mirror properly			✧	✧	Slow down in approaching the crossing			✧	✧	Do not stop in wrong position			✧	✧
Close door properly			✧	✧	Do not stop when it is not necessary			✧	✧	Do not stop when not necessary			✧	✧
Ensure windscreen or windows not obscured			✧	✧	Do not hit the speed bumps			✧	✧	Do not start before signal turns green			✧	✧
Fasten seat belt			✧	✧	Give way to pedestrians crossing			✧	✧	Do not proceed on amber when could have stopped safely			✧	✧
Starting			✧	✧	Compile with the 10 km/hr rule			✧	✧	Do not proceed on red signal			✧	✧
Start engine smoothly			✧	✧	**Pedestrian's Crossing (P3)**					Do not cross continuous white line			✧	✧
Avoid race engine			✧	✧	Slow down in approaching the crossing			✧	✧	Do not fail to notice lights			✧	✧
Depress clutch fully			✧	✧	Do not stop when it is not necessary			✧	✧	**Traffic Light(L2)**				
Start with right gears			✧	✧	Do not hit the speed bumps			✧	✧	Do not stop in wrong position			✧	✧
Release hand brake			✧	✧	Give way to pedestrians crossing			✧	✧	Do not stop when not necessary			✧	✧
Stop Sign					Compile with the 10 km/hr rule			✧	✧	Do not start before signal turns green			✧	✧
Notice or obey mandatory signs("Stop")			✧	✧	**Round about (R2)**					Do not proceed on amber when could have stopped safely			✧	✧
Do not stop too far from the Stop Sign			✧	✧	Being certain of obligation			✧	✧	Do not proceed on red signal			✧	✧
Check condition before moving again			✧	✧	Proceed when has opportunity to do			✧	✧	Do not cross continuous white line			✧	✧
Do not proceed if way is not clear			✧	✧	Give appropriate signals (turn to right or left)			✧	✧	Do not fail to notice lights			✧	✧
Do not Stop in wrong position			✧	✧	Give signal not too short or long			✧	✧	**Round about (R5)**				
T-junction (T1)					Do not give wrong signal			✧	✧	Being certain of obligation			✧	✧
Do not approach intersection too slowly			✧	✧	**Round about (R3)**					Proceed when has opportunity to do			✧	✧
Do not brakes or swerves at last minute			✧	✧	Being certain of obligation			✧	✧	Give appropriate signals (turn to right or left)			✧	✧
Do not approach intersection too fast			✧	✧	Proceed when has opportunity to do			✧	✧	Give signal not too short or long			✧	✧
Look both ways in approaching intersection			✧	✧	Give appropriate signals (turn to right or left)			✧	✧	Do not give wrong signal			✧	✧
Do not proceed if way is not clear			✧	✧	Give signal not too short or long			✧	✧	**Traffic Light(L3)**				
Proceed when has opportunity to do			✧	✧	Do not give wrong signal			✧	✧	Do not stop in wrong position			✧	✧
Will give way (right hand rule)			✧	✧	**Pedestrian's Crossing (P4)**					Do not stop when not necessary			✧	✧
Do not turn across oncoming traffic			✧	✧	Slow down in approaching the crossing			✧	✧	Do not start before signal turns green			✧	✧
Do not swing too wide on corner			✧	✧	Do not stop when it is not necessary			✧	✧	Do not proceed on amber when could have stopped safely			✧	✧
Do not cut corner			✧	✧	Do not hit the speed bumps			✧	✧	Do not proceed on red signal			✧	✧
Do not swing too wider on corner			✧	✧	Give way to pedestrians crossing			✧	✧	Do not cross continuous white line			✧	✧
Do not turn across oncoming traffic			✧	✧	Compile with the 10 km/hr rule			✧	✧	Do not fail to notice lights			✧	✧
Pedestrian's Crossing (P1)					**Round about (R4)**					**Round about (R6)**				
Slow down in approaching the crossing			✧	✧	Being certain of obligation			✧	✧	Being certain of obligation			✧	✧
For not stop when it is not necessary			✧	✧	Proceed when has opportunity to do			✧	✧	Proceed when has opportunity to do			✧	✧
Do not hit the speed bumps			✧	✧	Give appropriate signals (turn to right or left)			✧	✧	Give appropriate signals (turn to right or left)			✧	✧
Give way to pedestrians crossing			✧	✧	Give signal not too short or long			✧	✧	Give signal not too short or long			✧	✧
Compile with the 10 km/hr rule			✧	✧	Do not give wrong signal			✧	✧	Do not give wrong signal			✧	✧
Round about (R1)					**T-junction (T2)**					**Round about (R7)**				
Being certain of obligation			✧	✧	Do not approach intersection too slowly			✧	✧	Being certain of obligation			✧	✧
Proceed when has opportunity to do			✧	✧	Do not brakes or swerves at last minute			✧	✧	Proceed when has opportunity to do			✧	✧
Give appropriate signals (turn to right or left)			✧	✧	Do not approach intersection too fast			✧	✧	Give appropriate signals (turn to right or left)			✧	✧
Give signal not too short or long			✧	✧	Look both ways in approaching intersection			✧	✧	Give signal not too short or long			✧	✧
Do not give wrong signal			✧	✧	Do not proceed if way is not clear			✧	✧	Do not give wrong signal			✧	✧

Appendix B: Driver's General Behaviour Score Sheet

Driver's General Behaviour Score Sheet	**Date/Time:**	**ID Code:**	**The total score of the participant =**

This sheet should be completed by the investigator within 10 minutes after the road test

In Part I, column A
Score 5 ----- If "Assessor is confident of the manoeuvre of the participant and the assessor will perform the same in the task or react to the situation like the participant."
Score 4 ----- If "Although the manoeuvre of the participant is not perfect, however, assessor is still comfortable with the outcome. The assessor do not concern the safety of the manoeuvre."
Score 3 ----- If "Assessor feels uneasy or anxious about the manoeuvre/driving habit of the participant, however, safety is not a concern. Assessor considers the participant should improve in his performance of the tasks with training or more practice."
Score between 1 and 2 ----- If "Assessor considers the manoeuvre causes inconvenience to other drivers or is unsafe and feel obligated to prompt the participant to correct the mistake."
Score 1 ----- If "With repeated V/P from the assessor, participants is unable/has no intention/is reluctant/is insightless to correct the mistake."

In Part I, column B
Score 5 ----- If "Participant is independent in physical and cognitive function. No Verbal prompting (VP)/Physical assistance (PA) is required to initiate and accomplish the task."
Score 4 ----- If "Participant requires minimal verbal prompting or physical assistance or both to accomplish the task."
Score 3 ----- If "Participant requires moderate verbal prompting or physical assistance, or both to complete the task."
Score 2 ----- If "Participant modify the behaviour with V/P and P/A from the assessor."
Score 1 ----- If "Participant is unable to modify his/her behaviour
If score 4 or less in Column B, must tick the ✧ in either V/P or P/A.
In Part II, items only mark "Yes" or "No"

Part I					**Part II**		
	A	**B**	V/P	P/A		Yes	No
#1. Gear					**#4. Normal driving**		
Do not clash gears			✧	✧	Keep reasonably to left	✧	✧
Do not look at gear level while changing gear			✧	✧	Drive with reasonable speed	✧	✧
Do not jolt vehicle while changing gear			✧	✧	Do not drive on erratic speed	✧	✧
Do not change gear while turning corner			✧	✧	Do not take erratic course	✧	✧
Do not coast in neutral or depresses clutch			✧	✧	Use rear view mirror frequently	✧	✧
Proper use of gears according to traffic conditions			✧	✧	Do not exceeds speed limit	✧	✧
					Do not follow too closely to the front car	✧	✧
#2. Steering					Do not overtake too many vehicles	✧	✧
Erratic movement of the steering wheel			✧	✧	Do not over the centre line, except overtaking	✧	✧
Do not put arm and elbow out of window			✧	✧			
Do not allow steering wheel to self centre			✧	✧	**#5. Crisis reaction once recognised a mistake had been made:**		
Do not incorrectly position of their hand			✧	✧	Do not drive in the car park P24	✧	✧
Do not do unnecessary on hand drive			✧	✧	Notices in a wrong place once turn in the car park	✧	✧
					Does not notice in a wrong place until drive for more than 10 M	✧	✧
					Need to be told that a mistake had been made at the end of the car park	✧	✧
#3. Stopping					Rectify the mistake by doing a U-turn safely	✧	✧
Do not depress clutch before brake in high gear stopping			✧	✧			
Do not stop too far from given mark			✧	✧	**#6. Crisis intervention**		
Do not stop too suddenly (except in emergency)			✧	✧	Stop suddenly	✧	✧
Do not stop too slowly in quick stop test			✧	✧	Do a hasty U-turn without observing the traffic	✧	✧
Do not stall engine			✧	✧	Do not know what to do and require verbal prompting to rectify the	✧	✧
					Fail to check other traffic by turning head	✧	✧
					Poor signal to indicate intention in about turn	✧	✧
					Fail to look to rear either directly or in mirror	✧	✧