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Using a driving simulator to identify older drivers at inflated risk of motor vehicle crashes

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Abstract

Problem: To develop appropriate assessment criteria to measure the performance of older drivers using an interactive PC-based driving simulator, and to determine which measures were associated with the occurrence of motor-vehicle crash. *Method:* One hundred and twenty-nine older drivers residing in a metropolitan city volunteered to participate in this retrospective cohort study. Using the driving simulator, appropriate driving tasks were devised to test the older drivers, whose performances were assessed by 10 reliable assessment criteria. Logistic regression analysis was then undertaken to determine those criteria that influence the self-reported crash outcome. *Results:* As expected, driving skill of older drivers was found to decline with age. Over 60% of the sample participants reported having at least one motor-vehicle crash during the past year. Adjusting for age in a logistic regression analysis, the cognitive abilities associated with the crash occurrence were working memory, decision making under pressure of time, and confidence in driving at high speed. *Summary:* The findings of this retrospective study indicated those individuals at inflated risk of vehicle crashes could be identified using the PC-based interactive driving simulator. Prospective studies need to be undertaken to determine whether the driving simulator can predict future crash events. *Impact on industry:* This study demonstrated an economical driving simulator approach to screen out problematic or unsafe older drivers before a more detailed but expensive road test is considered.
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Keywords: Driving simulator; Off-road assessment; Older drivers; Simulated driving performance; Vehicle crash

1. Introduction

Currently, about 20% 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). 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 (Retchin & Anapolle, 1993). In countries such as the United States and Australia, driving is vital to daily living activities, independence, and the social network of older persons (Janke & Eberhard, 1998). Losing the privilege of driving may upset their balance of life at home and leisure (Marottoli et al., 1993; Marottoli et al., 1997).

It has been established that age-related declines in cognitive, perceptual, and physical abilities are associated with an increased accident risk (Brayne et al., 2000). In particular, the attributes associated with vehicle crashes include decrement in memory (Bedard, Molloy, & Lever, 1998; Cooper, Tall, Tukko, & Beatties, 1993; Wallace, 1997), deficit in visual perceptual skills, impairment in visual acuity and useful field of view (Owsley et al., 1998), decrease in visual attention (Duchek, Hunt, Ball, Buckles, & Morris, 1998), as well as difficulty in judging and responding to traffic flow (McGwin, Sims, Pulley, & Roseman, 2000; Voelker, 1999). Medical impairments have also been documented as related to driving difficulties (McGwin, Sims, Pulley, & Roseman, 1999; Sims et al., 1998). In a survey of 3238 older drivers applying for license renewal, Stutts (1998) found a clear pattern of lower annual mileage and greater avoidance of high-risk driving situations associated with lower levels of cognitive and visual functions. The current license renewal processes in the

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United States are inadequate in assessing driving competency and safety, with many jurisdictions requiring no specific test (Janke, 2001). Currently, epidemiological studies investigating crashes are unable to identify criteria that facilitate clinical decisions with respect to older drivers (Ray, 1997). An understanding of the factors that influence the older driver's risk of vehicle crash is therefore important.

Several studies have shown that older drivers regulate their driving (Hakamies-Blomqvist & Wahlstrom, 1998) or self-impose restrictions on their driving routine (De Raedt & Ponjaert-Kristoffersen, 2000) to avoid risky driving conditions such as driving at night, during rush hours, in bad weather, or in unfamiliar areas. In some circumstances, older people stop driving of their own accord to avoid potential accidents (Andersen, Cisneros, Saidpour, & Atchley, 2000). Although older drivers have a higher crash involvement on a per-mile basis compared with younger age groups, most older persons can drive safely (Evans, 2000). 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 (Janke, 2001; Schieber, 1994).

Rapidly expanding electronic and computer technology has made possible the development of relatively low-cost, PC-based driving simulators (Allen, Stein, Aponso, Rosenthal, & Hogue, 1990), which have a better face validity than psychometric tests, such as pencil-and-paper tests, in assessing driving skill (Desmond & Matthews, 1997). Driving simulators provide a safe and cost-effective means of testing driving performance and allow drivers to make decisions and take actions that can have potentially dangerous consequences on the highway (Allen et al., 1990; Ivancic & Hesketh, 2000). A driving simulator system was developed at Western Kentucky University to identify visual-processing difficulties among the elderly, in addition to assisting those with field-of-view limitation (Ward, 1996). In another study, a driving simulator was used to compare elderly and younger drivers in responding to helpful and distracting subsidiary tasks while undertaking the primary driving task (Fraser, Hawken, & Warnes, 1994). The result showed that the two groups coped with the situations using different strategies. Recently, interactive simulators were used to study the driving behaviors of older drivers suffering from Alzheimer disease (Rizzo, McGehee, Dawson, & Anderson, 2001).

It is known that neither a single nor a combination of psychometric measures would be indicative of the overall driving ability (Guerrier, Manivannan, Pacheco, & Wilkie, 1996; Odenheimer et al., 1994). By including relevant cognitive measures to predict adverse driving events, limited successes have been achieved with respect to the relationship between cognitive and/or physical deficits and the crash risk (Marottoli et al., 1998). To the best of our knowledge, however, there is no published research documenting the correlation between simulators and crashes among older adults. This paper considers the assessment of older drivers using a driving simulator. Appropriate assessment criteria were developed that encompassed a range of practical driving abilities. Logistic regression analysis was then undertaken to determine which criteria influence the crash outcome. A significant association would confirm the usefulness of driving simulators to identify older drivers at inflated risk of motor-vehicle crashes.

Fig. 1. A participant being tested by the STISIM Driving Simulator. Reproduced with participant's consent.

2. Methods

2.1. Participants and procedure

One hundred and twenty-nine drivers aged 60 years or more, residing within the metropolitan area of the state capital, volunteered to take part in the study. The volunteer participants were required to hold a valid driving license with no obvious visual deficits such as cataract and glaucoma that could affect their driving ability. They were also required to report to the assessment center in their own cars. Each assessment included a 30-min initial interview and a 45-min simulated-driving session. Participants were reimbursed $10 for fuel expenses and debriefed at the completion of the assessment. The initial interview was conducted to collect crash and other information from each participant. Confidentiality of the information provided was assured.

2.2. Driving simulator

The interactive PC-based STISIM Driving Simulator, developed by System Technology Incorporated (Allen et al., 1990), was used to study the behavior of the participants in simulated driving (Fig. 1). A laboratory technician, who was blinded to the driving history of the participant, monitored the simulated-driving assessment. Measures such as vehicle speed, indicator usage, lane position, and stopping distance were captured automatically by the machine. Other driving behavior including observing traffic rules, rear mirror usage, and the ability to address two tasks simultaneously were recorded by the

Table 1
Driving tasks and assessment criteria

Tasks required to be performed by the participants	Dominant skill/ability	Measure (score)
Rules Compliance: Lane changing in double-lane road, where participant's car was on the right lane. KEEP LANE signs displayed every 55 yards to prompt participants to go back to the inner lane.	Knowledge and compliance to traffic regulations	Follow "keep lane" 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: Drive through STOP, GIVE WAY, and pedestrian crossings safely.	Compliance to traffic signs	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 proceeding (1). Max. possible score = 6
Driving Speed: Drive 1.5 miles along the road according to the designated speed of double-lane straight road (40 miles/h speed limit).	Speed perception	Speed (1.25 miles/run time of the distance)
Use of Indicator: Drive around "road work" obstacles blocking the road and return to the inner lane as soon as possible	Psychomotor coordination in driving and crisis response	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: Observe traffic conditions and drive safely through T-junctions leading to main road with STOP signs.	Ability to organize information and judgement	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 and Judgement: Avoid crashing into pedestrians 30 yards ahead running across the road hastily, car parked on the roadside moving out without signaling and car in front suddenly slowing down.	Rapid decision, judgement under time pressure	One mark for each success in avoiding accident when confronted with simulated dangerous driving scenarios. Max. possible score = 15
Working Memory*: recall five street names and five maneuvers (turn left or right) after 10 minutes' simulated driving.	Working memory	Names and maneuvers recalled (1 for each correct answer, up to 8). Sequence of maneuver (3, in perfect order; 2, 2–3 correct; 1, 1 correct, and 0, none). Max. possible score = 10
Two Simultaneous Tasks: Starting from 100, take away "5" every time the "SUBTRACT" billboard comes out. Fifteen billboards with "SUBTRACT" sign were posted along the road.	Time pressure and attend to two tasks simultaneously	Correct answer (1). Max. possible score = 15
Speed Compliance: Observe and maintain a speed close to the posted speed limits (40, 45, and 70 miles/h), which vary according to traffic conditions.	Confidence in driving with appropriate speed	Number of tokens received when the driving speed is close to the designated speed (± 3 miles/hr)
Divided Attention Tasks: Signal the traffic indicator when the "diamond" shapes on the monitor screen change to "triangle" randomly and stay for 15 s.	Functional reaction time	Correct responses. Max. possible score = 14

* Subjects were given 5 min to memorize the route to a fictitious park marked on a road map, followed by 10 minutes of unrelated driving, and then asked to recall the maneuvers and street names on the route.

laboratory technician. An operational manual (available on request) was adopted to ensure uniformity and consistency of the data collection procedure.

2.3. Driving tasks and assessment criteria

A computer program was developed to generate 10 simulated-driving tasks especially appropriate for testing older adults. The performances of participants were gauged by the corresponding assessment criteria, which were formulated after an extensive literature review and consultations with stakeholders (geriatricians, occupational therapists, clinical psychologists, and experienced driving instructors). Table 1 provides a brief description of the tasks and associated measures. The dominant skill in each driving task had been identified by activity analysis (Levine & Brayley, 1991) and shown in the table.

2.4. Ethical considerations

Approval to conduct the study was obtained from the Human Research Ethics Committee of the researchers' institution. The assessment procedure was explained to each participant before commencement of testing. Participants were fully informed of their freedom to withdraw at any stage. To ensure privacy and confidentiality, only the principal researcher and the laboratory technician were present during the evaluation. A formal written consent was sought from each participant. The subjects were advised of study objectives and that tabulated results of their assessment would be provided to them on request. In the event that a participant's performance indicated unsafe driving practice, free counseling and advice were available. With the permission of the individual concerned, a follow-up referral would be arranged to address the issue.

2.5. Statistical analysis

All data were coded and analyzed using SPSS (Norusis, 1999). In addition to descriptive statistics, reliability of the assessment criteria scales was assessed by Cronbach alpha coefficients. Bivariate Pearson correlation was used to examine the association between each assessment score and the chronological age of participants. The occurrence of crash (1 = event, 0 = non-event) was the dependent variable of interest. Logistic regression analysis was undertaken to determine a subset of cognitive abilities that influence the self-reported crash event. Because of the expected collinearity among the independent variables, a stepwise procedure was performed. A significant association would provide evidence of validity of the simulator to successfully identify older drivers at inflated risk of motor-vehicle crashes.

3. Results

3.1. Demographic and driving information

The age of the 129 participants ranged between 60 and 88 years ($M = 72.9$, $SD = 7.1$), and 22% of the drivers were female. The prevailing medical conditions, as provided voluntarily by the sample participants, were high blood pressure (38%), visual problem (36%), arthritis (26%), hearing problem (25%), heart diseases (15%), and diabetes (10%). Over 70% reported that they were suffering from multiple medical conditions and took daily medications including analgesic, anticoagulant, and antihypertensive and anti-inflammatory agents, but they perceived that such medications did not interfere with their driving activities.

All participants reported that they were retired. The estimated driving per week varied from 1 to 35 h ($M = 11$, $SD = 8.35$). Shopping and social activities were the most common reasons that participants used their vehicles. Almost all (95%) of the participants had received eight or more years of education and about 31% of them were college graduates. Around 12% of the participants were either courier workers or taxi or truck drivers before retirement, which required driving a vehicle regularly. Although 90% of drivers reported checking their mirror frequently, it was observed that the majority seldom used the rear mirror of the simulator during the assessment. Despite 9% of participants developing and reporting some degree of simulator sickness such as mild dizziness during the simulated-driving session, the symptoms lasted only for a short time and did not prohibit them from undertaking the assessment. None of the participants requested or required a follow-up referral or counseling.

3.2. Analysis of simulated-driving criteria

Table 2 presents descriptive statistics for the 10 assessment criteria, whose measurement properties were examined by reliability analysis. The Cronbach alpha coefficient was

Table 2
Descriptive statistics of assessment criteria and their correlation with age ($n = 129$)

Measures[a]	*M*	*SD*	Max	Min	Pearson coefficient
Rules Compliance	4.40	1.84	8	0	– .548
Traffic Sign Compliance	2.98	1.61	6	0	– .303
Driving Speed	38.53	8.30	70.92	28.32	– .422
Use of Indicator	5.42	2.53	8	0	– .529
Road Use Obligation	7.65	1.76	12	1	– .460
Decision and Judgement	9.97	3.38	14	0	– .509
Working Memory	8.31	2.56	11	0	– .486
Two Simultaneous Tasks	8.48	2.63	14	0	– .539
Speed Compliance	5.29	3.52	17	0	– .488
Divided Attention Tasks	9.32	3.98	14	0	– .596

[a] Measure unit in number of correct responses (except driving speed in miles/h).

Table 3
Logistic regression results for self-reported crash event based on stepwise analysis

Variable	Coefficient	*SE*	*p* value	Odds ratio	95% Confidence interval	
					Lower	Upper
Working Memory	− .59	.24	.007	0.55	0.35	0.88
Decision and Judgement	− .94	.27	.001	0.39	0.23	0.66
Speed Compliance	− .19	.09	.046	0.83	0.69	1.00
Age	.12	.06	.046	1.13	1.00	1.27
Constant	5.75	5.11	.264			

.742, confirming the internal consistency of the scales that measured performance in the simulated-driving tasks. As expected, there is significant negative correlation between each criterion and the age of participants, suggesting that simulated-driving performance worsens with increasing age.

3.3. Association between crash occurrence and simulated-driving criteria

The objective is to identify a subset of driving abilities that are closely related to the self-reported crash event. Seventy-nine participants (61.2%) reported having at least one traffic crash in the past year, but none of them had an accident involving personal injury. The largest Pearson correlation coefficient among the assessment criteria was .833. Results of the stepwise logistic regression are presented in Table 3. Overall, the regression was significant ($\chi^2 = 100.96$, $df = 4$, $p < .001$). Performance of participants in driving tasks involving Working Memory, Decision and Judgement, and Speed Compliance was found to be negatively associated with the occurrence of a crash. According to the fitted model, each added point on the Working Memory scale was associated with a 45% decrease in risk, on the Decision and Judgement scale with a 61% decrease in risk, and on the Speed Compliance scale with a 17% decrease in risk. On the other hand, the model indicated an increase of 1 year in age could elevate the accident risk by 13%.

Goodness of fit of the logistic regression model is satisfactory (pseudo R^2=.737). Of participants without an accident history, 82.3% specificity was observed. Of those with an accident history, 91.4% sensitivity was evident in this sample. Overall, 87.7% of the 129 participants were correctly classified on the occurrence/nonoccurrence of the event. The 11 participants suffering simulator sickness were next excluded from the logistic regression model. However, neither the model fit nor the significance of the variables was affected by these observations.

4. Discussion

In this study, appropriate driving tasks were chosen to test older drivers using a PC-based driving simulator. Ten reliable assessment criteria were developed to measure each participant's performance in these tasks. The negative correlation between individual assessment score and age provided evidence that driving skills generally decline with age (Brayne et al., 2000).

This study further investigated the identification of older drivers at inflated risk of motor-vehicle crashes. The logistic regression analysis showed that cognitive skills such as working memory, ability to make rapid decisions, judgement under time pressure, and confidence in driving at high speed were associated with the crash event. The presence of impairments of these skills increased the odds of crash occurrence. The inability to make rapid decision and judgement was found to be influential and highly significant. This finding is logical and supported by previous studies that suggested driving simulators can reliably reflect on-road driving behaviors and functions (Ivancic & Hesketh, 2000; Odenheimer et al., 1994; Sims, McGwin, Allman, Ball, & Owsley, 2000; Van der Winsum & Brouwer, 1997).

In this study, nearly two thirds of the participants reported having at least one traffic accident in the past year before the study. Self-reported crash was used in the current investigation, which typically yielded higher counts than the state records (Marottoli, Cooney, & Tinetti, 1997; Marottoli et al., 1998), because official records are limited to more severe crash events. The identification of older drivers at inflated risk of adverse driving events that included self-reported minor accidents is desirable and legitimate. The volunteered participants should have no apparent reason to provide untrue information. However, their recall of driving history cannot be guaranteed (Tuokko & Tallman, 1995; Voelker, 1999). A binary outcome variable denoting event and nonevent was therefore used in modeling and analysis.

The relatively small size of the monitor display, together with the nature of the computer-generated stimuli, may limit the simulator to assess driving tasks that require the use of visual detail in complex traffic scenarios. Nevertheless, low-cost PC-based simulators can effectively measure cognitive and perceptual abilities (Ward, 1996). The participants who volunteered for this study cannot be taken as representative of the population of older drivers, because the sample was not randomly selected but only covered some sectors of the community. Selection bias is thus unavoidable in the recruitment of participants. However, random sampling is neither possible nor practical. Another limitation relates to the difficulty in implementing on-road validation of the driving simulator due to ethical and practical constraints. Nevertheless, some preliminary results are available and will be reported elsewhere.

Rapid advances in computer technology have led to more complex simulators that are financially out of reach for those wanting to use them for routine driver screening. On the contrary, PC-based simulator is sufficiently affordable to be used as a screening tool. This retrospective

study suggests that the STISIM driving simulator can be used to identify older drivers at inflated risk of motor-vehicle crashes. Prospective studies need to be undertaken to determine whether the driving simulator can predict future crash occurrences. Once validated with broader population-based samples, this type of simulator will be a safe and cost-effective tool to screen out problematic drivers.

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