Driving simulation in the clinical setting: utility for testing and treatment

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Abstract

Driving simulation has the potential to be useful in the clinical setting for testing and treating impairments of visual perception, cognitive functioning and driver safety across a wide variety of conditions and age ranges. It also may be used alone, or adjunctively with pharmacologic intervention, as a treatment to improve visual (e.g. visual search, kinetic depth), cognitive (e.g. attention, situational awareness, learning) and driving skills (avoidance of hazardous situations and conditions). Driving simulation offers the advantages of testing performance, rather than function alone, because it integrates perceptual input, cognitive processing and behavioral output into a single dynamic, feed-forward and feed-back iterative loop. It can reveal impaired performance when visual acuity is good and cognitive impairment is mild. Validation, reliability and generalizability studies will need to be done before driving simulation is widely used in clinical settings. Future research is needed to develop open standards for driving simulation tests (e.g. attention, time to crash, car following, hazard avoidance) and to validate these tests against other tests of visual perception, cognition and learning, as well as, on-road driving performance (testing) and experience (driving habits, tickets, crashes). For testing and treatment, issues of practice effect and required levels of fidelity relative to visual perception and cognitive functioning (e.g. attention) will need further clarification. Ways of avoiding simulation sickness will also need to be addressed. Lastly, research is needed to develop diagnostic and treatment protocols to determine which battery (profile) of driving simulation capabilities is best suited for which conditions.

Keywords – Driving simulator, clinical setting, cognitive, functioning, performance testing

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1. Introduction

Driving simulation has the potential to be an important test and treatment for perceptual (vision) and cognitive impairments [1-18]. It can also help to evaluate and remediate educational deficits in knowledge, skills and abilities involving driver safety independent of these impairments to improve judgment, attention and situational awareness [19]. Visual and cognitive impairment, as well as, driver safety are big, growing and costly problems [20, 21]. Caltrans reported 174, 882 accidents on California highways alone, costing drivers and society 3.1 billion dollars in lost lives, property and productivity [21]. For people with health related problems, this is due to an aging population, an increased awareness and improved diagnosis of visual and cognitive impairments, and a rapidly growing pipeline of costly treatments and procedures for these conditions. This is compounded by a lack of sufficiently good methods to evaluate visual and cognitive impairments and to determine which treatments are best under which circumstances. For people without significant vision or cognitive impairments, evaluating driver safety represents an opportunity to engage in effective public health prevention. Larger, more powerful vehicles, travel at higher rates of speed, increasing traffic congestion, technology driven distractions both inside and outside the vehicle, road rage, road and sign design issues are a few of the growing driver safety issues that driving simulation might address, particularly in the elderly. As a test of diver knowledge, skills and abilities, simulation could identify areas of needed improvement; as a teaching or learning device, it might provide a compelling means of enhancing situational awareness, improving judgment and re-enforcing good driving habits and knowledge of rules of the road. Driving simulation, in patients with or without vision and cognitive impairment, can simulate the dangers and risks of driving, without its consequences. Its value lies in its ability to realistically present real time feedback and replay of driving errors and deficits of attention, which might lead to hazardous situations and injurious crashes. Furthermore, driving simulation connects to real world activities in ways that typical clinical tests do not. The remainder of this paper will focus on the utility of driving simulation for evaluating impairments of vision and cognition.

2. Background

As the population ages, there is growing concern about driver safety, which is directly related to declining visual and cognitive performance [22]. Cataracts, glaucoma, macular degeneration and diabetic retinopathy are the principal causes of impaired vision in patients over 55 years of age [22; 23]. With advancing age, Alzheimer's disease, stroke, Parkinson's disease and related conditions cause declines in cognitive abilities [22], but also impair vision and visual functioning, even when visual acuity remains relatively good [24,25,29,30].

To older people driving represents freedom, independence and dignity, and loss of driving privileges and restricted mobility would result in a significant reduction in quality of life. This is an emotional issue, which often results in difficult judgments and choices regarding driver safety. While many older drivers adapt to declining physical and cognitive abilities and either restrict or stop driving, some do not. Furthermore, these difficulties are compounded by blurred boundaries of the transition zone between competent and incompetent driving performance [22,23].

In the non-elderly population there are also a wide variety of medical conditions in which vision and cognitive impairments are present. These include patients with acquired brain injury associated with depression [5], HIV [28], attention deficit disorders [8], sleep disorders [11], chronic pain [31.32], alcohol/drug abuse [33,34], transplant surgery [35], cardiac arrhythmias [36], traumatic brain injury [37] and other disorders. It is equally challenging to evaluate driving competence in these patients as in the elderly [22].

DMV officials and healthcare professionals are increasingly concerned by the lack of useful screening tests to evaluate driver safety [22,31]. DMVs traditionally have relied on vision and road testing. Testing high contrast visual acuity is necessary, but far from sufficient to evaluate impaired driving abilities, particularly in the elderly [24-27]. Visual acuity can remain relatively high when contrast sensitivity and visual functioning are significantly impaired 24,25,27]. Vision care specialists go beyond visual acuity to include visual fields and examination of the eye to detect conditions that impair vision (e.g., cataracts, macular degeneration), but do not routinely test other important psychophysical dimensions of vision including contrast sensitivity, visual processing speed, direction of motion, optic flow or kinetic depth perception. Furthermore, relevant cognitive components of vision are also excluded in routine eye exams, even in the elderly. For example, measures of visual search, visual attention, and visual memory are not part of the usual repertoire employed by clinicians evaluating vision.

Because it is not widely appreciated that cognitive and vision impairments are closely linked, screening for these conditions is not typically being conducted during the same visit or by the same clinician. Ophthalmologists and optometrists do not assess cognitive decline; likewise, primary care physicians and neurologists do not typically screen for visual impairment.

Driving simulation offers the advantages of testing performance, rather than function alone, because it integrates perceptual input, cognitive processing and behavioral output into a single dynamic, feed-forward and feed-back iterative loop. Combined measurement of visual and cognitive performance during driving simulation is becoming a valuable method of assessing early vision and cognitive impairments [3-12]. In patients with cataracts, for example, further evaluation beyond routine eye tests may be indicated because visual and cognitive impairments are predictive of injurious and non-injurious car crashes [33,39]. Driving simulation is also useful for evaluating driving ability in people without those impairments. Driving simulation has high face validity because many aspects of visual and cognitive performance are widely recognized as a requirement for safe driving and are understood by patients, clinicians and regulatory agencies alike. Further, visual and cognitive performance during driving simulation, under varying road and weather conditions, is closer to "real world" activities than clinical tests [31,38,40] of visual acuity or contrast sensitivity

3. Barriers to the use of driving simulators in the clinical setting

However, driving simulation tests typically have been expensive, lacked portability, and were often time consuming to perform. Further, there are few published validation studies for driving simulators that demonstrate significant correlations to known crash rates, driving habits or clinical measures. For these reasons driving simulation tests have not been widely deployed in academic, clinical or DMV settings. More recently, PC-based driving simulators and technologies offering greater portability show promise. The purpose of this type of platform is to permit relatively automated measurement of visual performance during driving simulation in clinical settings and other relatively uncontrolled environments with minimal supervision.

4. Utility and efficacy as a performance test

It has been long recognized that vision and cognition are both pre-requisites to safe driving, but we have had insufficient methods for evaluating safe driver performance in the medical setting. Driving simulation's value as a test of dynamic visual perception and cognition lies in its capability to measure performance rather than isolated aspects of organ system functioning because it integrates perceptual input, cognitive processing and behavioral output into a single dynamic, iterative, feed-forward and feed-back loop. In some ways it can be thought of as a "treadmill" test for the brain and can be used much like the treadmill test is used in cardiology, as a second tier test to aid decision making in diagnosis and treatment. As a second tier test, the driving simulator will be most useful in three ways: to stratify risk and severity of illness at a point in time, to follow disease progression over time; and as an outcome measure of different disease treatments when impairment in vision and cognition are involved. First, stratifying risk and determining severity of illness will help patients, families and DMVs establish boundaries for driver safety that map driver performance more closely to measures of clinical impairment. Second, utilizing driving simulation to follow the natural course and treatment outcomes of different diseases will improve clinicians' ability to provide prognoses that are salient to patients because it will incorporate patient functioning as a direct measure of quality of life. Thirdly, driving simulation will serve as an outcome measure and external criterion to determine the effectiveness among and between different medical treatments and procedures.

Driving simulation will help to guide medical decision-making and improve choices between alternative treatments or procedures, for visual and cognitive impairments that may have similar effects on clinical measures, but different impacts on functioning and quality of life. For example, different medications for memory or attention may have similar effects on visual processing speed or the Mini-Mental State Exam, but may have significantly different impacts on attention and vigilance in driving simulation scenarios. Furthermore, early treatment of cataracts, glaucoma and macular degeneration, or mild cognitive impairment, may be indicated when visual acuity is moderately reduced or cognitive impairment is mild, but driving simulation results reveals significant declines. Validation, reliability, sensitivity, specificity and generalizability studies will be needed before driving simulation can be widely used as a test in clinical settings. Ease of use and administration will also influence its deployment, as will ease of interpreting test results and applying them to medical decisions. Furthermore, understanding the "practice effect" on repeated measures and variation of results due to fluctuation of disease states, will improve interpretation of test results and treatment outcomes. Lastly, the establishment of outcome profiles of different driving simulation scenarios will help clinicians use standardized scenarios to evaluate different treatments of different disorders.

5. Utility and Efficacy as a Treatment

Although not yet validated for this purpose, driving simulation's greatest value may be in its use as a treatment. As a therapeutic device, driving simulation would be used to treat vision and cognitive impairments across a wide variety of conditions and age ranges. Driving simulation would be employed as a learning tool to correct deficiencies in knowledge and re-enforce previously learned driving skills lost through declines due to disease or aging. For example, driving simulation might be used to improve identified deficiencies or prepare drivers to regain driving privileges after cataract or laser eye surgery and in patients with stroke, Alzheimer's or Parkinson's disease. Impairments of visual and spatial memory, kinetic depth perception, change blindness, attention, judgment, situational awareness and other dimensions of vision and cognition are potential treatment targets that driving simulation could uniquely provide to patients with different acquired brain injuries. These are uncharted territories, but the potential for sustained improvement in perceptual and cognitive abilities may be significant when intervention is early and driving simulation is combined with medical therapy.

6. Future Directions

Although driving simulation may have significant potential as a useful clinical test, treatment, or educational device, there are a number of areas that need further development and investigation. Driving simulation has the advantage of high face validity and intuitive appeal. However, before driving simulation is widely accepted and deployed for use in clinical settings, studies of efficacy and reliability are needed, as are demonstrations of its generalizability across different health conditions, geographical locations and cultures.

Development of open standards for simulation scenarios (e.g. attention, time to crash, car following, hazard avoidance) are needed and the relationship between simulation fidelity and underlying constructs of vision and cognition requires further exploration. An understanding of the latest research on visual perception, visual attention and visual memory is necessary for valid scenario development. For example, how much visual fidelity is sufficient to evaluate motion in depth with car following? What level of ecological representation is needed to assess efficiency of visual search and selective attention in hazard avoidance, lane maintenance and detection of control devices? Defining these and other issues of scene content are necessary to ensure the validity between simulation tasks and their underlying visual and cognitive functions. Driving simulation's ability to map to on-road driving performance and experience (driving habits, tickets, crashes), as well as other activities of daily living, also require further clarification. Lastly, developers and clinicians will have to find ways to minimize or eliminate simulation sickness.

7. Conclusions

As a performance test, driving simulation has the potential to be useful across a wide variety of conditions and age ranges, to evaluate impairments of perception and cognition, and to remediate deficits in knowledge, skills or abilities related to driver safety. It may be possible to use driving simulation as both a test and a treatment. As a test it may be useful for screening and early detection of different diseases and conditions, following disease progression and assessing severity of illness, and as an outcome measure of different treatments. Driving simulation technology has become affordable, and can be easily transported from one location to another. Further, simulation software is extensible and easily upgraded. Development of open test standards, measurement criteria, and validation and reliability studies are needed to demonstrate its efficacy and cost-effectiveness in clinical settings.

References

1. Gaba D.M. (2004). The future vision of simulation in health care. *Qual Saf Health Care*.;**13(1)**, i2-i10.
2. Campagne A., Pebayle T., Muzet A. (2004). Correlation between driving errors and vigilance level: influence of the driver's age. *Physiol Behav*. **80(4)**, 515-24.
3. Lee H.C., Lee A.H., Cameron D., Li-Tsang C. (2003). Using a driving simulator to identify older drivers at inflated risk of motor vehicle crashes. *J Safety Res.*, **34(4)**, 453-9.
4. Roenker D.L., Cissell G.M., Ball K.K., Wadley V.G., Edwards J.D. (2003). Speed-of-processing and driving simulator training result in improved driving performance. *Hum Factors*, **45(2)**, 218-33.
5. Brunnauer A, Laux G. (2003). Driving capacity and antidepressive drugs. *Psychiatr Prax*., **30(2)**, S102-5
6. Hancock PA, de Ridder SN. (2003). Behavioural accident avoidance science: understanding response in collision incipient conditions. *Ergonomics*, **46(12)**, 1111-35.
7. Lee H.C., Cameron D., Lee A.H. (2003). Assessing the driving performance of older adult drivers: on-road versus simulated driving. *Accid Anal Prev*. **35(5)**, 797-803.
8. Lee H.C., Lee A.H., Cameron D. (2003). Validation of a driving simulator by measuring the visual attention skill of older adult drivers. *Am J Occup Ther*. **57(3)**, 324-8.
9. Freund B., Gravenstein S., Ferris R., Shaheen E. (2002). Evaluating driving performance of cognitively impaired and healthy older adults: a pilot study comparing on-road testing and driving simulation*. J Am Geriatr Soc*. **50(7)**, 1309-10.
10. Moller J.C., Stiasny K., Hargutt V., Cassel W., Tietze H., Peter J.H., Kruger H.P., Oertel W.H. (2002). Evaluation of sleep and driving performance in six patients with Parkinson's disease reporting sudden onset of sleep under dopaminergic medication: a pilot study. *Mov Disord.* **17(3)**, 474-81.
11. Orth M., Leidag M., Kotterba S., Widdig W., de Zeeuw J, Walther J.W., Duchna H.W., Schafer D., Schlafke M.E., Malin J.P., Schultze-Werninghaus G., Rasche K.. (2002). Estimation of accident risk in obstructive sleep apnea syndrome (OSAS) by driving simulation. *Pneumologie*. **56(1)**, 13-8.
12. Rizzo M., McGehee D.V., Dawson J.D., Anderson S.N. (2001). Simulated car crashes at intersections in drivers with Alzheimer disease. *Alzheimer Dis Assoc Disord.,* **15(1)**, 10-20.
13. Featherstone K.A., Bloomfield J.R., Lang A.J., Miller-Meeks M.J., Woodworth G., Steinert R.F. (1999). Driving simulation study: bilateral array multifocal versus bilateral AMO monofocal intraocular lenses. *J Cataract Refract Surg*. **25(9)**, 1254-62.

14. de Waard D., van der Hulst M., Brookhuis K.A. (1999). Elderly and young driver's reaction to an in-car enforcement and tutoring system. *Appl Ergon*., **30(2)**, 147-57.
15. Cox D.J., Quillian W.C., Thorndike F.P., Kovatchev B.P., Hanna G. (1998). Evaluating driving performance of outpatients with Alzheimer disease. *J Am Board Fam Pract*., **11(4)**, 264-71.
16. Szlyk J.P.,Pizzimenti, C.E.,Fishman G.A., Kelsch R.,Wetzel L.C.,Kagan S.,Ho K.(1995).A comparison of driving in older subj.s with/without age-related macular degen. *Arch Ophthalm*., **113(8)**:1033-40.
17. Szlyk J.P., Seiple W., Viana M. (1995). Relative effects of age and compromised vision on driving performance. *Hum Factors*, **37(2)**, 430-6.
18. Szlyk J.P., Brigell M., Seiple W. (1993). Effects of age and hemianopic visual field loss on driving. *Optom Vis Sci*., **70(12)**, 1031-7.
19. Vancic K., Hesketh B. (2000). Learning from errors in a driving simulation: effects on driving skill and self-confidence. *Ergonomics*, **43(12)**, 1966-84.
20. Litman T Transportation Cost Analysis: Techniques, Estimates and Implications. Victoria Transport Policy Institute, June 2002.
21. Caltrans, Collision Data on State Highways, 2001
22. Rizzo M., Kellison I.L. (2004). Eyes, brains, and autos. *Arch Ophthalmol*. **122(4),** 641-7.
23. Uc E.Y., Rizzo M., Anderson S.W., Shi Q., Dawson J.D. (2004). Driver route-following and safety errors in early Alzheimer disease. *Neurology*. **63(5),** 832-7.
24. Cronin-Golomb A., Corkin S., Growdon J.H. (1995). Visual dysfunction predicts cognitive deficits in Alzheimer's disease. *Optom Vis Sci.*, **72(3)**, 168-76.
25. Cronin-Golomb A. (1995). Vision in Alzheimer's disease. *Gerontologist*. **35(3)**, 370-6.
26. Rizzo M. (2000). Clinical assessment of complex visual dysfunction. *Semin Neurol*., **20(1)**, 75-87.
27. Rizzo M., Anderson S.W., Dawson J., Nawrot M. Vision and cognition in Alzheimer's disease.
28. Marcotte T.D., Wolfson M.A., Rosenthal M.E. et al. (2004). A Multimodal Assessment of Driving Performance in HIV Infection. In press
29. Mapstone M., Steffenella T.M., Duffy C.J. (2003). A visuospatial variant of mild cognitive impairment: Getting lost between aging and AD. *Neurology*, **60(5)**, 802-8.
30. Mapstone M., Rosler A., Hays A., Gitelman D.R., Weintraub S. (2001). Dynamic allocation of attention in aging and Alzheimer disease: uncoupling of the eye and mind. *Arch Neurol.*, **58(9)**, 1443-7.
31. Schuler M., Njoo N., Hestermann M., Oster P., Hauer K. (2004). Acute and chronic pain in geriatrics: clinical characteristics of pain and the influence of cognition. *Pain Med.*, **5(3)**, 253-62.
32. Ersek M., Cherrier M.M., Overman S.S., Irving G.A. (2004). The cognitive effects of opioids. *Pain Manag Nurs*. **5(2)**, 75-93.
33. Anttila T., Helkala E.L., Viitanen M., Kareholt I., Fratiglioni L., Winblad B., Soininen H., Tuomilehto J., Nissinen A., Kivipelto M. (2004). Alcohol drinking in middle age and subsequent risk of mild cognitive impairment and dementia in old age: a prospective population based study. BMJ. ;329(7465):539. Epub 2004 Aug 10.
34. Tapert S.F., Ozyurt S.S., Myers M.G., Brown S.A. (2004). Neurocognitive ability in adults coping with alcohol and drug relapse temptations. *Am J Drug Alcohol Abuse*, **30(2)**, 445-60.
35. Perez-San-Gregorio M.A.,Martin-Rodriguez A.,Asian-Chaves E.,Gallego-Corpa A.,Correa-Chamorro E., Perez Bernal J. (2003). Psychopathological features in transplant patients. *Transplant Proc*. **35(2)**, 744-5.
36. Ylikoski R., Ylikoski A., Raininko R., Keskivaara P., Sulkava R., Tilvis R., Erkinjuntti T. Cardiovascular diseases, health status, brain imaging findings and neuropsychological functioning in neurologically healthy elderly individuals.
37. Schretlen D.J., Shapiro A.M. (2003). A quantitative review of the effects of traumatic brain injury on cognitive functioning. *Int Rev Psychiatry*. **15(4)**, 341-9.
38. Owsley C., Stavely B.T., Wells J., Sloane M.E., McGwin G. (2001). Visual risk factors for Crash involvement in older drivers with cataract. *Archiv Ophthalmol*: 119:
39. Owsley C., Ball K., McGwin G., Sloane M.E., Roenker, D.L., White M.F., Overley E.T. (1998). Visual processing impairment and risk of motor vehicle crash among older adults. *Jama*,; **279**, 1083-1088.
40. Owsley C. Sloane M.E. (1987). Contrast sensitivity, acuity and the perception of “real” world targets **71**, 791-796.