The assessment of driving abilities

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Abstract

Driving an automobile is an activity deeply embedded in many societies. As one of the most dangerous of daily tasks, there has been increased interest in establishing methods for identifying drivers at risk for accidents, both in the normal aging population and neurologic cohorts. The aim of this paper is to review the major methodologies that have been applied for the assessment of driving abilities, and to discuss their relative benefits and limitations. Laboratory measures, such as neuropsychological tests, have been used to infer poor driving skills based upon poor test performance, but have met with mixed success. While poorer global cognitive performance is associated with impaired driving, the specificity of the neuropsychological measures has been limited. Measures of visual attention appear to be the most promising of the in-clinic measures. Accident history (often based upon accidents per million miles) has been used to examine whether certain populations are at greater risk for on-road accidents. While this provides a valid measure of "real world" risk, it does not inform researchers and clinicians regarding individual risk and may over- or under-estimate risk depending upon the driving environs. On-road evaluations, either on public streets or a closed course, are often considered the gold standard for determining driving impairment. These assessments have the best face validity, most closely approximating true driving, but there remains some question as to whether they adequately assess all important driving skills (e.g., judgment and executive functioning). Lastly, the emergence of driving simulators has provided an exciting opportunity to evaluate underaddressed skills such as accident avoidance and navigational abilities, and to experimentally delineate the components of driving performance. Concerns remain regarding their realism and usability in various populations. Given the limitations of each method in detecting impaired drivers, we recommend a multi-modal approach to assessing risks at both the group and individual level. Future directions include application of new technologies such as eye trackers to better evaluate aspects of the driving process, such as attentional allocation. Lastly, we briefly review the development of a driving research program at the HIV Neurobehavioral Research Center in the United States.

Keywords – Driving, driving assessments, driving simulations

1. Introduction

In developed nations, driving an automobile is an important everyday activity that is often associated with an individual's sense of identity. Many areas lack the public transportation infrastructure necessary to provide adequate mobility to individuals without vehicle use, and driving continues to be the primary form of transportation [1]. Driver safety is therefore of the utmost concern, and extensive research has focused on effective ways to detect individual impairment in driving ability, mostly in aging populations. However, one has to approach the identification of unsafe drivers with caution, as designating an individual's driving ability as "impaired" can preclude driving privilege, at times incorrectly. The loss of one's license can hamper independent living and individual freedom, and driving cessation has been associated with an increase in depressive symptoms in older drivers [2, 3]. Although not addressed in this paper, in acknowledgement of the dearth of transportation alternatives that are available in many countries, there has been a strong emphasis on the development of remediation methods in order to maximize that period over which individuals can drive safely.

Older driver safety is an increasing public health concern. For example, although older drivers in the United States have the lowest crash rate per licensed driver of all age groups, their accident rate per million miles driven is higher than most other age groups (with the exception of the 16 – 20 year old age group), and even more alarming, their fatality rate per accident is higher than any other age group [4, 5]. However, the cause of the higher accident rate is unclear. Slight declines in driving performance have been shown to occur with normal aging [e.g., 6, 7], but there is by no means consensus regarding the extent or even occurrence of such declines [8]. It has been argued that age itself is not necessarily a risk factor for increased accidents, but rather the specific changes that often accompany aging [9, 10]. As such, older age groups are potentially at greater risk of driving impairment due to increased medication use, functional injuries, and medical conditions that affect driving ability, and subgroups with these conditions may increase the average risk for the entire age group [11].

The prevalence of the aforementioned crash risk factors are even greater in clinical disease samples, particularly in conditions that affect the central nervous system. To this end, impairments in driving ability have been reported in individuals with Alzheimer's disease [e.g., 12, 13], vascular dementia [14], Parkinson's disease [e.g., 15, 16], traumatic brain injury [e.g., 17, 18, 19], stroke [e.g., 20] and Huntington's disease [e.g., 21]. In addition, research has recently begun to focus on neurological conditions in younger populations more likely to be current drivers, finding poor driving performance in cognitively impaired individuals with HIV [e.g., 22, 23], liver disease [e.g., 24], and Multiple Sclerosis [e.g., 25, 26].

Importantly, most studies of neurologic patients have found that a diagnosis alone is not necessarily sufficient cause for a person to lose his or her drivers license. For example, Hunt et al. [12] found that some individuals with mild Alzheimer's Disease continued to have adequate driving skills, and in our own research only a subset of all persons with HIV-associated cognitive impairment evidence a significant decline in driving performance. It is thus incumbent upon clinicians and researchers to develop effective methods of identifying at-risk individuals, since one cannot rely on broad classifications for such a critical decision.

Establishing efficient and accurate assessments of driving impairment, however, poses a significant challenge. Driving is a complex task requiring intact attention, perception, tracking, choice reactions, sequential movements, judgment, and planning. Michon [27] has proposed a hierarchical control structure involved in driving, composed of simultaneous activity on strategic, maneuvering (tactical), and operational levels. With such a wide range of skills involved, operationalizing the concept of impaired driving and determining the best method of assessing driver impairment have been significant challenges, and although on-road evaluations are often used as a 'gold standard,' they are not universally accepted as such [28]. The results of many driving assessments are often determined by a subjective global assessment that may not comprise all possible problem areas. Even when driving assessments are standardized and comprehensive, they are often not validated against criterion variables of interest, such as accidents or violations. Studies that do validate against driving history may have insufficient statistical power, in that accidents and violations are relatively rare events and are often underreported [29]. Furthermore, if a study does find significant differences or an increased risk ratio between clinical and control populations, it is often not clear how much individuals are actually at risk in the real world due to these differences. This is especially of consequence in disease populations, where a diagnosis can often mean the loss of a license, even without additional assessments of driving competence. In addition, reliable and criterion based cutoffs for failure on many measures have not been established, leading to different concepts of an “unsafe performance.”

At the same time, significant advances in driving assessment have taken place in the last decade. There has been an increased focus on standardizing on-road evaluations, possibly leading to more reliable and replicable studies [29]. Driving simulators have become both state of the art and increasingly affordable, with enhanced technology, graphics, and realism. In addition, there have been significant advances in developing focused tests that may help delineate the specific cognitive and sensory components involved in driving behavior.

The objective of this paper is to examine the various methodologies of assessing driving behavior in potentially impaired populations. The first section will review clinic based performance measures, such as neuropsychological and attention/perceptual tests, that have attempted to predict driving performance in clinical populations. The next section will focus on the various approaches to driving assessments, such as on-road assessments, review of driving history, and simulator assessments, and their relative strengths and limitations. The final section will briefly address the development of our driving assessment lab at the HIV Neurobehavioral Research Center.

2. Laboratory based assessment approaches

2.1 Neuropsychological Tests

Despite a long history of using neuropsychological (NP) tests to infer driving competence, investigations of the relationship between NP tests and driving have historically met with mixed results. Early investigations into the prediction of driving competence in brain injured or disease populations used NP tests that assessed functions the authors assumed were both relevant to the driving tasks and impaired in these populations, although the predictor variables (NP tests used) and the criterion variables (usually driving tests or driving history) varied by study [30-33]. Results have thus been inconsistent.

Later studies developed more standardized road tests and multi-modal forms of assessment (such as combinations of on-road, simulator, and medical evaluations and NP tests), leading to increased reliability and validity in criterion variables. However, results still varied. Although some studies found NP tests to be predictive of on-road [e.g., 14, 34, 12] and driving simulator performance [e.g., 21, 35, 23], others still found poor relationships between the two [e.g., 36, 37]. In studies that did find relationships, tests of visuospatial abilities (e.g., WAIS-III Block Design, Motor-Free Perceptual test), executive function (e.g., Trail Making Test B), visual search (Letter Cancellation test), motor skills (e.g., Finger Tapping), and attention (e.g., WAIS-III Digit Span) tended to be the most robust. Regardless, there is still no clear consensus regarding which NP measures best identify high risk drivers. The weakness of correlations between NP test results and on-road driving performance makes it difficult to determine from NP tests alone whether cognitively impaired subjects are safe or unsafe drivers. It has been argued that this might occur because NP tests only assess impairment at the strategic or tactical level of driving, which might raise questions about the ecological validity of the evaluation [38]. More likely, it seems that a general consensus on the relationship is difficult to attain, in part due to varying participant populations, divergent test batteries, and different gold standards regarding what constitutes driving impairment [39, 40]. However, as indicated in a review by Withaar et al. [39], the general conclusions are that cognitively impaired individuals as a group perform significantly worse than controls on both neuropsychological and driving measures, and increased levels of cognitive impairment are found in groups involved in traffic accidents. Since no single evaluation of driving safety can possibly assess all abilities involved in an activity as complex as automobile driving, NP tests remain a reasonable modality for evaluating aspects of a patient's fitness to drive.

2.2 Attentional and Perceptual Tests

Variable success in predicting driving behavior has been achieved with attentional and perceptual tests. Despite their widespread use, tests of visual acuity and visual field loss have been reported as weakly associated with driving behavior, if at all, except in cases of ocular injury [41, 42]. Contrast sensitivity deficits, on the other hand, have shown stronger associations and deserve further study [43, 42]. Some aspects of visual cognition that may affect driver safety, such as attention and object perception, are rarely measured in standard clinical visual assessments [44].

Tests of visual attention, such as the Useful Field of View (UFOV) [45], have been shown to be more sensitive indicators of driving impairment [46]. The UFOV is a computerized measure that assesses the amount of time it takes an individual to accurately acquire both central and peripheral visual information without head or eye movements. In aging populations, worse UFOV has been correlated with higher rates of past [47] and future automobile accidents [46], and associated with poor performance during on-road driving evaluations [48, 49]. UFOV is also significantly reduced in many patient populations, including persons with traumatic brain injury [50], multiple sclerosis [25], stroke [51, 52], HIV [53], and mild Alzheimer's disease [48]. UFOV is commercially available, easy to administer on a traditional PC, and has been shown to provide incremental validity to standard laboratory tests, and thus may offer diagnostic utility to clinicians and researchers.

3. Direct approaches to driving assessment

There are a variety of methodologies for directly assessing driving abilities, each with its own strengths and limitations. These include evaluating abilities based upon an on-road drive (open and closed course), reviewing recent driving history, and assessing performance on a laboratory-based driving simulator.

3.1 Behind the Wheel Evaluations

3.1.1 On-Road Driving Evaluations

On-road evaluations are most often considered the gold standard for identifying impaired drivers, as they provide the greatest face validity, with true sensory feedback and quasi-'real world' situations [39]. Participants typically drive a standardized route and are scored by driving rehabilitation specialists on tasks such as scanning the environment, maintaining safe distances, and whether they make dangerous or risky maneuvers. Studies that utilize structured evaluations through clinical ratings have achieved adequate reliability [54, 34, 22], but questions still exist regarding the validity of the tests. Often the participants are presented with step by step instructions that do not necessarily emulate the decisions made in 'real world' conditions (e.g., reactions to novel or emergency conditions such as a pedestrian appearing in the roadway or navigational decisions), and evaluations may not be able to detect certain problem areas (e.g., specific instructions may not facilitate detection of deficits in executive functions), leading to inaccurate estimates of safety. Interestingly, even though subjects may complete a similar route, under real traffic conditions unanticipated cueing can take place, affecting the standardization of scoring. For example, in a study of mildly impaired Alzheimer's disease patients [55], individuals drove through an unregulated intersection without slowing. However, if the car in front of the participants slowed at the intersection, they would mimic the behavior and also slow at the intersection. Ratings of on-road driving are also complicated by the fact that the primary examiner often needs to worry about safety issues (e.g. grabbing the steering wheel if it is unsafe). Thus, on-road evaluations are typically oriented towards a clinical impression of the individual's driving ability and do not necessarily utilize objective criteria that have been clearly delineated. Despite these limitations, this methodology still provides valuable insights regarding how some individuals may perform under reasonably controlled, and 'real life' situations.

3.1.2 "Closed Course" On-Road Driving Evaluations

"Closed course" evaluations provide the same sensory feedback but offer an additional level of situational control. Often these evaluations measure basic operational skills, such as the standard deviation of lateral position (a measure of the degree to which individuals adjust lane position while driving), reaction time in braking or recognition, or maneuvering through cones or other objects [e.g., 56, 30, 31]. Some add a divided attention task to increase complexity [e.g., 7]. Most are conducted without interaction with other vehicles and therefore ensure a level of control that in-traffic evaluations cannot provide. However, it is often not practical to find a location to conduct these evaluations. Furthermore, "closed course" evaluations, depending upon their design, may only capture one level (operational) of Michon's [27] three levels of driving performance, and do not assess many important skills such as decision making or maneuvering in traffic. Therefore, these have been recommended only as a precursor to actual on-road assessment [29].

3.2 Accident History

In order to get the most realistic impression of how individuals perform in their usual driving environment, investigators often examine a driver's accident history. It provides a sample of behavior over an extended period of time, thus avoiding one limitation of laboratory-based assessments (only providing a 'snapshot' of the person's functioning). In addition, this extended sampling adjusts for an individual's avoidance of certain situations and overall amount of exposure. For example, one individual who believes he is poor at highway driving may consistently avoid highways, and thus be at much less accident risk than another who may continue to drive on the highway. Studies have shown differential use of compensatory strategies (either reduction of miles driven or avoidance of certain situations) between control and cognitively impaired groups [57, 58, 51, 59, 21], although this is a complex relationship that may be mediated or moderated by other factors, such as gender or the availability of other drivers in the household [60]. Nonetheless, many cognitively impaired individuals do continue to drive, and there is no clear evidence that compensatory strategies are effective in actually reducing the risk of future crashes [11].

A review of driving history also does not directly inform us of how an individual would perform under unusual (but not entirely rare) situations, such as a car maneuvering in front of the driver. In addition, other unidentified factors may affect accident rates. For example, an accident can be caused by another driver, leading to overestimates of driver impairment, or an accident can be avoided because of the defensive behavior of other drivers on the roadway, leading to underestimates of driver impairment. Another difficulty concerns the availability of appropriate accident statistics. State motor vehicle records are often difficult to obtain and tend to reflect underreporting of accidents, since most individuals do not report minor accidents. Self report of accidents and violations is complicated by possible biases, including the desire to look good to the researcher and the inaccuracy of normal memory, much less cognitive impairment in neurologic populations.

3.3 Driving simulators

Driving simulations overcome some of the limitations detailed earlier and enable the investigator to examine driving behavior under more controlled and standardized conditions. Simulations range from as simplistic as having the participant press a pedal when a specified target appears on the screen, to full motion systems that provide horizontal and longitudinal travel, nearly 360 degrees of rotation, thus providing the driver with realistic acceleration, braking, and steering cues (e.g., the University of Iowa/National Highway Traffic Safety Administration's National Advanced Driving Simulator; Simulator III at the Swedish National Road and Transport Research Institute). In between these two extremes are high-fidelity, low cost simulators that are modifiable and provide a feasible alternative to many researchers wishing to measure driving behavior in normal controls, as well as the effects of medical conditions or medications on everyday activities of daily living. Simulator performance has been considered both an outcome, indicative of poor driving abilities [61-64, 23, 25] as well as a useful predictor of poor on-road performance [65, 22, 66].

Although much of routine driving involves overlearned behaviors, there are also times when drivers must take quick, decisive action, or anticipate risks and adjust their driving accordingly. This could be considered analogous to piloting an aircraft, in which the vast majority of activities are entirely routine. But in a crisis situation it is imperative that the pilot/driver be cognitively intact across many domains. Thus, a principle advantage of simulator technology is the ability to place participants into accident avoidance situations (e.g. pedestrians walking into the roadway), wherein they must take evasive action, as well as novel conditions (e.g., fog, mountain driving) that are not reproducible during on-road evaluations [61, 23]. Since these responses require higher level and integrated skills such as attention, spatial processing, processing speed, and executive functioning (self-monitoring, judgment), abilities which cannot always be assessed during a directed on-road drive, simulators provide an effective and safe method of evaluation.

Hardware for most present simulations include a steering wheel (proprietary or off-the-shelf joystick style), and brake/accelerator pedals, with the image presented on anything ranging from a single computer monitor to a 360 degree field of view projector system. Methodologies utilized in on-road evaluations, such as tracking the standard deviation of lateral position, and car following behavior, have also been adapted for simulations [62, 67, 68], although the degree to which on-road and simulation performance are interchangeable remains controversial [69]

Another key advantage of simulators is the ability to perform detailed investigation of driving behavior, and its correlates, under controlled conditions. This includes analyses of specific driving maneuvers in potential accident situations [61], application of eye movement analyses to infer attentional allocation [70], and facilitation of high resolution magnetic resonance imaging studies, such as fMRI [e.g., 71], that might provide insights regarding the possible brain regions involved in driving.

There remain limitations to simulator technology. Despite tremendous advances in graphics and processing capabilities, simulators still do not fully recreate the multi-sensory driving experience (i.e., three-dimensional environment, sounds, feel of the roadway, number of typical cars in the road). At the same time, it should be noted that many factors affect how "real" the simulation feels to the participant, including lag time between driver input and car response, screen refresh rates, and the behavior of other simulated vehicles. Interestingly, despite the attention it receives, graphics quality is not necessarily the most salient feature regarding whether participants "buy in" to the experience. For example, in one of our studies in the mid-1990s, the graphics consisted of triangular mountains and square cars displayed on a single VGA monitor. One of the young adult participants derided the examiner for the simulator's lack of realism; later, he proceeded to look over his shoulder to see if it was safe to change lanes!

Even though participants may take the testing seriously, and strive to avoid accidents, they are still aware that a simulator accident will not cause property damage or bodily injury, and thus may not drive as cautiously as they might in the real world. And, although much information can be garnered from computer simulations, they do not negate the necessity for behavioral observation to fully grasp what the participant was doing at the time of an accident.

Lastly, simulation sickness is a constant concern. As realism increases, and participants have a sense of motion, there is greater likelihood of individuals becoming nauseated. This appears to be particularly true for older individuals, especially females. While interventions such as keeping the room cooled and ventilated help prevent motion sickness, they do not eliminate it entirely. And, unfortunately, common motion sickness medications are not indicated since they may themselves affect driving ability.

4. Driving research at the UCSD HIV Neurobehavioral Research Center

The driving research program at the HIV Neurobehavioral Research Center (HNRC) in San Diego evolved out of data in the early 1990s suggesting that impaired cognition is frequent among individuals infected with the Human Immunodeficiency Virus Type-I (HIV+). While a relatively small subset of HIV+ individuals develop severe dementia [72], 30-50% of HIV+ individuals [73] may encounter a more mild form of cognitive impairment that nonetheless impacts everyday functioning. For example, data at the time demonstrated that HIV+ individuals with cognitive impairment short of dementia were less likely to be employed, and those who were employed were more likely to report difficulties on the job [74].

As a result of these and similar findings, in the mid-1990s we initiated a pilot project in collaboration with Systems Technology, Inc., one of the early pioneers in low cost driving simulations [82], to determine whether there was any evidence that these cognitive impairments affected driving performance. For this study, the first to examine driving within an HIV+ cohort, we used two simulations. One simulation was an abbreviated version of a previously validated measure that assessed lane tracking in the context of a divided attention task (taking place in the upper corners of a single monitor), while the other was a more novel, fully interactive simulation in which participants were required to pass cars, follow traffic signs, and respond quickly to accident avoidance situations during a 12 minute drive. In this study (N = 68), HIV+ NP Impaired individuals did more poorly on both tasks, showing increased standard deviation of lateral position and total accidents [23].

Given this initial finding, we embarked on a more comprehensive study of driving performance in HIV infection, as well as the laboratory measures that might best predict driving outcomes. Subsequent studies included application of a 3-monitor wide-field-of-view system to further enhance the realism of the simulations, as well as development of a novel, 5 x 6 block Virtual City, in which navigational and egocentric spatial abilities can be assessed. In collaboration with driving rehabilitation instructors and the California Department of Motor Vehicles, we also have developed structured on-road evaluations [22] that include residential and commercial districts, as well as highway driving.

Although we demonstrated that a subset of those HIV+ individuals with cognitive impairment do more poorly on the simulations (and on-road driving), it still remained to be seen whether simulator performance relates to real world driving. Additional results from our studies do in fact suggest that individuals who have had an accident in the past year [75], as well as licensed drivers who fail an on-road evaluation [22], do significantly more poorly on a variety of simulations, thus supporting the convergent validity of the simulations.

What are the best laboratory-based predictors of poor driving? To date, our research has focused on HIV-associated functioning and suggests that cognitive impairments in executive functioning, attention/working memory, and motor abilities are most closely associated with poor simulator and on-road driving performance. Importantly, it appears that NP tests and simulator evaluations provide unique, independent data regarding the abilities required for intact driving, and thus a multi-modal assessment approach appears most promising [22]. Recently we have begun to explore more focused cognitive constructs, such as the useful field of view [53] and attentional allocation using eye tracking systems, to determine how they might better enhance our ability to detect impaired functions that lead to poor driving performance.

We have also expanded our research program to better clarify the degree to which the relationship between NP functioning and driving performance is disease specific by using the same comprehensive battery (NP testing, driving simulations, and on-road driving evaluations) across varying neurologic disorders (e.g., Alzheimer's Disease, Parkinson's Disease, and stroke). This work is still in progress, as are studies of simulator performance in individuals with hepatitis C infection and participants receiving cannabis treatments for HIV and multiple sclerosis associated maladies.

5. Conclusion

The last decade has seen significant advances in driving assessment. There is increasing appreciation of the importance of establishing the reliability and validity of on-road assessments as well as their limitations. Simulator technology has dramatically improved and perhaps holds the best promise for detailed study of driving behavior, with the ability to put individuals in novel and challenging driving scenarios within a controlled environment. Emerging technologies, such as minimally intrusive eye tracking systems, which measure gaze patterns and allocation of visual attention while driving may in the future be able to identify differences in eye movements between unsafe and safe drivers [e.g., 76, 77]. In-car systems that track automobile movement and instrumentation may also significantly improve our understanding of the cognitive components and physical dynamics of automobile accidents.

As the field matures, and if driving assessment methods such as simulations are to have widespread applicability, it will be increasingly important to develop standardized, psychometrically sound methodologies. Most investigators use methods developed within their own labs, and few assessment methods relating to driving have been widely dispersed for general use (UFOV as an exception) [45]. This limits our ability to translate findings across diseases and within comparable cohorts. In addition, basic psychometric data such as test-retest reliabilities, have been lacking, with a few exceptions [78-80, 54, 22, 81].

In the meantime, a surge in the number of researchers investigating the impact that cognitive impairments have upon driving ability, as well as the increase in rapidly emerging technologies, bode well for our future understanding of this most complex and dangerous of everyday activities and how it is impacted by alterations in brain function.

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