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Driving Difficulties in Parkinson's Disease

Matthew Rizzo,* MD, Ergun Y. Uc, MD, Jeffrey Dawson, ScD,
Steven Anderson, MD, and Robert Rodnitzky, MD

Department of Neurology, College of Medicine, University of Iowa, Iowa City, Iowa, USA

Abstract: Safe driving requires the coordination of attention, perception, memory, motor and executive functions (including decision-making) and self-awareness. Parkinson's disease and other disorders may impair these abilities. Because age or medical diagnosis alone is often an unreliable criterion for licensure, decisions on fitness to drive should be based on empirical observations of performance. Linkages between cognitive abilities measured by neuropsychological tasks, and driving behavior assessed using driving simulators, and natural and naturalistic observations in instrumented vehicles, can help standardize the assessment of fitness-to-drive. By understanding the patterns of driver safety errors that cause crashes, it may be possible to design interventions to reduce these errors and injuries and increase mobility. This includes driver performance monitoring devices, collision alerting and warning systems, road design, and graded licensure strategies. © 2010 Movement Disorder Society

Key words: cognition; driving simulation; instrumented vehicles; car crash; human factors

Automobile driving has become an indispensable activity of daily life, yet vehicular crashes injure millions and regularly kill over 40,000 people in the United States each year at a cost of about $230 billion dollars (NHTSA, 2004).[1] Vehicular crashes kill about 1.2 million people die worldwide and injure tens of millions.[2]

A host of medical, neurological, and psychiatric disorders (e.g., Alzheimer's disease, Parkinson's disease, sleep disorders, personality disorders, and effects of licit and illicit drugs) can impair driving ability. These conditions affect behavior, leading to greater risk of driving errors and crashes. This causal pathway often involves a concatenation of factors, some of which can be prevented or controlled.[3] Relevant interventions can operate before, during or after a crash occurs at the levels of driver capacity, vehicle and road design, and public policy.[4]

*Correspondence to: Dr. M. Rizzo M, 200 Hawkins Drive, 2007 RCP, Iowa city, Iowa, 52242 E-mail: matthew-rizzo@uiowa.edu

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Relationships between driver performance factors and safety errors can be represented by an imaginary triangle[5] or "iceberg."[6] Visible above the "water line" are safety errors that produce car crashes resulting in fatality, injury, or (most frequently) only property damage. Although crashes produce an overwhelming public health burden, they are relatively infrequent events in a statistical sense.[7,8] Hidden below the water line are behaviors that are less directly related to crashes and occur more frequently. These range from less serious errors such as failing to adjust a seat belt, to more serious errors such as driving while drowsy or distracted, leading to near crashes (a.k.a., "near misses").

A key step for determining crash risk in Parkinson's disease (PD) and other disorders is to discover the relationships between high frequency/low severity events that produce errors or near-misses but not crashes, and the low frequency/high-severity events that lead to reported crashes in states' epidemiologic records. It is also important to understand how mental mechanisms and vehicle and road system design features underpin cognitive errors in real world tasks.

PD can interrupt driver performance at several levels of an information processing model for understanding driver errors that may lead to vehicle crashes. The driver: (1) Perceives and attends to stimulus evidence (e.g., through vision, audition, vestibular, and somatosensory inputs) and interprets the situation on the road; (2) formulates a plan based on the particular driving situation and relevant previous experience or memory; (3) executes an action (e.g., by applying the accelerator, brake, or steering controls); and (4) monitors the outcome of the behavior as a source of potential feedback for subsequent corrective actions. The driver's behavior is either safe or unsafe as a result of errors at one or more of these stages in the driving task.

The risk of driver errors in PD increases with deficits of attention, perception, response selection (which depends on memory and decision-making), response implementation (a.k.a., executive functions), and awareness of cognitive and behavioral performance (a.k.a., metacognition). Emotional state, level of arousal (or sleepiness), psychomotor factors and general mobility[9–11] are also relevant. Individuals with impairments in these domains (measured with neuropsychological tests, disease rating scales, and other "off-road" assessment tools) are more likely than unimpaired drivers to commit errors that cause motor vehicle crashes. Drivers normally monitor their performance, detect their errors when feedback on driving performance fails to match expectations, and take corrective action.[12] Drivers with cognitive deficits are less likely to recognize their errors or impairments, and less likely to take corrective action.

FIG. 1. **A**: An "over the shoulder" view shows setup of a driver in SIREN approaching the police car parked by the side of the virtual road. **B**: Normal response: A driver slows down and moves to the left. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

EVIDENCE ON DRIVING

State Records

The main data that transportation researchers have on actual collisions and contributing factors are collected post-hoc (in forensic or epidemiological research). These data are highly dependent on eyewitness testimony, driver memory, and the police reports, all of which have limitations. The best information regarding near-collisions generally comprises anecdotal reports by driving evaluators and instructors (usually testing novice drivers) and police reports of moving violations. Most of these potential crash precursors, if ever recognized, are known only to the involved parties and are never available for further study and dissemination of safety lessons.

Driving Simulator

Driving simulators have been applied to quantify driver performance in cognitively impaired drivers, study basic aspects of cognition in drivers with brain lesions, probe the effects of information processing overload on driver safety, and optimize the ergonomics of vehicle design. Driving simulation offers advantages over the use of road tests or driving records in assessments of driver fitness. Simulator studies provide the only means to replicate exactly the experimental road conditions under which driving comparisons are made and simulations are safe, with none of the risk of the road or test track. There are several different types of simulators such as film, noninteractive, interactive, fixed vs. motion based, desktop, full cab, and so on. Key situations to test in driving scenarios include driving through intersections, around curves, while following other vehicles, while multitasking, and near pedestrians.

Figure 1A shows how driving simulation may be applied to study drivers with PD. In this simulation, which we originally applied in drivers with Alzheimer's disease,[13] subjects drive on a virtual highway passing an emergency vehicle (a police car) stopped by the shoulder of the highway. To minimize the chance of contact with the vehicle or nearby pedestrian the driver had to perceive, attend to, and interpret the roadway situation, formulate an evasive plan, and exert appropriate action on the accelerator, brake, or steering controls, all under pressure of time. Figure 1B shows the typical response of a normal individual, slowing and steering around the parked police vehicle. In our

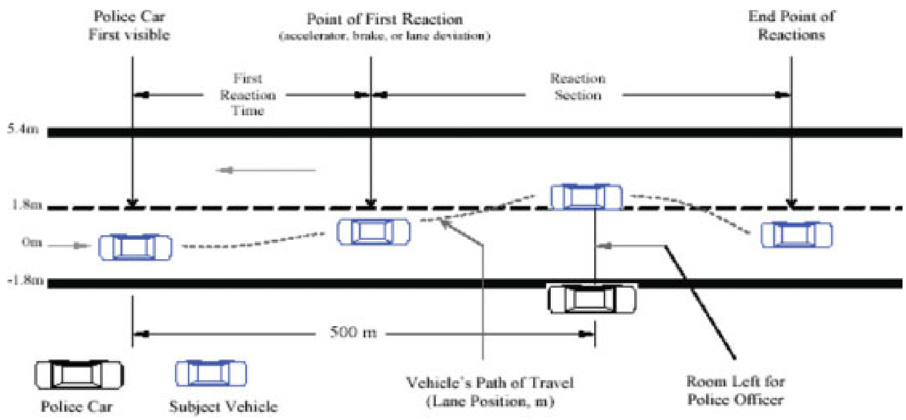

FIG. 2. NIRVANA. **A**: Exterior view. **B**: Interior view showing touch screen for experimental control and data acquisition. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

driving simulator, drivers with PD had worse vehicular control during a motor distracter task[9] and were at a higher risk of crashes under foggy conditions during an illegal intersection incursion by another vehicle.[14]

A relative drawback to simulation research is simulator adaptation syndrome (SAS), characterized by autonomic symptoms including nausea and sweating. The discomfort is believed to be due to a mismatch between visual cues of movement, which are plentiful, and inertial cues, which are lacking or imperfect, even in simulators with a motion base.[15] Choice of equipment and scenario design (e.g., avoiding sharp curves, left turns, frequent stops, and crowded scenes) can minimize SAS.

Another issue in simulator-based research is the need to test the validity of the simulation, which may involve detailed comparisons of driver performance in a simulator with performance in an instrumented vehicle (IV) and with state records of crashes and moving violations in each population of drivers being studied. The apparent face validity of the simulation, that is, the driver appears to be driving a car and is immersed in the task, does not guarantee a life-like performance. Drivers may behave differently in a simulator where no injury can occur, compared with real-life driving situations in which life, limb, and licensure are at stake. They may even perform differently when the same scenario is implemented on different simulator platforms, motivating calls for development of standard scenarios by an international Simulator Users Group (http://www.engineering.uiowa.edu/simusers/, accessed December 1, 2007).

Future application of driving simulation to study drivers with medical impairments will benefit from a standardized approach to scenario design, certification standards for ecological validity of simulator graphics and vehicle dynamics, uniform definitions of measures of system performance, and cost-effective methods for geo-specific visual database development.[16]

INSTRUMENTED VEHICLES

IVs permit quantitative assessments of driver performance in the field, in a real car, under actual road conditions. These natural or naturalistic measurements are not subject to the type of human bias that affects inter-rater reliability on a standard road test. For these reasons, we developed the multipurpose field research vehicles known as the Automobile for Research in Ergonomics and Safety (ARGOS) and Nissan-Iowa Instrumented Research Vehicle of Advanced Neuroergonomic Assessment (NIRVANA; see Fig. 2A,B). These vehicles are designed to examine objective indices of driving performance in normal and potentially unfit drivers and to assess the safety and usability of prototype automotive technologies. Each consists of a midsized vehicle with extensive instrumentation and sensors hidden within its infrastructure.

The driving assessment in an IV can incorporate segments of "baseline" driving to assess vehicle control on uneventful segments of highway under conditions of low-cognitive loading. The drives can also incorporate essential maneuvers such as left turns, right turns, stopping at a stop sign, and maintaining vehicle control. Kinematic measures of driver control during vehicle maneuvers include speed, lateral and longitudinal acceleration, yaw, and others.[17] For example, large lateral accelerations indicate when a driver has swerved to miss an obstacle while large longitudinal accelerations occur when a driver either braked hard or accelerated hard to avoid an obstacle.

In addition, standardized challenges can be introduced that stress critical cognitive abilities during the driving task. These tasks are comparable with scenarios implemented in driving simulators and include route-finding tasks,[18] sign identification,[19] and multitasking, that is, driving while performing distracter tasks (as in holding a conversation or using in-vehicle devices such as cell phones and navigation equipment).[20] At the baseline evaluation of our ongoing longitudinal study, drivers with PD performed significantly worse than control drivers on all motor, cognitive, visual tests, and driving experiments.[21] In an IV on the road, drivers with PD identified fewer targets during visual search,[10] were at higher risk for increase in safety errors during verbal distraction,[11] made more incorrect turns and got lost more often while following a route,[22] and committed more safety errors. Driving performance and safety of drivers with PD on these tasks was predicted by deficits in attention, executive functions, memory, visual perception, and visuospatial abilities, rather than motor dysfunction, emphasizing the disabling effects of cognitive and visual dysfunction even in relatively early stages of PD and the need for a multidisciplinary approach to predict safety of driver with PD.

The advantage of using IVs to study patients with relatively specific cognitive impairments is exemplified in the recent findings of preserved procedural knowledge for driving skills in drivers with relatively circumscribed and dense amnesia following bilateral hippocampal and parahippocampal lesions caused by herpes simplex encephalitis.[23] Radar equipped IVs have provided insights on traffic entry judgments in older drivers with attention impairments.[24]

NATURALISTIC DRIVING

Multiple studies have used IVs in traffic safety research. In most cases an experimenter is present, and drivers who are aware of being observed are liable to drive in an overly cautious and unnatural manner. Because total data collection times are often less than an hour and crashes and serious safety errors are relatively uncommon, no study until recently has captured precrash or crash data for a police-reported crash or on general vehicle usage.

Internal networks of modern vehicles allow continuous detailed information from the driver's own car, including vehicle speed, emissions controls, seatbelt and headlight use, climate and traction control, antilock brake system activation, and other measures. Lane-tracking video can be processed with computer algorithms to assess lane-keeping behavior. Radar systems in the vehicle can gather information on the proximity, following distance, and lane-merging behavior of the driver and other neighboring vehicles on the road. GPS systems can show where and when a driver drives, takes risks, and commits errors. IVs equipped to detect RF signals associated with possible cell phone use (without recording conversations) can assess potential driver distraction and risk acceptance. Wireless systems can check the instrumentation and send performance data to remote locations. These developments can provide direct, real-time information on driver strategy, vehicle usage, upkeep, drive lengths, route choices, and decisions to drive during inclement weather and high traffic.

A person driving his or her own IV is exposed to the usual risk of the real-world road environment without the psychological pressure that may be present when a driving evaluator is in the car. Road test conditions can vary depending on the weather, daylight, traffic, and driving course. However, this is an advantage in naturalistic testing, because repeated observations in varying real-life settings can provide rich information regarding driver risk acceptance, safety countermeasures, and adaptive behaviors, and unique insights on the ranging relationships between low-frequency, high-severity driving errors and high-frequency, low-severity driver errors.

Such "brain-in-the-wild" relationships[25] were explored in detail in a study of naturalistic driving performance and safety errors in 100 neurologically normal individuals, driving 100 total driver years.[26,27] All enrolled drivers allowed installation of an instrumentation package into their vehicle. Data collection provided almost 43,000 hr of actual driving data, over 2,000,000 vehicle miles. There were 69 crashes, 761 near crashes, and 7,479 other relevant incidents. In short, naturalistic studies of driver behavior offer unique insights on vehicle usage by at-risk drivers, which hitherto relied on questionnaires completed by individuals who may have unreliable memory and cognition, and beg to be applied in PD.

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