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The Potential Utility of Driving Simulators in the Cognitive Rehabilitation of Combat-Returnees With Traumatic Brain Injury

Henry L. Lew, MD, PhD; Peter N. Rosen, MD; Darryl Thomander, PhD, ABPP; John H. Poole, PhD

A large number of Operation Enduring Freedom/Operation Iraqi Freedom returnees are seeking DOD and VA rehabilitative care for war-related traumatic brain injury (TBI). This article reviews evidence on the utility of driving simulators as tools for assessment and training in TBI rehabilitation. Traditionally, cognitive rehabilitation has been shown to improve specific cognitive skills. However, there are few studies and only weak evidence to show that these gains transfer to everyday activities. Theoretically, modern driving simulators may be useful in cognitive rehabilitation because they can systematically present realistic and interesting tasks that approximate driving activities, while automatically monitoring performance. The use of simulation technology for patients with TBI provides cognitive stimulation in an ecologically compatible setting, without the risks associated with a corresponding real-world experience. The utility, limitations, and future directions for the use of driving simulator in the rehabilitation of patients with war-related TBI are discussed. **Keywords:** *cognitive assessment*, *cognitive rehabilitation*, *cognitive training*, *driving simulator*, *transfer of training*

A LARGE NUMBER of Operation Enduring Freedom/Operation Iraqi Freedom returnees are seeking DOD and VA medical and rehabilitative care for traumatic brain injury (TBI) suffered during wartime.[1] Typically, patients with TBI suffer from cognitive deficits, which often interfere with their functional independence.[2] Driving is an important component of activities of daily living for many individuals and is one of the determinants of their level of independence.[3] From a cognitive standpoint, driving is an activity that requires multiple levels of mental faculty. In addition, driving is an activity with which TBI patients often have prior experience and is an activity that they are interested in reacquiring, since loss of driving skills is not only associated with disability but is also a major obstacle to continued rehabilitation.

After surveying recent reviews on the effectiveness of cognitive training,[4–12] we came to the following conclusions: (1) Cognitive rehabilitation can modestly improve scores on cognitive tests and simulations of daily life that require the same cognitive skill as was trained, namely, specific attention, visual scanning, memory, executive and communication skills. (2) The cognitive aspects of driving that have been chosen for training most often by rehabilitation researchers are attention and basic visual-spatial skills. There has been little study of training on complex visual-motor tasks, dynamic problem solving, or driving safety judgment. (3) There is only sparse evidence that successful cognitive training transfers to improved performance in activities of daily life.

Much of the research has involved cognitive training of simplified, specific components of daily life tasks rather than utilizing training activities that simulate the complexity of real life. Nevertheless, several studies suggest that multimodal training of complex skills may be more effective than training simple skills.[5,8,12] Other studies indicate that active interaction with systems that simulate the real world may be more effective than the training of discrete cognitive skills.[6,13–15] An interactive, contextualized rehabilitation approach may provide the

From the VA Boston Healthcare System, PM&R Service, Boston, Massachusetts (Dr Lew); Sharp Rees-Stealy Medical Group, Ophthalmology, The Driving Performance Laboratory, Sharp Memorial Hospital Rehabilitation Center, and Division of Health Care Sciences, Department of Family and Preventive Medicine, University of California, San Diego, California (Dr Rosen); Polytrauma Transitional Rehabilitation Program (Dr Thomander) and Defense & Veterans Brain Injury Center, Polytrauma Network Site (Dr Poole), Veterans Affairs Palo Alto Health Care System, Palo Alto, California.

Corresponding author: Henry L. Lew, MD, PhD, Veterans Affairs Boston Health Care System, 150 South Huntington Ave, Boston, MA 02130 (e-mail: henry.lew@va.gov).

best possibility for training to generalize.[16] The linking factors between human and animal rehabilitation research for cognitive recovery and transfer of abilities to other domains seem to rely on integrative training that includes repetition and, perhaps most important, the personal salience and richness of experience associated with contextualized cognitive training.[17,18] This has been recognized by the Society for Cognitive Rehabilitation, which has published *Recommendations for Best Practice in Cognitive Rehabilitation Therapy: Acquired Brain Injury*. This document emphasizes the need to improve real-world functioning and offers practice in real-life settings to promote generalization and transfer of knowledge.[19] Driving simulators should be ideal for this purpose because they safely involve the trainee in a close approximation of this frequently performed, complex life activity.

UTILITY OF DRIVING SIMULATORS IN REHABILITATION SETTINGS

There has been considerable interest in developing cognitive training approaches to improve driving ability in patients with TBI. Driving simulator systems offer a means to provide cognitive stimulation in an ecologically valid setting without the risks involved in encountering actual real-world experiences. Simulators can be used in 2 principal ways in rehabilitation after brain injury: for assessment and for treatment or training. As an assessment device, it can be used both to evaluate driver fitness[13–15,20,21] and to assess cognitive impairment.[22–25] For treatment or training, it can be used to improve driving skills[15,20] and possibly to stimulate improvements in general neurocognitive abilities.[26,27]

The use of driving simulators for assessment

The most obvious use of simulators is as a step in evaluating driver fitness before on-road testing, which is relatively expensive in terms of equipment, staff, and time. Thus, using the simulator to determine eligibility for on-road testing can save time and resources. Furthermore, because of the demands of conducting a safe evaluation, on-road testing cannot systematically address driver response to dangerous road situations or to contexts that may trigger risky driving behaviors.[20,28]

Simulators can also be used to evaluate cognitive impairment.[22–25] In the special February 2002 issue of *The Journal of Head Trauma Rehabilitation* that was devoted to driving assessment and TBI, Lengenfelder et al[29] concluded that virtual reality technologies, such as driving simulators, potentially offer an improved method of evaluating cognitive functions in the context of an everyday task that has not been available through traditional neuropsychological assessment. Driving is a complex, cognitively demanding activity,[30,31] which requires the ability to remain awake and alert, vigilance, making fast and accurate responses, depth and motion perception, spatial orientation and path finding, divided attention, multitasking, planning and decision making, hazard recognition and avoidance, safety judgments, and emotional self-control. Simulators can be programmed to simultaneously collect data related to a large number of these basic and higher-order processes, to determine whether they fall outside normative ranges.

Driving assessment measures for driver fitness and for evaluation of cognitive impairment are virtually the same, because driving behaviors are highly dependent on complex, integrated cognitive functions. Driving impairment, when not related to visual impairment at the level of the eye, is related to perceptual and cognitive impairments at the level of the brain. Poor driving behaviors can be the result of perceptual and cognitive impairments, which in turn lead to driving errors.[15,20]

Driving simulators provide a safe, controlled, repeatable driving experience in which errors can be made without cost to life, health, or property.[15,20,32] Unlike static paper and pencil cognitive and vision tests, a driving simulator can evaluate the dynamic aspects of driving skills and abilities that may be impaired by TBI, such as spatial orientation, situational awareness, as well as tactical and operational vehicle control.[22] They have only recently become affordable enough to make their deployment outside research settings feasible.[33,34] Higher-quality graphics and faster processing speeds are now affordable, resulting in a more realistic driving experience.[34]

Much of the research on driving after TBI has been related to assessing impaired driving skills and identifying predictors of safe return to driving.[35,36] A recent study found that performance in the driving simulator was a better predictor of actual driving skills within the community than was performance in an on-road test.[37] The authors suggested that this was because the simulator exposed the driver to a wider range of demands than is safely feasible on the road, while simultaneously measuring both lower-level and higher-level skills in these situations.

Driving simulators are being used to evaluate tactical and operational vehicle control as predictors of crash risk.[38–40] Neurocognitive “predictors” of accident risk being identified by these studies include visual-spatial impairment, impaired attention, reduced working memory, poor decision making under time pressure, and low driver confidence. Useful field of vision and contrast sensitivity have also been found to be correlated with injurious and noninjurious crash risk.[41,42]

Over the last 35 years, numerous studies have examined whether simulator performance is sensitive to differences between various groups of drivers (discriminant validity). Reviewing this literature through 2005, Lew et al[37] concluded that driving simulators can readily characterize significant driving problems in people with a variety of conditions, including acquired central nervous system disorders, specific visual deficits, advanced age, different amounts of prior driving experience, or sleep deprivation. They also reviewed 14 studies that compared simulator and road test evaluations (concurrent validity). Agreement was moderate to high in 5 of 7 studies on normal individuals and 5 of 7 studies on patients with acquired brain injuries. They found only 3 studies that compared simulator ratings to actual long-term driving performance in the community (ecological validity). Examining normal individuals and persons with visual or neuropsychological deficits, these 3 studies found little or no correlation between subjects' simulator performance and history of driving citations and accidents. In principle, counts of rare critical events are less sensitive measures than are continuous dimensional measures of performance during the same time period. Unfortunately, our review of the literature have not found any simulator studies that provide test-retest reliability data for driving simulators. This is an area of future research that will have to be addressed, so that clinicians and researchers can use the driving simulator as a test or treatment with confidence.

In addition to reviewing the driving simulation literature, Lew et al[37] conducted a small prospective study of driving in patients recovering from moderate to severe TBI, using multiple dimensional ratings of driving. Eleven subjects were evaluated on the simulator, using both automated measures and standardized observer ratings. Ten months later, a designated family member, trained to assess driving skills, accompanied each subject as they drove for over 1-month period and then completed standardized ratings of multiple driving skills. Using this methodology, simulator performance predicted who passed or failed the ratings with 82% accuracy but, as in prior studies, only weakly predicted driving accidents and citations. The most significant predictors of subsequent driving skills in the community were simulator measures of speed and direction control, divided attention, and judgment. These simulator measures predicted drivers' subsequent ability to handle automobile controls smoothly, (speed and direction control) their emotional control behind the wheel, and safety judgments. The authors concluded that future research on the predictive value of driving simulators must include observer-rated driving performance in the community over an extended period of time as outcome criteria.

Driving simulators as training devices

Simulators have potential as training devices to improve driving performance by providing practice within a wide range of driving scenarios.[15,20] These may require the regulation of vehicle speed and direction, obeying traffic signs and signals, negotiating curves, merging into traffic, maintaining safe following distance, vigilance to rear-view mirrors, finding simple and complex routes, response to errors by others (such as J-walking) and running lights, response to different light and weather conditions, and safety judgments such as making left-turns or passing into oncoming traffic.

In addition, practicing on the simulator provides stimulation and challenges that may lead to improvements in complex neurocognitive skills.[15,26,27] Skills that can potentially benefit from simulator "workouts" may include simultaneous attention, endurance, mindfulness to somatic and environmental cues, prioritizing and problem solving on the fly, visual-motor response time and accuracy, tolerance for frustration, and control of impulsivity. Learning may be enhanced when a therapist provides feedback during or after the patient's simulator experience.[15]

While simulators are beginning to be used for training in rehabilitation settings, there is, as yet, not enough evidence that improved performance, judgment, or insight gained on the simulator translates to similar improvements on the road. This question of transfer of simulator training is an important area for future research. Nevertheless, driving simulators have increasingly been used in attempts to improve specific neurocognitive skills and abilities needed for safe driving.[43–45] Simulators present virtual-reality environments to the driver, which create the dynamic sensory conditions that mimic the neurocognitive demands of on-road driving.[20,26–28,30] They engage patients in an interactive, dynamic task that activates the same perceptual, cognitive, and motor-controlled processes used in real-world driving.[20]

The replay feature of simulations is particularly useful in training because it allows patients to review their own driving behaviors, without the pressure of time, and to gain insight into their driving skills and abilities, to better understand how these might be improved.[15] Metacognition is often impaired after brain injury.[20–25] Error correction can take place only when error production is recognized. Replaying error-producing driving behaviors may improve situational awareness as executive control pathways are strengthened through "reliving" the driving experience. Driving is a continuously adaptive process of minimizing or correcting errors, and reliving poor and risky driving behaviors in safe environments is one potential way to improve driving skills and abilities. Replaying recorded performance may also prove valuable to researchers for deconstructing complex, dynamic patterns, such as error-causing and error-correcting behaviors during driving. Further research will be needed to determine what specific role replay features take in the overall training function of simulators.

Recent reports are beginning to demonstrate the utility of driving simulators in treatment settings.[21,24,25,36–38] Akinwuntan[46] used the driving simulator as a training device in a randomized controlled trial to demonstrate that it can improve the rate of those who return to driving after stroke. Rosen[45] has likened the simulator to a "treadmill for the brain" because it challenges brain functioning across many levels and systems. Just as running on a treadmill stresses and strengthens the respiratory, cardiovascular and musculature systems, the driving simulator presses component neurocognitive systems to work in an integrated and coordinated fashion.

As in other approaches to rehabilitation, driver training on the simulator can utilize either a "bottom-up" approach, emphasizing the training of specific skills such as attention, accurate perception, and motor coordination, or a "top-down" approach, emphasizing the training of higher-order complex skills such as planning, path finding, and judgment. The bottom-up approach to therapy may be termed "restorative" because it targets specific component skills and abilities for improvement. The top-down approach may be termed "compensatory" because it challenges the person to learn ways to work with or work around weak skills and abilities. Restorative (bottom-up) and compensatory (top-down) processes are probably best thought of as being interactive, each influencing the other.[5,8,47,48] Our review of cognitive rehabilitation suggested that training individual neurocognitive skills may improve some fundamental elements of cognition, such as attention and visual scanning, which provide the necessary basis for an iterative loop of perceptual and cognitive input to behavioral output (Fig 1).[5,8,47,48] Conversely, top-down training of complex driving skills may contribute to more generalized effects, because this approach utilizes more natural, reality-based experiences.[5,8,45–48]

Figure 1 is intended to reflect some of the complexity and interactivity of the driving task, although it is difficult to convey the degree of simultaneous processing and integration going on at the neural level in a 2-dimensional drawing. The degree to which motivational, top-down or automatic, bottom-up control is activated depends on age, personality, experience, disease, fatigue, and drugs, and probably many other factors. Top-down or motivational control (strategic, tactical, and operational) is upregulated and downregulated to adjust safety buffers (speed, lane choice, etc) and reduce errors when driving. Age and many medical conditions affect brain functioning and impair top-down control modulation by producing deficits in sensory input, working memory, visual search, attention, speed of information processing, and decision making. Age and disease may also impair automaticity or bottom-up control, possibly mediated by reentry circuits modulating memory retrieval and motor responses. Driving simulation is capable of measuring various situation-specific, time-dependent features of the top-down and bottom-up control

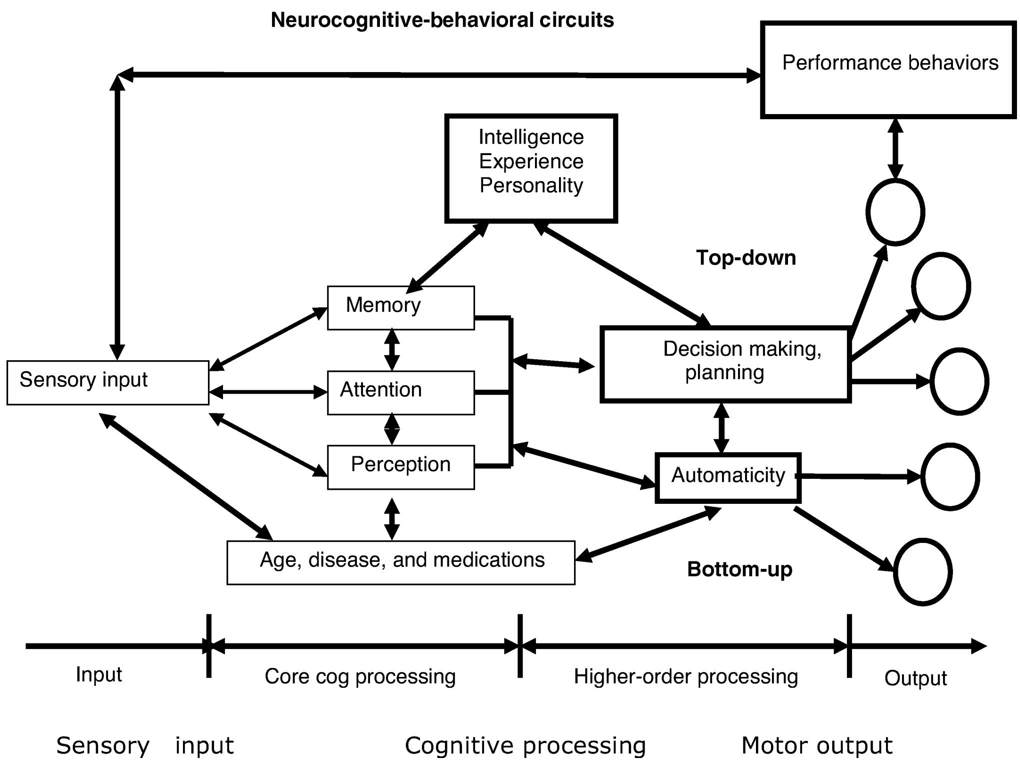

Figure 1. Interaction of basic and higher-order abilities in driving performance.

architecture, making it possible to quantify margins of error in ways that vision and neuropsychologic tests on the one hand and on-road tests on the other cannot. Driving simulations seem uniquely positioned between these 2 classes of tests to include the interactivity and complexity of driving while pushing the limits of risk without its consequences.

CONCLUSIONS

The most effective approaches to cognitive rehabilitation need to have high ecological validity. This is where modern driving simulators offer potential advantages over the more traditional approach. The training environment closely approximates a real-life activity. Multiple aspects of cognition that are used during driving are trained simultaneously in the simulator: visual-motor speed and accuracy, vigilance and sustained attention, divided or simultaneous attention, as well as higher-order executive skills such as planning, safety judgment, and self-control. For these reasons, we would expect this form of cognitive training to transfer more readily to the real-life activity of driving in the community than more segmented, task-specific approaches. Furthermore, driving simulation is a compelling technology that patients and clinicians find attractive and fun, thus facilitating motivation in the training process. When used for assessment, simulators are unique in that they provide realistic and dynamic spatial-temporal challenges involving the coordination of multiple perceptual-motor skills for goal-directed problem solving. If attention, perception, memory, executive, and emotional functions are not well integrated and coordinated, impairments will be revealed in the form of poor driving behaviors.[48–50]

However, driving simulators have their limitations. The different simulator manufacturers do not adhere to a common set of standards for constructing hardware or when creating software. A consistent set of reliable and valid scenarios and measurement parameters is needed in simulators. The sensitivity and specificity of simulation tests in specific populations still needs to be determined. A further practical limitation is "simulator sickness" (dizziness and nausea), which is likely due to a disjuncture between visual cues that one is moving and kinesthetic cues that one is stationary. The development of affordable motion-based simulators is likely to reduce this effect.

A significant number of patients with TBI in the VA's polytrauma system of care have had their driving privileges suspended. Improving the strength and integration of cognitive functions needed for driving will promote their transition from injury to the community. The future of cognitive rehabilitation in the treatment of patients with TBI appears to be moving in a promising direction, and driving simulators have the potential to play a significant role in that process.

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