Traumatic Brain Injury and Driving Assessment: An Evidence-Based Literature Review

Sherrilene Classen, Charles Levy, Dennis McCarthy, William C. Mann, Desiree Lanford, J. Kay Waid-Ebbs

OBJECTIVE. We conducted a literature review of assessment tools predicting driving performance for people with traumatic brain injury (TBI).

METHOD. Data sources were Web of Science, EBSCOhost, PubMed, and recently published literature from experts and team members not yet catalogued in the databases. We used the American Academy of Neurology’s classification criteria to extract data from 13 studies, and we assigned a class (I–IV, with I being the highest level of evidence) to each study. We grouped primary studies into categories of driving assessment (neuropsychological; simulator; off-road; self-report, other report, and postinjury disability status; and comprehensive driving evaluation) and synthesized the predictability of these tools as it relates to driving performance for people with TBI.

CONCLUSIONS. To assist clinicians and researchers in making decisions regarding testing the driving performance of people with TBI, we provide recommendations for neuropsychological tests; off-road tests; self-report, other report, and postinjury disability status; and comprehensive driving evaluation.


Traumatic brain injury (TBI) is a common disorder in the United States, causing significant cognitive, physical, emotional, social, and economic impact. Close to 1.4 million people sustain TBI each year; 50,000 do not survive, 235,000 require hospitalization, and 1.1 million are treated and released from emergency departments. The typical person who experiences TBI is male (1.5 times more often than female) and 15–19 years old at the age of onset (Langlois, Rutland-Brown, & Thomas, 2004). The Centers for Disease Control and Prevention has estimated that at least 5.3 million people in the United States (2% of the population) require long-term assistance with activities of daily living (ADLs) because of impairments imposed by TBI (Crooks, Zumsteg, & Bell, 2007; Heegaard & Biros, 2007). Costs of long-term impairments and disabilities associated with TBI are estimated at $56.3 billion annually (Thurman & Guerrero, 1999), whereas the full human cost is incalculable (McMahon, West, Shaw, Waid-Ebbs, & Belonia, 2005).

TBI is commonly categorized with the Glasgow Coma Scale (GCS) as severe, moderate, or mild (Lezak, Howieson, & Loring, 2004). Severe and moderate TBI each account for 10% of cases, and mild TBI accounts for 80%. The TBI classifications (mild–severe) are most commonly determined by either the presence and extent of coma or the duration of posttraumatic amnesia (Lezak et al., 2004). The GCS score is based on motor response, eye opening, and verbal response at the time of the injury. A GCS score of 3 to 8 indicates a severe TBI, 9 to 12 indicates a moderate TBI, and 13 to 15 indicates a mild TBI (Teasdale & Jennett, 1974).
Posttraumatic amnesia is often used in conjunction with the GCS. A posttraumatic amnesia of <5 min is very mild, 5–60 min is mild, 1–24 hr is moderate, 1–7 days is severe, 1–4 weeks is very severe, and >4 weeks is extremely severe (Bigler, 1990).

Pathophysiology of TBI and Effect on Body Systems and Function

The brain weighs approximately 3 lb and consumes 20% of the body’s oxygen supply and 15% of cardiac output. To function normally, there must be adequate cerebral perfusion pressure, which is maintained by dilation and constriction (autoregulation) of cerebral blood vessels. Damage inflicted by TBI can be caused by primary and secondary injury.

Primary injury can be further broken down into direct and indirect injury. Direct injury occurs when the head is struck by an object or its motion is arrested by another object. Tissue damage occurs because of the breaching of the skull or shockwaves propagated by the impact. A common example of indirect injury is that of an acceleration–deceleration injury, such as what may occur in an auto accident with a restrained driver (whiplash). The cranial contents are set into vigorous motion, resulting in diffuse axonal injury. Damage may also occur as the brain strikes the skull or dural structures.

Secondary injury refers to disruption of the brain’s normal homeostasis, typically resulting in increases of intracranial pressure and decreasing cerebral perfusion, which in turn result in ischemia. Destruction of brain tissue may also set off a cascade of deleterious metabolic events that widen the zone of damage (Crooks et al., 2007; Ghajar, 2000; Heegaard & Biros, 2007).

The functional consequences of TBI are determined by the extent and location of the damage and can be blunted or exacerbated by several factors, including premorbid health and personality; intelligence; age; and societal, economic, psychological, and economic status. Depending on the nature of the injury, a variety of systems, such as the motor, cognitive, sensory, and affective systems, may be involved. The impairment sustained by a mild TBI (mTBI) is likely to be less than what would result from either a moderate or a severe TBI; thus, it would be reasonable to expect a return to driving. Many people who sustain mTBI never receive medical attention for their injury and may appear to be relatively intact after the injury. However, they may suffer from characteristic symptoms including headache, dizziness (vertigo), poor balance, forgetfulness, slowed thinking, impaired concentration, decreased executive function, fatigue, forgetfulness, irritability, visual impairment, or sensitivity to light or noise—any of which could negatively affect driving performance (Crooks et al., 2007; Heegaard & Biros, 2007).

Driving and TBI

Driving is an “occupation enabler.” That is, driving allows people to participate in various life activities, including basic activities of daily living (ADLs) and instrumental ADLs (IADLs), work, education, and other favored activities (American Occupational Therapy Association [AOTA], 2002). A key focus of rehabilitation is to empower people with TBI to resume IADLs and societal participation. Driving has important implications for many aspects of IADL and societal participation, including fulfilling roles such as student, parent, or spouse. Driving is a complex task requiring the integration of visual–perceptual stimuli, information processing, good judgment and decision making, and the performance of appropriate motor responses. TBI potentially affects those functions. Many people with TBI experience sensory, cognitive, and motor changes that may limit their ability to safely return to driving (Fisk, Novack, Mennemeier, & Roenker, 2002; Innes et al., 2005, 2007).

TBI may affect performance skills and patterns, including motor, process, and communication skills necessary for safe driving (AOTA, 2002; Fisk et al., 2002; Innes et al., 2005, 2007). Coordination, strength, and range of motion necessary for driving may be affected by TBI. Processing skills enable a person to obtain information from the driving environment, process that information, execute a response, monitor the effectiveness of that response, and make the required adjustments. Communication skills (e.g., unspoken driving etiquette, such as waving to indicate that a pedestrian or a car can pull out in front of you) are essential for safe driving.

Thus, for people with TBI, limitations in any of the areas described may affect driving performance and pose safety risks (e.g., crash-related injuries, fatalities) for the driver, passengers, other motorists, or pedestrians. The impact of TBI on safe driving is related to the severity of injury, but studies often do not report severity of TBI, making generalizability of findings to this group difficult (Coleman et al., 2002; Sivak, Olson, Kewman, Won, & Henson, 1981). People with TBI often lack insight into their deficits and, therefore, fail to accommodate for them, whether by restricting their driving or by ceasing driving (Korteling & Kaptein, 1996).

Approximately 80% of TBI survivors return to driving, even though many have been told not to do so (Lew et al., 2005). In another study (N = 83), more than 60% of people with TBI who had returned to driving reported driving every day and >50 miles per week (Fisk, Schneider, & Novack, 1998). TBI survivors frequently received advice about driving from family members, physicians, or nonphysician health care professionals, but more than half (63%) had not been
professionally evaluated for driving competency (Fisk et al., 1998). Helping people with TBI return to safe driving has significant value because it can help prevent harm to the driver and members of society; enable the driver’s occupations and participation; and allow a return to productive roles, work, and other favored activities. For example, in one study with 186 adults with TBI, ages 18 to 62, driving was identified as an independent moderator for employment stability (Kreutzer et al., 2003).

Significant controversy exists regarding the most appropriate way to assess driving ability (Yale, 2003; Yale, Hansotia, Knapp, & Ehrfurth, 2003); the controversy is reflected in the outcome measures of studies of driving performance. Many family members or caregivers believe assessing fitness to drive is the responsibility of physicians. Physicians, however, are generally not prepared to make such a determination because they lack specialized training in driving assessment and do not have the time to complete thorough assessments (Marshall & Gilbert, 1999). Moreover, in some jurisdictions, the law requires physicians to report to transportation authorities if any of their patients have diagnoses that may render them unfit to drive. Occupational therapists can greatly assist physicians in this determination.

Still, it is difficult to determine what the level of evidence is in studies of the assessment of driving ability in people with TBI, particularly because the published studies lack consistency in method or results. Tamietto and colleagues (2006) reported that the discrepant results among studies relates to (1) type of predriving predictors included in the analysis, (2) criterion measures used to determine fitness to drive, (3) severity of TBI, (4) extent of the neural structures damaged by the TBI, and (5) the length of follow-up. We are encouraged by recent studies that include medical, psychosocial, and personality measures and on-the-road studies in the assessment of driving performance.

### Determining Fitness to Drive in Clients With Traumatic Brain Injury

The following section describes five approaches used in assessing fitness to drive.

#### 1. Clinical Tests: Neuropsychological and Psychosocial Tests

Patients evaluated for TBI typically undergo a neuropsychological exam (Côté, Syam, Vogel, & Cowper, 2007), which may vary widely in predicting driving ability (Yale, 2003). Depending on the tests used and the driving outcomes studied, predictive power may range from approximately 0.20 to 0.94 (Korteling & Kaptein, 1996). Although neuropsychological testing can discriminate among groups with differing ability levels required for safe driving, the tests are insufficient to determine fitness to drive (Korteling & Kaptein, 1996; Schanke & Sundet, 2000).

#### 2. Simulator Testing

Although driving simulators provide benefits related to safety (e.g., simulated crashes) and cost in measuring driving performance, current evidence of their ability to predict safe driving is lacking in the literature. One study has shown ecological validity between simulator testing and real-world driving performance for people with brain injury (Lew et al., 2005).

#### 3. Off-Road Screenings

Attempts to validate a variety of off-road screening tools as reasonable substitutes for on-the-road tests have been undertaken. Such screening tools include the useful field of view (UFOV; Fisk et al., 2002) and neurocognitive computer-based assessment, specifically the Neurocognitive Driving Test (Schultheis, Hillary, & Chute, 2003). Most of these studies are limited by the use of correlational designs and instruments that are not sufficiently sensitive in predicting driving ability of those with mTBI.

#### 4. Self-Report, Significant Others, and Postinjury Disability Status

Self-report of driving performance may be susceptible to social desirability bias (answering questions in an overly acceptable or positive way; Sundstrom, 2008), but significant others may provide useful information on the driving status of their loved ones, telling of their real-world driving performances (Rapport, Hanks, & Bryer, 2006). Tamietto et al. (2006) suggested that predictive studies are confounded by differences or by the absence of measuring postinjury disability. Therefore, each of the three factors (self-report, proxy report, postinjury disability status) may be predictive of the driving performance of those with TBI.

#### 5. Comprehensive Driving Evaluation

The Comprehensive Driving Evaluation (CDE) is the gold standard in driving assessment (Korner-Bitensky, Sofer, Kaizer, Gelinas, & Talbot, 1994; Odenheimer et al., 1994; Rizzo & Dingus, 1996). A CDE consists of a clinical assessment using tools that correlate with driving performance or crashes, followed by on-the-road assessment. A CDE is administered by a driving rehabilitation specialist, who typically is a specially trained occupational therapist. Controversy exists with regard to the use of CDEs, however. CDEs are not standardized (i.e., the specific content of the battery may vary across practitioners), and findings in both the clinical and the on-road portions may vary across practitioners.
Moreover, the approach is expensive, not widely available and, possibly, intimidating. We do not know how valid CDEs are for people with TBI, both because of predictive limitations and because there is no substitute for the observation of behind-the-wheel performance.

**Significance and Purpose**

Clearly, TBI affects the performance skills and patterns as well as the occupations, activities, and social participation of the person affected. Driving is a critical task for engaging in activities on the societal level and for participation in the community. A key issue is to have ecologically valid tools for assessing a TBI client’s real-world driving performance. Still, we do not know what the level of evidence is for accurately determining safe driving performance among those with TBI, and published studies lack consistency in method or results (Tamietto et al., 2006). From this premise, we conducted an evidence-based review of the current literature to discern the level of evidence for each type of driving assessment by level of TBI severity. Thus, the focus of this research is to answer the following question: How predictive are current driving assessment tools, simulators, and on-the-road driving (with the presence of an evaluator) of real-world driving (without the presence of an evaluator) performance?

**Method**

**Research Team**

Rehabilitation science researchers, occupational therapists, a physiatrist, and two doctoral-level graduate students from the University of Florida’s Institute for Mobility, Activity, and Participation in Gainesville actively participated in this literature review. We consulted with the Health Science Center’s reference librarian for aspects of the literature search.

**Procedure**

The research team assembled, critically appraised, and synthesized the results of primary investigations addressing the topic of TBI and driving. Specifically, we focused on the evidence used to determine safe driving performance after sustaining a TBI. To conduct this review, the following search strategy was implemented: a literature search, determination of inclusion and exclusion criteria, and rating of the evidence and recommendations.

**Literature Search.** Using research synthesis guidelines, we created a search strategy, with search terms and various databases selected with input from the reference librarian (Cooper & Hedges, 1994). Search terms were as follows: “TBI OR traumatic brain injury, automobile driving, driving performance, driving ability, simulator, virtual reality, and measurement OR measures.” MeSH headings were (((“TBI”[MeSH] AND English[Lang])) AND (“Automobile Driving” [MeSH])) AND (“Measures”[MeSH]). Limiters were the language (English only) and year of publication (January 1, 1995–April 1, 2008) because the science of driving has been shaped by an increased interest in this field since the mid-1990s. We used Web of Science, EBSCOhost, and PubMed to access primary studies in psychological and social sciences, medicine, biological science, and engineering. Experts and team members added recently published literature (not yet catalogued in the databases) to expand on those sources delivered by the original search.

**Inclusion and Exclusion Criteria.** Thirty-two sources were found. Sherrilene Classen and a doctoral graduate student (J. Kay Waid-Ebbs) screened all 32 sources by title and abstract to include studies containing the keywords described in the search terms. Sources were excluded for analysis if they

- Were published before 1995;
- Were duplicates;
- Were not primary studies;
- Were mainly qualitative or descriptive studies;
- Emphasized or established psychometrics;
- Mentioned driving, but not as a main outcome; and
- Included samples of mixed diagnostic groupings (e.g., dementia, TBI).

Primary peer-reviewed studies meeting the inclusion criteria were obtained in full text through online retrieval, library access, and collections from the University of Florida team’s library. From the original 32 abstracts reviewed, we included 18 in the full-text review; of those we analyzed, 13 full-text studies met all inclusion and exclusion criteria. We used team consensus for inclusion of the articles and did not embark on backtracking articles by reviewing reference lists of articles found by database searches.

**Rating the Evidence and Making Recommendations.** We rated each article using Sackett’s criteria (Sackett, Straus, Richardson, Rosenberg, & Haynes, 2000) but did so more specifically by applying the classification criteria of the American Academy of Neurology (Edlund, Gronseth, So, & Franklin, 2004). On the basis of a set of specific parameters, described in Table 1, each article was assigned a class (Class I–IV, with I being the highest level of evidence). The primary studies were next grouped by the five categories of assessments (neuropsychological tests; simulator testing; off-road screenings; self-report, significant other report, and postinjury disability status; and CDE). Using the criteria in Table 1, we made an evidence-based conclusion and provided a recommendation on the predictability of the assessment tool as it relates to driving performance for people with TBI. The recommendations include four levels: A, B,
Table 1. American Academy of Neurology Criteria for Rating a Study by Class and Making an Evidence-Based Recommendation (Edlund et al., 2004)

<table>
<thead>
<tr>
<th>Rating article by class</th>
<th>Class I</th>
<th>Class II</th>
<th>Class III</th>
<th>Class IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evidence provided by a prospective study in a broad spectrum of people with the suspected condition using a gold standard for the case definition. Test should be applied in a blinded evaluation. All people undergoing the test have the presence or absence of the condition (TBI).</td>
<td>Evidence provided by a prospective study of a narrow spectrum of people ($N &lt; 100$) with the suspected condition or a retrospective study of a broad spectrum of people with an established condition by gold standard compared with a broad spectrum of control participants.</td>
<td>Evidence provided by a retrospective study in which either people with the established condition or control participants are of a narrow spectrum ($N &lt; 100$); the reference standard, if not objective, is applied by someone other than the person performing the test.</td>
<td>Any design in which the test is not applied in an independent evaluation OR evidence provided by the expert opinion alone or in descriptive case series (without control participants).</td>
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<tr>
<th>Rating by recommendation</th>
<th>Level A</th>
<th>Level B</th>
<th>Level C</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommendation: Established as effective or useful or predictive or not: “Should be done or should not be done.”</td>
<td>Recommendation: Probably effective or useful or predictive or not: “Should be considered or should not be considered.”</td>
<td>Recommendation: Possibly effective or useful or predictive or not: “May be considered or may not be considered.”</td>
<td>Data inadequate or conflicting; given the current knowledge or test, the treatment is unproven.</td>
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</tbody>
</table>

| Condition for rating by recommendation | Requires two consistent Class I studies or one Class I study in which the magnitude of the effect is large and all criteria have been met. | Requires at least one Class I study or two consistent Class II studies. | Requires at least one Class II study or two consistent Class III studies. |

Note. TBI = traumatic brain injury.

C, and None (A = assessment established as effective, useful, or predictive or not; B = assessment probably effective, useful, or predictive or not; C = assessment possibly effective, useful, or predictive or not; None = insufficient evidence to provide a recommendation), also summarized in Table 1. We have also indicated the severity of the TBI.

Results

Descriptive Profile of the Primary Studies
The 13 studies appeared between 1996 and 2006. Only 6 of the studies indicated funding by federal or foundation grants. Sample sizes varied from 27 to 80 for the experimental designs, 17 to 142 for the observational designs, and 563 for the descriptive qualitative study. For TBI severity, we found that 6 studies indicated no severity, 2 indicated mild to severe severity, 1 indicated mild severity, and 4 indicated moderate to severe severity. The primary studies included 5 with experimental designs, 7 with observational designs (5 retrospective and 2 prospective), and 1 with a descriptive qualitative design.

Level of Evidence, Conclusions, and Recommendation
Table 2 provides a summary of the 13 primary studies included in this literature review. From this table, and for each of the five categories of tests, we provide the integrated result, conclusion, and recommendation pertaining to the use of the tests as valid predictors of driving performance. These results, conclusions, and recommendations are based on the criteria outlined in Table 1.

Neuropsychological Tests

Result. The review yielded two Class II studies (Korteling & Kaptein, 1996; Meyers, Volbrecht, & Kaster-Bundgaard, 1999) and two Class III studies (Leon-Carrion, Domínguez-Morales, & Martin, 2005; Pietrapiana et al., 2005).

Conclusion. From the two Class II studies, we concluded that although neuropsychological tests distinguish between two levels of drivers (discriminant function analysis correctly classified 94.4% of the drivers as competent or not competent), they explained (in the other Class II study) only 35.3% of the variance in on-the-road tests. Neither study indicated the level of TBI severity.

Recommendation—Level B. Although neuropsychological tests may classify drivers with TBI (levels of severity unknown) into two categories, they are not predictive of on-the-road performance and thus insufficient to replace the on-the-road test.

Simulator Tests

Result. The review yielded one Class II study (Lew et al., 2005) of people with moderate to severe TBI.

Conclusion. Although Lew at al. (2005) concluded that simulator tests may be more predictive of real-world driving than on-the-road studies, we discerned that this one Class II study provided insufficient evidence to make a definitive
statement about the ecological validity of simulators in testing participants with TBI.

**Recommendation—None.** The evidence on simulator tests as a valid substitute for real-world driving is lacking; therefore, no recommendation can be made at this time. More research is needed to discern validity between simulator and on-the-road studies.

### Off-Road Screening Tests

**Result.** Four Class II studies emerged (Fisk et al., 2002; Novack et al., 2006; Schneider & Gouvier, 2005; Schultheis et al., 2003).

**Conclusion.** Three Class II studies specifically addressed the UFOV. One study (Schneider & Gouvier, 2005) found no statistically significant differences ($p < .05$) between the mTBI group and healthy control participants on any of the UFOV subtests. However, Fisk et al. (2002) found that participants with mild to severe TBI (1) had higher (worse) UFOV scores than young adults, (2) had higher scores on divided attention and selective attention, and (3) took longer to complete the UFOV than young adults. Likewise, Novack et al. (2006) found that the second subtest of the UFOV (divided attention) predicted on-road driving performance of those with moderate to severe TBI. The fourth Class II study evaluated the Neurocognitive Driving Test (NDT) against on the road testing and found a high correlation for ranked driving ability in participants with brain injury (severity was not specified); the NDT’s cutoff score successfully categorized 80% of all participants with brain injury.

**Recommendation—Level B.** The UFOV should probably not be considered a valid predictor of on-the-road driving performance for people with mTBI; however, it should be considered a predictor of on-the-road driving performance in people with moderate to severe TBI, specifically related to Subtest 2 (divided attention) and functional visual field and visual processing ability. The NDT has utility for evaluating people with TBI and should be considered a predictor of on-the-road performance.

### Self-Report, Significant Others, and Postinjury Disability Status

**Result.** We identified one Class II (Coleman et al., 2002), one Class III (Rapport et al., 2006), and one Class IV study (Hawley, 2001).

**Conclusion.** Significant others’ perceptions of the patient with TBI’s (severity unknown) fitness to drive predicted driving status ($p = .002, R^2 = .29$) and driving frequency ($R^2 = .33, p < .001$), whereas postinjury disability (and neuro-psychological functioning) explained 30% of the variance ($R^2 = .30, p = .003$) in the Department of Motor Vehicles incident records. Patients with moderate-to-severe (Class III) TBI significantly predicted their driving status ($R^2 = .32$). No definitive conclusions can be derived from the Class IV descriptive study.

**Recommendation—Level C.** The evidence suggests that families’ and significant others’ report may be used as a possible predictor of driving status for people with moderate to severe TBI and for frequency of driving (severity unknown) in the real world, whereas postinjury disability at discharge may be used as a possible predictor for driving incidents as measured by the Department of Motor Vehicles.

### CDE

**Result.** The review yielded one Class II study of people with TBI (severity unknown; Schultheis, Matheis, Nead, & DeLuca, 2002).

**Conclusion.** We found that 5 years after performing on-the-road tests, no greater number of crashes or violations existed among TBI participants (severity unknown) than among healthy control drivers as measured in real-world driving.

**Recommendation—Level C.** Given the lack of studies examining the predictive validity of CDE to real-world driving performance in people with TBI, we recommend more longitudinal studies to help discern the predictive validity of the CDE in this population.

### Discussion

We have summarized the findings of 13 primary studies that have met rigorous criteria to discern the level of evidence for five different methods used to predict on-the-road (performed with an evaluator) or real-world driving (without an evaluator in the vehicle) performance. We have classified the studies by level of evidence and provided recommendations to assist clinicians and researchers in decision making regarding testing the driving performance of people with TBI. As such, we have now defined the level of evidence for accurately determining safe driving performance among those with TBI, and through the evidence-based classification method, we are bringing consistency in method or results of the published studies, specifically as it pertains to our research question.

Interestingly, no Class I studies emerged, and no Level A recommendations could be made. This result is perhaps a direct function of studies having small sample sizes, not being blinded, lacking controlled conditions, or not being randomized and of the small number of studies. Similar to Tamiello et al.’s (2006) comment, we have also found that the studies did not consistently identify the severity of TBI. This lack of clarity is problematic, because recommendations may not be generalizable to clients with different severity levels of TBI. If the primary study was specific in discerning...
### Table 2. Evidence Table for Traumatic Brain Injury (TBI) and Driving Literature Review

<table>
<thead>
<tr>
<th>Title, Authors (Year), and Funding</th>
<th>Question or Purpose</th>
<th>Sample</th>
<th>Independent Variable</th>
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<tbody>
<tr>
<td><strong>Neuropsychological tests</strong></td>
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<tr>
<td>Neuropsychological driving fitness tests for patients with brain damage, Korteling &amp; Kaptein (1996)</td>
<td>To evaluate driving fitness of patients with brain damage</td>
<td>N = 38: 33 men and 5 women who had recovered from TBI with valid driving licenses pre-TBI</td>
<td>Four predictor tests: Perceptual Speed test; WAIS Symbol-Digit Substitution test; Tracking-Reaction Dual task; and a Time Estimation task</td>
</tr>
<tr>
<td>No funding</td>
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<tr>
<td>Driving with cognitive deficits: Neurorehabilitation and legal measures are needed for driving again after severe traumatic brain injury, Leon-Carrion, Dominguez-Morales, &amp; Martin (2005)</td>
<td>To discern whether posttraumatic cognitive deficits prevent people with severe TBI from safely returning to driving</td>
<td>N = 17: 17 patients with severe TBI measured by GCS</td>
<td>FIM™ and FAM Revised Scale; neuropsychological battery</td>
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<tr>
<td>No funding</td>
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<tr>
<td>Driving is more than pedal pushing, Meyers, Vobrackt, &amp; Kaster-Bundgaard (1999)</td>
<td>To determine the usefulness of neuropsychological tests for predicting driving competency</td>
<td>N = 312: 230 drivers and 82 nondrivers</td>
<td>Comprehensive neuropsychological battery</td>
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<td>No funding</td>
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<tr>
<td>Role of premorbid factors in predicting safe return to driving after severe TBI, Pietrapiana et al. (2005)</td>
<td>To predict postinjury fitness to drive safely among patients with severe TBI</td>
<td>N = 132: 66 pairs of adults</td>
<td>Sixteen measures, with four domains: demographic, medical functional, neuropsychological, and psychosocial</td>
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<tr>
<td>Funding: Grant from Ordine Mauriziano di Torinoto to Marco Tamietto (2005)</td>
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<tr>
<td>Simulator testing</td>
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<tr>
<td>Predictive validity of driving simulator assessments following TBI, Lew et al. (2005)</td>
<td>To evaluate whether a driving simulator and road test evaluation can predict real-world driving performance 10 months later</td>
<td>N = 27: 11 patients with moderate to severe TBI and 16 HC were tested to provide normative values on the simulator at baseline. The patients’ ages ranged from 18 to 58 years (M = 29, SD = 12), and the HC’s ages ranged from 22 to 58 years (M = 36, SD = 11); 82% men with TBI and 75% men in the HC group. The age distribution and gender ratio of the groups did not differ s/s (p &gt; .10, by t test and chi-square test, respectively).</td>
<td>Time 1: Simulator driving performance measured with Simulator Performance Index and Driving Performance Inventory by DRS On-the-road DPI by DRS</td>
</tr>
<tr>
<td>No funding</td>
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<tr>
<td>Off-road screening tests</td>
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<tr>
<td>Useful field of view after traumatic brain injury, Fisk, Novack, Mennemeier, &amp; Roenker (2002)</td>
<td>To explore the possibility that the UFOV is compromised after TBI</td>
<td>N = 41: 23 TBI (mild, moderate, severe) survivors and 18 young adults without neurological impairment</td>
<td>Snellen eye chart; neuropsychological battery; Trail Making A; Trail Making B</td>
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<tr>
<td>Funding NRSA Training Grant</td>
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<tr>
<td>Utility of UFOV test with mild traumatic brain injury, Schneider &amp; Gouvier (2005)</td>
<td>Can UFOV predict motor vehicle crashes for people with mTBI?</td>
<td>N = 80: 40 college students with self-reported mTBI (at least momentary LOC) and 40 HC, matched for age, gender, and race. 32 (40%) male; 68 (85%) White, 10 (12.5%) AA, 2 (2.5%) Hispanic. Mean age TBI group = 21.95 years (SD = 4.07) Compared with 21.98 (SD = 3.97) for HC Groups did not differ s/s in alcohol or medication use.</td>
<td>Neuropsychological measures Trails A; Trails B; WAIS–III; Processing speed index; SDMT; UFOV</td>
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<td>Outcome Variable</td>
<td>Design</td>
<td>Main Findings</td>
<td>Level of Evidence and Conclusion</td>
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<td>Open-road criterion standard</td>
<td>One group, pre-post experiment; no blinding</td>
<td>Performance on both the Perceptual Speed task and the Time Estimation task were s/s correlated with driving performance ($p &lt; .05$). When combined with coma duration and driving experience, the Perceptual Speed and Tracking-Reaction tests together explained 35.3% ($r = .59$) of the variance in on-road driving performance.</td>
<td>Class II (small sample size, no control)</td>
</tr>
<tr>
<td>Driving status</td>
<td>retrospective study</td>
<td>Patients showing physical functionality $&gt;$80% returned to driving, regardless of cognitive or emotional deficits and against doctor recommendations. Severe TBI survivors, not certified as fit to drive, are at increased risks for driving incidents; some experienced confusion, disorientation, and confrontation with people. After multidisciplinary neurorehabilitation, $&gt;$70% of survivors of severe TBI can return to safe driving.</td>
<td>Class III (small sample size, retrospective)</td>
</tr>
<tr>
<td>Driving status (patient and family member reports of driving ability)</td>
<td>Case control</td>
<td>The discriminant function analysis correctly classified 94.4% of the overall sample.</td>
<td>Class II (retrospective, broad spectrum with control participants)</td>
</tr>
<tr>
<td>Driving status: post-TBI drivers vs. nondrivers</td>
<td>Retrospective case control</td>
<td>Compared with post-TBI nondrivers, postinjury drivers had shorter coma duration ($p = .042, \eta^2 = .063$). With regard to driving safety, the final multiple regression model combined four predictors (years postinjury, accidents, and violations before TBI, pre-TBI risky-personality index, and pre-TBI risky-driving-style index) and explained 72.5% of variance in the outcome measure.</td>
<td>Class III (retrospective, narrow spectrum)</td>
</tr>
<tr>
<td>Real-world driving</td>
<td>Two-group experiment with longitudinal follow up; no blinding</td>
<td>At Time 1, patients were s/s impaired on SPI measures of driving skill, including speed, steering control, crashes, and divided attention. SPI s/s predicted the aspects of family DPI at Time 2 in handling car controls, speed regulation, direction, higher-order judgment, self-control, and trend-level association with car crashes. Compared with Time 1 DPI, the SPI was more sensitive and accurate to predict Time 2 DPI. The road test DPI at Time 1 showed no s/s relation to DPI at Time 2.</td>
<td>Class II (small sample size, no randomization)</td>
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<tr>
<td>UFOV performance</td>
<td>Experiment with two groups; no blinding</td>
<td>TBI survivors had higher UFOV scores ($M = 19.7; \text{SEM} = 3.1$) than young adults ($M = 4.3; \text{SEM} = 1.1; U = 33.5, p &lt; .001$), and s/s higher scores on divided attention ($U = 144, p &lt; .011$), and selective attention ($U = 41.0, p &lt; .001$), and took longer to complete the UFOV ($M = 21.1; \text{SEM} = .76$) than young adults ($M = 18.7; \text{SEM} = .36$ ($t[102.7] = 2.8, p &lt; .008$).</td>
<td>Class II (small sample size, no randomization)</td>
</tr>
<tr>
<td>Self-report driving status: (1) number of crashes within past 2 years (2) traffic citations within past 2 years</td>
<td>Two-group experimental design, without randomization or blinding</td>
<td>No s/s differences ($p &lt; .05$) between mTBI group and HCs on any of the UFOV subtests. Neuropsychological measures did not predict driving ability in this mTBI group. Number of reported citations s/s higher in mTBI group than in HC group. Number of reported accidents s/s higher for mTBI group ($M = 0.33, t[78] = -1.833, p &lt; .05, \alpha = .41$ [one-tailed]).</td>
<td>Class II (small sample size, no randomization)</td>
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</table>
### Table 2. (continued)

<table>
<thead>
<tr>
<th>Title, Authors (Year), and Funding</th>
<th>Question or Purpose</th>
<th>Sample</th>
<th>Independent Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UFOV performance and driving ability following traumatic brain injury</strong>&lt;br&gt;Novack et al. (2006)&lt;br&gt;<strong>Funding:</strong> NIH &amp; NIDRR</td>
<td>To investigate the relationship between performance on the UFOV and driving performance after TBI</td>
<td>(N = 60): 38 men and 22 women with TBI referred for driving evaluation; (M_{\text{age}} = 53) (range = 16–68); (M_{\text{education}} = 12.7) years (range = 7–20); 54 White, 6 AA. All participants had a TBI ((M = 17.5) months; range = 2 months–19 years) before study. Most (72%) had a severe TBI (GCS score of ≤ 8), with 18% in the moderate range (GCS 9–12). All had a PTA duration of ≥ 1 week suggesting severe TBI. For those with injury severity data (45 cases), 36 (80%) had a severe TBI. All participants had a valid driver’s license.</td>
<td>Age test braking reflex test; Trails B; UFOV</td>
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<tr>
<td><strong>The Neurocognitive Driving Test: Applying Technology to the assessment of driving ability following brain injury</strong>&lt;br&gt;Schultheis, Hillary, &amp; Chute (2003)&lt;br&gt;No funding</td>
<td>To compare the NDT with an established driving assessment method</td>
<td>(N = 30): 15 adult volunteers with ABI, ages 21–59, referred for a driving evaluation and 15 HCs. No s/s differences in ages, gender, education, or years of driving experience between groups.</td>
<td>Overall performance on the NDT</td>
</tr>
<tr>
<td><strong>Self-report, significant other report, or postinjury disability status</strong>&lt;br&gt;Hawley (2001)&lt;br&gt;<strong>Funding:</strong> Department of Health, UK</td>
<td>To determine whether patients who return to driving after TBI can be considered safe to do so and to compare the patient characteristics of those who return to driving with those who do not</td>
<td>(N = 563): 563 adults with TBI (mild to very severe) registered during a 2.5-year period. (M_{\text{age}} = 32.5) years, (SD = 13.13); 71.1% men. Recruitment varied from immediately after hospital admission to several years postinjury. Patients and their families were interviewed 3–6 months after recruitment. A total of 383 (67.5%) participants were interviewed within 1 year of injury, of whom 270 (47.6%) were interviewed within 6 months of injury.</td>
<td>Presence or absence of driving-related problems by drivers and ex-drivers and scores on FIM and FAM</td>
</tr>
<tr>
<td><strong>Barriers to driving and community integration after TBI</strong>&lt;br&gt;Rapport, Hanks, &amp; Bryer (2006)&lt;br&gt;No funding</td>
<td>To examine the relations among driving status, perception of barriers to resume driving, and community integration after TBI</td>
<td>(N = 51): 6 women and 45 men, all survivors of TBI (majority, moderate to severe TBI). Mean GCS score at admission = 8.8 ((SD = 4.4)). Mean years postinjury = 4.3 ((SD = 3.5)). 39% resumed driving, 61% had not resumed driving. No difference in education between drivers and nondrivers.</td>
<td>BDQ; Positive and Negative Affectivity Scale; Social Provision Scale; Craig Hospital Assessment and Reporting Technique</td>
</tr>
<tr>
<td><strong>Predictors of driving outcome post-TBI</strong>&lt;br&gt;Coleman et al. (2002)&lt;br&gt;<strong>Funding:</strong> NIDRR</td>
<td>To examine predictors of driving status and fitness to drive post-TBI</td>
<td>(N = 142): 71 pairs of adults with TBI and their significant others. TBI group: ages 17 to 77 years ((M = 40.2), (SD = 13.0)); 57 men (80.3%), 14 women (19.7%); Ethnicity: 64.8% AA, 28.2% White, 2.8% Hispanic, and 4.2% AA and White. Education range = 7 to 16 years ((M = 11.7), (SD = 1.7) years). Significant other group: 73% ((n = 52)) women and 27% ((n = 19)) men. 83% were primary caregivers. Age range: 24–80 ((M = 53.1), (SD = 13.9)). Race: 67.6% AA, 29.6% White, and 2.8% Hispanic. Education: range = 5–18 years ((M = 12.0), (SD = 2.4)).</td>
<td>Retrospective: GCS Becker conversion; Disability Rating Scale Propective: Neuropsychological battery: WAIS–III; (letter–number sequence, matrix reasoning, and colored trails) Self-report: PCRS (patient); SPS (significant others)</td>
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<td><strong>Comprehensive Driving Evaluation</strong>&lt;br&gt;Drawing behaviors following brain injury: Self-report and motor vehicle records&lt;br&gt;Schultheis, Mathes, Nead, &amp; DeLuca (2002)&lt;br&gt;<strong>Funding:</strong> Charles Edison Foundation; NIH (NICHHD)</td>
<td>To examine group differences of driving behaviors occurring in the past 5 years for people with TBI who completed a CDE compared with HC</td>
<td>(N = 69): 47 with TBI, matched to 22 HC for age, gender, education, and years of driving experience</td>
<td>Age, gender, education, and years of driving experience</td>
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**Note.** AA = African-American; ABI = acquired brain injury; BDQ = Barriers to Driving Questionnaire; CDE = comprehensive driving evaluation; DMV = Department of HC = healthy control participants; LOC = loss of consciousness; $M = mean$; mTBI = mild TBI; NDT = Neurocognitive Driving Test; NICHHD = National Institute for Competency Rating Scale; PTA = posttraumatic amnesia; $SD = standard deviation$; SDMT = Symbol Digit Modalities Test; SPI = Simulator Performance Index; Whitney $U$ test; UFOV = useful field of view; WAIS–III = Wechsler Adult Intelligence Scale–III.
<table>
<thead>
<tr>
<th>Outcome Variable</th>
<th>Design</th>
<th>Main Findings</th>
<th>Level of Evidence and Conclusion</th>
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<tr>
<td>On-the-road tests: Measured with Global Rating Scale and Driver Assessment Scale</td>
<td>Experiment—on-the-road testing; no blinding</td>
<td>Participant performance diminished as the complexity of the UFOV subtests increased. The second subtest of the UFOV (divided attention) predicted on-road driving performance ($R^2 = -3.2$, $p &lt; .02$). DAS $R^2 = -3.5$, $p &lt; .02$). Participant ages and Trails B were also predictive of driving performance.</td>
<td>Class II (no control or randomization) Conclusion: The second subtest of the UFOV predicts on-road driving performance in this predominantly driving severe TBI group.</td>
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<tr>
<td>Overall performance on a CDE</td>
<td>Two-group prospective design; no blinding</td>
<td>Comparison of the rank orders of driving ability for participants with ABI revealed a s/s Spearman correlation ($r = .743$, $p &lt; .01$). NDT cutoff score successfully categorized 80% of all participants with ABI.</td>
<td>Class II (no randomization, small sample size) Conclusion: Results help establish the potential utility of the NDT for evaluating driving ability in people with ABI.</td>
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<tr>
<td>None</td>
<td>Multicenter qualitative study across 10 rehabilitation units</td>
<td>Current drivers reported problems with behavior (anger, aggression, irritability $67 = 48.2%$); memory (89 = 64%); concentration and attention (39 = 28.1%); and vision (39 = 28.1%). Drivers reported most driving-related problems as often as ex-drivers. Current drivers scored s/s higher on the FIM and FAM (indicating greater independence) than ex-drivers ($p = .002$ on a $\chi^2$ test of significance). The driving group had sustained less severe TBI than ex-drivers; 78 (56.2%) current drivers had a severe TBI. Few (61 = 16%) ex-drivers reported receiving formal advice about driving after TBI.</td>
<td>Class IV (descriptive; qualitative) Conclusion: The existence of problems that may affect driving does not stop patients from returning to driving after TBI. Patients should be assessed for mental and physical status and recommendations need to be given before they return to driving after TBI.</td>
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<tr>
<td>Driving status postinjury; community integration</td>
<td>Correlational research using logistic and multiple regression analyses to predict driving status for drivers vs. nondrivers</td>
<td>BDO domains predicted driving status: Model was s/s: $\chi^2 (5) = 1.29, p = .0025$; -2 log likelihood = 51.6, Nagelkerke $R^2 = .32$. Social barriers such as directives against driving from significant others accounted for the most variance in survivor driving status (odds ratio $= 3.30$, $p &lt; .05$). Perceptions of driving barriers predicted community integration ($p &lt; .05$) in hierarchical multiple regression models.</td>
<td>Class III (small sample size, no randomization) Conclusion: Research must address fitness to drive with the decisions made by survivors and their families. Interventions must be developed to maximize driving independence of people with TBI.</td>
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<tr>
<td>Driving status (return to driving), driving frequency; miles driven per week Postinjury driving incident recorded by DMV</td>
<td>Retrospective and prospective cohort (range 4 months–10 years post-TBI); no blinding</td>
<td>Logistic and hierarchical regression analyses indicated that the significant other’s perceptions of the patient’s fitness to drive were the strongest predictor of patients' driving status ($R^2 = 0.29, p = .002$) and driving frequency ($R^2 = 0.33, p &lt; .001$). However, years postinjury, disability at discharge, and current neuropsychological functioning best predicted postinjury driving safety ($R^2 = .30, p = .003$).</td>
<td>Class II (Cohort—retrospective and prospective) Conclusion: Significant other’s perceptions of the client’s fitness to drive should be considered as a predictor of the client’s driving status and driving frequency.</td>
</tr>
<tr>
<td>Subjective: Self-reported measure of driving behavior and characteristics Objective: Crashes, citations and violations from NJ DMV</td>
<td>Telephone survey and cross sectional analysis of DMV records after a CDE; no blinding</td>
<td>Subtle descriptive differences in driving characteristics were observed between the two groups. However, comparison of self-reported and documented reports of aberrant driving behaviors did not reveal a s/s greater number of crashes or violations among TBI participants compared with HC drivers.</td>
<td>Class II (narrow spectrum, retrospective, gold standard comparison) Conclusion: Participants with TBI who successfully complete a driving evaluation program are able to reintegrate into real-world driving.</td>
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</table>
severity, however, we considered that feature in reaching conclusions and making recommendations. A clear need exists to study driving performance among people with differing severity of TBI.

The neuropsychological tests and the UFOV have received the most study relative to the predictive validity for on-the-road driving performance. The neuropsychological tests are probably not predictive of on-the-road driving performance. For the UFOV, however, the evidence suggests (Level B recommendation) that it is probably predictive of the attention and visual processing skills for on-the-road performance in people with moderate and severe TBI.

Driving simulators offer the potential for a cost-effective and safe approach to assessing people with TBI. Because of a paucity of studies, and despite the claims of ecological validity made by the researchers (Lew et al., 2005), recommendations cannot be made for their use as a valid substitute for on-the-road tests.

Self-report, significant others’ reports, and postinjury disability status, not surprisingly, may be predictive (Level C recommendation; Coleman et al., 2002; Hawley, 2001; Rapport et al., 2006) of real-world driving. Occupational therapists and researchers alike may choose to start gathering evaluation and assessment information at the level of the client, family, and postinjury disability status. This approach not only makes sense from a client-centered perspective but is also pragmatic and suggests a reasonable baseline for further data gathering.

The CDE received a Level C recommendation, suggesting that it is possibly predictive of real-world driving among people with TBI. Occupational therapists and researchers must consider this gap in the evidence, remembering that this recommendation is based on the absence of a rigorous Class I study.

The implications for future research are clear: We need Class I evidence with Level A recommendations to make sound clinical decisions for assessing driving performance among people with differing severity of TBI. Thus, in this population, well-designed randomized clinical trials are indicated for assessing driving performance in the UFOV, the driving simulator, and on the road.

The limitations of this study include not considering studies in languages other than English or studies published >13 years ago. We did not search the “gray” literature (government reports) or backtrack on reference lists in the articles that we used. We used team consensus, rather than rater reliability, to select the articles and did not control for publication bias by seeking unpublished manuscripts (Cooper & Hedges, 1994). This study, however, is the first that summarizes the literature on TBI and driving in a way suitable for clinical decision making and identifying areas where further research is needed. The study team included faculty specializing in driving research and a clinician performing TBI assessments. ▲

References


