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HOT TOPIC

Driving After Traumatic Brain Injury: Evaluation and Rehabilitation Interventions

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Abstract The ability to return to driving is a common goal for individuals who have sustained a traumatic brain injury. However, specific and empirically validated guidelines for clinicians who make the return-to-drive decision are sparse. In this article, we attempt to integrate previous findings on driving after brain injury and detail the cognitive, motor, and sensory factors necessary for safe driving that may be affected by brain injury. Various forms of evaluation (both in clinic and behind-the-wheel) are discussed, as well as driver retraining and modifications that may be necessary.

Keywords Brain injury · Driver rehabilitation · Driver evaluation · Driving performance · Neuropsychology

Introduction

Close to 1.4 million Americans suffer from a traumatic brain injury each year, and nearly 2 % of the population requires assistance with activities of daily living (ADLs) as a result of brain injury (BI) [1••]. BI can be classified as mild, moderate, or severe, and its accompanying symptoms and long-term effects vary depending on a host of factors including the severity of injury, location of injury, premorbid health, socioeconomic status, access to health care, pre-injury intelligence, and age at time of injury [1••]. Long-term symptoms of BI include a variety of physical, cognitive, and behavioral sequelae that can impact several aspects of everyday functioning for these individuals. One highly valued and instrumental activity of daily living that can be compromised by these deficits is the ability to drive an automobile.

The ability to return to driving has been identified as one of the most important quality of life concerns for individuals with brain injury [2, 3]. The importance of regaining driving privileges cuts across the spectrum of BI severity, with 50–70 % of adults with moderate to severe BI returning to driving after injury [4••, 5]. As driving enables engagement in various life activities, loss of this privilege can negatively impact functional re-integration, independence, and life satisfaction [6]. Research findings have demonstrated that the loss of this privilege is associated with reduced rate of return to work and vocational instability [7] and with decreased participation in social roles and community re-entry [4••]. Emotionally, driving cessation is associated with increased depression and sadness as well as a loss of life roles and personal identity [1••, 4••, 7, 8].

Driving is a complex task that requires the successful integration of perceptual, physical, cognitive, and emotional systems. BI survivors, along with their families and care providers, are often faced with having to make a determination about an individual's capacity to return to driving after BI. Unfortunately, there remains a lack of consensus regarding standard driving evaluation and retraining methodologies, which is further confounded by conflicting evidence from both the clinical and transportation literature. The purpose of this paper was to (1) provide a brief summary of the primary areas of assessment relevant to determining driving capacity following BI, (2) outline current driver assessment/rehabilitation options, and (3) introduce future directions for enhancing this important area of rehabilitation.

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Driving After Brain Injury

The current literature reporting the effects of return to driving for individuals with BI is significantly limited by a lack of defined driving performance outcome measures. Most recently, a comprehensive review of all relevant studies commissioned by the Federal Motor Carrier Safety Administration lamented the insufficient evidence to address basic questions regarding the impact of BI on safety risk [9]. Some recent studies have reported elevated risk for crash involvement after BI. In a study out of Italy, Bivona et al. [4••] found that 63 % of individuals with severe BI who returned to driving were involved in subsequent car crashes. The researchers included a mix of new drivers (e.g., not licensed prior to injury) and both those with and without driver rehabilitation in their sample. Similarly, Schanke et al. [10] examined driving behaviors 6–9 years post-injury in a Norwegian sample including both TBI and cerebral vascular accidents. Their findings indicated that self-reported crash rates for drivers with brain injury were double that of a normal comparison group. This study also included a mix of participants with and without formal driver assessment. By contrast, a 5-year post-injury study of individuals with BI, which included only those that had received driver assessment and rehabilitation, did not find a higher rate of accident involvement compared to a match control [11]. Overall, these findings are mixed, and this uncertainty can be partially attributed to the heterogeneity of the reported study samples. Regardless, we do know that driving has an impact on overall functioning and quality of life, that most individuals with BI want to continue to drive, and that these patients often drive despite recommendations in favor of driving cessation [12].

While most studies raise questions about risk, they rely heavily on self-reported data and are limited to the most extreme outcome of driving (i.e., crash involvement). For example, there are little data regarding changes in driving frequency, self-limiting behaviors or modifications, risky behavior, and unreported motor vehicle accidents or violations. Yet, increased predictability of both crash-causing behavior and everyday driving capacity may provide more accurate prediction of successful re-integration into driving [13••].

Given the relevance of driving capacity to return to daily life roles and community integration, it is not surprising that studies indicate that up to 70 % of BI patients return to driving after injury [4••, 5]. However, the ability to drive safely is not formally tested in about two-thirds of those cases [14••]. One study found that less than 6 % of BI patients who decided to cease driving after their injury sought evaluation, while about only half of those who continued to drive were formally evaluated [2]. Therefore, lack of consistency in driving evaluation referrals is an important issue for this population. While external factors (e.g., state reporting laws) may also influence rate of referrals, initiation of the referral process is dependent on physician prescription/formal referral. Therefore, increased education of changes in driving capacity following BI for clinicians and providers is an important goal in increasing referrals for proper assessment of readiness for return to driving.

Factors Related to Driving Performance

To date, there is no one unified and standardized clinical driving evaluation. Driving evaluation is complicated by the lack of Federal guidelines and/or mandates to provide overarching directions to clinicians charged with the task of determining capacity. In order to evaluate driving ability, clinicians (including physicians, occupational therapists (OTs), and neuropsychologists) often rely on the assessment of a variety of factors that have been identified as relevant to driving. Across the literature, the consistently reported areas include vision, cognition, and motor/physical performance.

Vision

Although vision is the primary sensory related to safe driving and is the only sensory domain evaluated legally, there is a dearth of studies that have examined it specifically following BI. Existing legal visual requirements primarily focus on visual acuity (i.e., 20/20, or the ability to resolve detail at 20 feet), but these requirements are highly variable from state to state [15], and there is no clear evidence that acuity is a valid predictor of driving safety. Importantly, recent studies that have examined this relationship among healthy controls have found no significant relationship between visual acuity and crash involvement statistics [16, 17].

Given this lack of predictive validity, studies with neurological populations have demonstrated the relevance of visual domains other than visual acuity warrant consideration when determining driving risk [18]. Visual field is the second most commonly evaluated visual ability in relation to driving, and like acuity, the requirements for visual field vary on a state-by-state basis. Unlike visual acuity, which has clear metrics if not a universal minimum requirement, the definition of visual field differs across studies [19]. Conflicting findings result from these murky operational definitions. Taken together findings from this research suggest that individuals with visual field impairments may be compromised on some aspects of driving performance (e.g., identification of signage) but unaffected in other areas (e.g., speed estimation). Therefore, individualized driving assessments may still be necessary in lieu of standardized visual administration procedures.

Driving data from other neurological populations also indicate potential contributions of contrast sensitivity and visual processing speed. In older drivers, impaired contrast sensitivity is associated with a recent history of crash involvement [20] and with driving modification and difficulty [19]. Similarly, in older drivers, the slowed visual processing speed and visual inattention have been linked to number of crashes [21] and problems with vehicle control [22].

Overall, driving is a highly complex visual task, and each aspect of visual functioning must work within an integrated system in order to successfully navigate the driving environment. In a fitness to drive evaluation, therefore, it is recommended that the standard visual acuity test be supplemented with other assessments of visual functioning (e.g., contrast sensitivity, visual field, processing speed, and divided attention) [19].

Motor

Physical domains, including strength, coordination, grip, and reflexes in both the upper and lower extremities, are basic requirements for managing automobile control devices (e.g., steering wheel, pedals). Following TBI, these motor skills may be compromised due to residual difficulties with weakness, hemi-paralysis, ataxia, or rigidity.

Physical fitness should also be evaluated in clinic prior to on-the-road assessment. Physical abilities to be assessed include range of motion, muscle tone, strength and endurance, coordination, balance, proprioception, and mobility. Even minor impairments in a person's ability to integrate information from the sensory, motor programming, and muscular-skeletal systems can lead to significant disability. While motor and physical capacity are commonly evaluated by physical therapists, many driver specialists commonly incorporate gross motor measures of upper and lower extremity to determine the need for adaptive driving equipment (see section below).

Cognition

The majority of existing literature on driving after brain injury has focused on defining the relationship between cognitive impairment and driving performance. In general, the main areas of cognition identified as relevant are consistent with findings in other neurological cognitive compromised populations such as Parkinson's disease [23], dementia [24], and multiple sclerosis [25].

Deficits in selective and divided attention, memory, and information processing speed all negatively impact driving

Table 1 Tests of key cognitive domains for assessment of driving capacity

Cognitive domain	Terms used to describe this domain	Tests commonly used in literature
Attention	Divided attention	WAIS digit span
	Sustained attention	Trail making A
	Choice reaction time	Conners performance test
	Selective attention	UFOV
	Distractibility	
	Visual attention	
Visual spatial	Perception	WAIS block design
	Spatial perception	Raven progressive matrices
	Visual problem-solving	Rey figure
Processing speed	Information processing speed	Symbol digit modality
	Visual scanning	Trailing making test A and B
		PASAT
Executive functioning	Judgment	Stroop
	Disinhibition	Wisconsin card sort
	Decision-making	Tower of Hanoi
		WAIS-comprehension
		WAIS-abstract reasoning

safety [14••]. Attentional impairments are particularly concerning in an on-road environment, as BI survivors are often easily distracted, unable to recognize hazards, or unable to multi-task successfully. Similarly, a slower processing speed means a slower reaction time, slower driving, and slower decision-making. Executive functioning impairments, particularly in the areas of inhibition, planning, abstract reasoning skills, and self-awareness, can also affect driving performance [14••]. As judgment and insight can be impaired after BI, drivers may be prone to more risk-taking behaviors, demonstrate poor awareness of driving problems or accidents, or be unable to recognize driving errors. However, patients with mild to moderate deficits who appreciate their own cognitive limitations have been found to pass an on-the-road evaluation more successfully than patients with a similar neuropsychological profile, who also display anosognosia [26].

An important consideration in regard to cognition is the varying utility of formal cognitive testing dependent on the level of cognitive compromise. For example, cognitive testing maybe useful for detecting severe deficits in clients who may be unsafe behind the wheel prior to an on-the-road assessment and thereby help ensure the safety of both the driver and the evaluator. Much of the early literature demonstrated significant relationships between moderate and severely impaired individuals with BI and impaired driving performance [27]. By contrast, the relationship between mild cognitive impairment and driving performance is less defined.

To date, the literature includes a variety of neuropsychological instruments that have been used to clinically evaluate driving fitness, which reflects the field's absence of consensus regarding this matter [14••]. Unfortunately, there is limited empirical evidence to inform the specific cognitive aspects of driving and the consistency of predictive validity of these tests. However, integrating findings from across the various neurological populations have yielded some robust findings, including the identification of key cognitive domains. Generally, this includes attention, executive functions, visual–spatial, and visual perceptual skills (see Table 1 for summary).

More specifically, Coleman et al. [28] found that neuropsychological performance on tests of working memory, sustained visual attention, and abstract reasoning is predictive of driving status. Standard computerized assessment tools such as the useful field of view can also be used to guide clinical decision-making, particularly in people with moderate to severe BI. The trail making test (TMT) is another standard measure that can be useful in determining capacity to drive. Fisk et al. [29] found that a moderate and severe BI population scored significantly worse in the TMT than healthy controls, while Lundqvist et al. [30] showed that BI patients who returned to driving performed better on the TMT than BI survivors who had not returned to driving. Novack and Alderson [31] also found that poor performance on the TMT-B was predictive of failure in an on-road assessment of driving capacity.

Although neuropsychological testing alone is not sufficient to predict driving fitness, it can discriminate among groups with differing skill levels [1••] and provide useful information to supplement an on-the-road test. However, caution is warranted regarding generalization, as some studies have found that around 60 % of patients with neuropsychological scores that suggest driving difficulties are deemed to be safe drivers following an on-road assessment [26].

In sum, the contribution of cognitive capacity on driving performance has been demonstrated, yet, empirical findings providing further clarification of this relationship among such a heterogeneous group as BI remains limited.

Other Factors

Other factors to be considered in an assessment of driving capacity include the patient's premorbid driving history, as personality and risk-taking behaviors pre-injury may have implications for driving safety post-recovery. Lowered self-awareness and lack of insight into deficits is often a symptom of BI, and one study [11] found that adult drivers with BI rated themselves as having excellent or nearly excellent driving skills, similar to healthy controls. However, this study also found that drivers with BI are capable of recognizing changes in their driving skills and often self-limit their own driving (i.e., avoid driving at rush hour or at night). Finally, other consequences of BI such as fatigue, the inability to appreciate consequences, and emotional lability (e.g., impulsivity, anxiety, irritability, and apathy) may also lead to dangerous situations on the road [4••].

Finally, an important consideration that is commonly overlooked or not addressed clinically, but warrants additional research and integration into our conceptualization of driving capacity, is the need for repeated driving evaluations. Unlike the legal process (which requires some aspect of licensure renewal for all drivers), among clinical populations a formal driving evaluation process is typically seen as a one-time requirement. More specifically, the driver evaluation focuses on the readiness of the individuals to pass the legal driver examination. This is because clinical driver specialists do not have the authority to approve or decline legal driving status. Given this, after most individuals have received and passed a clinical driving evaluation, they go on to receive their state licensure. This license is then subject only to required renewals that are typically minimal and do not take medical aspects into consideration.

What is the most concerning about this process is the compiling evidence that the sequelae of BI can change over time and with the aging process [32]. BI residual symptoms may be experienced years after the injury and can include a variety of difficulties (e.g., daytime sleepiness; fatigue; risk of seizures; and cognitive, motor, and sensory deficits) [33]. More importantly, the aging process likely compounds these symptoms. As a result, aging adults with a positive history of BI may be at higher risk of driving accidents than their aging cohort [33]. However, to date, driving research has not examined driving capacity from a longitudinal perspective. Even among known progressive disorders (e.g., multiple sclerosis and dementia), there is a lack (both legally and clinically) of consideration for repeated driving assessment.

Driver Assessment and Rehabilitation—Current Status

A comprehensive evaluation, preferably addressing the various factors discussed, is the first phase of driver rehabilitation and precedes any driver retraining. A thorough evaluation often requires the coordination of physicians, OTs, and neuropsychologists. Legally, while many states require physicians to report a change in medical status to the licensing bureau of the state, they often lack the tools to evaluate driving capacity and refer this determination to specialized driver assessment programs. Given the lack of federal mandates, this process can vary greatly from state to state and even program to program. However, the generally agreed upon "gold standard" of driving evaluation typically includes assessments of both on-the-road and off-the-road (in clinic) performance.

Off-the-road Driving Evaluation

Aspects such as medical history and physical and cognitive functioning are typically included in the off-the-road evaluation. A driver rehabilitation specialist, either as part of their evaluation or in conjunction with evaluations of other professionals (i.e., physician and neuropsychologist), will compile the relevant history to help anticipate any difficulties in the on-road component of the evaluation. An important component of this off-the-road evaluation also includes gathering information about previous driver history and establishment of legal visual requirements.

On-the-road Driving Evaluation

Following the off-the-road component, individuals without gross deficits that would prohibit driving undergo a behind-the-wheel (BTW) (also referred to as on-the-road) assessment. The BTW assessment can serve several purposes. For drivers who lack insight to their driving deficits, this standardized assessment can provide objective clarification, in-the-moment feedback, and guidance regarding their driving capacity. For drivers who are able to drive but require some rehabilitation, this evaluation allows driving specialists to see what modifications may be necessary during retraining. Finally, these evaluations allow for psychoeducation and expert feedback to drivers who are competent and capable of driving independently, but perhaps require reassurance (often the case for families of those drivers as well).

The BTW drive is typically conducted in a dual-control vehicle and typically includes the client and a certified driving instructor; however, it is recommended that an additional evaluator be included in the on-the-road to minimize the demand on the driver specialists. The typical BTW lasts about ~30–45 min, occurs during daylight hours, and can include a route that encompasses a variety of driving environments (e.g., commercial road and residential zone). At a minimum, the skills to be tested include right and left turns, stops (at stop signs, lights, and intersections), speed adjustment, vehicle positioning, visual searching of surroundings, and signage recognition. The client is instructed to drive as they normally would, and driving evaluators generally utilize individualized checklists to record and quantify their observations. Unfortunately, there are no standardized checklists available, so these procedures vary by provider and are often subject to the qualitative interpretation of observed behaviors. Indeed, a common criticism of the BTW is the limited quantitative evidence for its validity and reliability as a measure of driving capacity [34, 35].

Table 2 Commonly used adaptive driving equipment

Device	Purpose
Lifts, platforms, wheelchair loading assists	For transfer into vehicle
Hand controls	Enables acceleration and braking for drivers with lower limb limitations (e.g., push/pull, push/right angle pull, push/twist, power assisted control units)
Left foot acceleration	For drivers with impairment in the right lower extremity
Steering column extensions and smaller steering wheels	For drivers in wheelchairs and/or for those with limited upper extremity strength
Foot operated steering	For drivers without upper extremities
Steering assistive devices	Allow access to all steering requirements with one extremity (e.g., spinner knobs, bi-pins, tri-pins, palm grasps, and custom splints)

During and after the BTW assessment, the evaluator must decide if any noticeable driving deficits exist, and if so, to what degree they are related to the BI. It is possible that some not recommended behaviors (such as rolling through stop signs or not using mirrors) are due to the driving habits of the individual in question and should not be attributed to changes due to BI. At the completion of both the off-the-road and on-the-road evaluations, the evaluator must integrate the findings to provide a recommendation for the client. Often, driving ability is not clearly "acceptable" or "unacceptable," yet this clinical decision is often pass/fail. In fact, there are three recommendations available to the clinician, and as this assessment is not yet standardized, clinical judgment plays a large role in the decision. A clinician can decide that a driver (a) can resume driving without restrictions, (b) requires driving training or rehabilitation, or (c) does not meet safe driving criteria.

Driver Training and Rehabilitation

This option is often recommended if a client shows driving deficits but demonstrates insight and the potential to learn compensatory strategies, or if the driver has had physical modifications to a vehicle and requires further practice driving. The length of retraining depends on the severity of deficits, as well as the client's driving experience and ability to adapt new strategies. The goal is to enable clients to be competent and independent drivers. Training incorporates fundamental driving skills (e.g., defensive driving, steering and lane use), compensatory techniques (e.g., memory strategies and adaptive equipment), and improvement strategies. Driver training often encompasses new adaptive technologies designed to help drivers compensate for motor/physical limitations. Recent technology has made it possible for many of these limitations to be overcome, and they no longer preclude a person from driving independently. The adaptation and training required for these modifications are often the responsibility of a Driver Rehabilitation Program or Certified Driver Rehabilitation Specialist (CDRS; often an OT) and can offer a variety of accommodations (see Table 2).

The necessity and use of each of these technology options depend on the unique circumstances of each client. By contrast, individuals who are referred for additional rehabilitation are often not yet prepared for the learning demands of utilizing adaptive driving equipment and in many cases, may be referred for additional cognitive rehabilitation to address their unique limitations.

Driver Assessment and Rehabilitation—Future Directions

Recently, a review of the literature [36] which included 35 papers reported that despite a widespread acknowledgment of the increased risk of accidents in this population, there is still no standardized and validated methodology for evaluating the impact of brain injury on driving. As reported by Classen et al. [1••], published studies on this topic show low evidence levels. The majority of these studies, while informative, are retrospective designs, which make it difficult to draw definitive conclusions regarding predictors of recovery and successful driving. Although neuropsychological tests have been shown to be useful, to date, no specific tests have been found to fully predict return to drive capacity.

In an attempt to address these existing limitations, some researchers have turned to novel technologies to enhance our clinical ability to evaluate driving capacity. One promising technology that offers new opportunities for driving assessment and rehabilitation is the use of driving simulators. Although simulator testing is not currently included in the "gold standard" of driving assessment, research indicates that simulators can provide novel and more specific measures of driving performance [37, 38].

Driving simulators offer a method for collecting both quantitative (e.g., brake distance, speed, lane deviations and eye tracking) and qualitative data on client skill level in multiple types of driving scenarios (e.g., easy, challenging) that are programmable, safe, and repeatable. This modality allows comparison between groups in research settings, and in clinical settings; furthermore, driving simulators can allow a clinician to train a driver to adapt to road environments that may not be safe for driving rehabilitation in the real world (e.g., through crowded cities or highways). The literature currently includes growing evidence for determining the validity of this methodology for assessing real-world driving, the evidence in favor of this claim remains limited, and more research is needed [1••]. However, with the continued technological advances that offer more accessible driving simulators (e.g., reduced cost, streamlined hardware), the potential to integrate driving simulators as a complementary component of a comprehensive multi-level driving assessment is encouraging [13••].

Conclusion

Clinical and research findings both support the relevance and importance of developing improved methods for evaluation driving capacity after BI. The need for identifying the key contributing factors to maintaining driving capacity is important both at the individual level (client needs; maintaining autonomy and supporting community and vocational goals), as well as at the global level (maintaining the safety of public and individuals).

While consensus exists regarding the relevance of this everyday tasks and the concern that risk for compromised driving performance exists following BI, the state of the field remains quite limited for guiding clinical practice. First, there is limited knowledge and availability of tests, tasks, or tools to accurately evaluate this skill. Second, the lack of federal guidelines and mandated standardization creates a wide degree of variability in how driving capacity is assessed, which subsequently minimizes the interpretation of findings from existing studies. Finally, it is important to note that the ability to drive a car is a complex task that requires both the independent and inter-dependent contributions of cognitive, physical, sensory, and behavioral abilities, and therefore determining how to best determine this capacity remains a challenge.

While additional research is clearly needed, experts have offered one area of agreement to guide clinical practice. Multi-level assessments, one that includes both off-the-road and on-the-road evaluation of multiple domains reviewed above, are critical. Currently, driver rehabilitation specialists lead the way in providing this important multi-level clinic service, and in conjunction, with other professionals (e.g., physicians, neuropsychologists, and physical therapists) can help increase overall awareness about the need to evaluate individual with TBI on this important activity of daily living.

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Compliance with Ethics Guidelines

Conflict of Interest MT Schultheis and EK Whipple declare no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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