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Driving After Traumatic Brain Injury: Closing the Gap Between Assessing, Rehabilitating and Safe Driving

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1. Introduction

The privilege of driving a vehicle is often a fundamental part of individuals' daily lives. For many individuals who have suffered a traumatic brain injury (TBI), the ability to return to driving post TBI is an integral step to recovering independence and enhancing community reintegration (Rapport et al., 2008). Approximately 50% of TBI survivors with moderate to severe injuries resume driving, often irrespective of medical-legal evaluations (Fisk, Schneider, & Novack, 1998; Lew et al., 2005; Tamietto et al., 2006).

Evidently, helping TBI survivors return to safe driving plays a pivotal role in their path to recovery and reintegration to the community. A proper assessment of a TBI survivor's strengths and weaknesses can help prevent harm to the driver and other members of society and further enable their return to productive roles, work, and other favored activities. For instance, Kreutzer and colleagues (2003) revealed that the ability to drive post TBI is an independent moderator for employment stability. Determining whether a TBI survivor is safe or unsafe to drive remains a challenging issue since driving is a functional task with varying levels of complexity that can be potentially compensated for if impairments exist. Unfortunately, two negative outcomes may occur as a result of inaccurate driving assessment. The first negative outcome may be removing the privilege to drive from a TBI survivor who is either safe to drive, or could become safe to drive after retraining or further recovery (false positive result). The second outcome is a false negative result where the brain injury survivor is a potentially unsafe driver who is allowed to resume driving. Previous research suggests that TBI drivers tend to receive greater traffic violations (Haselkorn et al., 1998), tend to drive slower (in a simulated environment; Stinchcombe et al., 2008), and perhaps most importantly, have an increased crash risk compared to uninjured controls (e.g., Formisano et al., 2005; Lundqvist et al., 2008; but see Haselkorn et al., 1998; Schultheis et al., 2002). For example, Schanke and colleagues (2008) assessed driving behaviour of TBI survivors both pre and post injury. Results indicated that the accident rate of the TBI survivors was twice as high as that of the general population. Cyr and colleagues (2009) observed that in a simulated driving environment, TBI survivors who had returned to driving, compared to uninjured controls, were significantly more likely to crash in reaction to a surprising and challenging event.

Similar findings were obtained by Lew and colleagues (2005) in a small sample of TBI survivors.

Driving a car is certainly one of the most cognitively complex daily activities. It requires the integration of continuously changing visual–perceptual stimuli, swift information processing, and correct motor responses. The elements of a roadway environment can vary in complexity from one moment to another or from one geographical location to another. Because of the continuously changing nature of the driving environment (e.g., other drivers and road users' reactions, road conditions, etc.), driving reactions cannot be fully predicted. Indeed, even if a large portion of driving responses can be planned in advance based on the anticipation of events, many reactions must be activated spontaneously and rapidly in response to unanticipated events (Michon, 1985). Consequently, driving requires good judgment and decision making. All of the above ultimately lead to safe reactions behind the wheel.

According to Michon's (1985) hierarchical model of driving which includes strategic, tactical and operational levels, safe driving requires the ability to correctly perform each level of driving as well as optimal interactions between the various levels (see Figure 1). Unfortunately, TBI survivors may have difficulty in executing a variety of the necessary driving abilities for safe driving, including adequate and rapid processing of simultaneous inputs and anticipation of danger (Van Zomeran, Brouwer, & Minderhoud, 1987). Additionally, due to the sensori-motor and cognitive sequelae (including impairments of vision, attention, speed, and executive functions) frequently observed in TBI survivors, inappropriate driving reactions can be observed, even in TBI survivors who have been deemed fit to drive (Innes et al., 2007; Cyr et al., 2009). Evidently, the difficulty in assessing the driving ability of TBI survivors' consists of pinpointing which abilities are impaired and whether these impairments will translate into unsafe reactions behind the wheel.

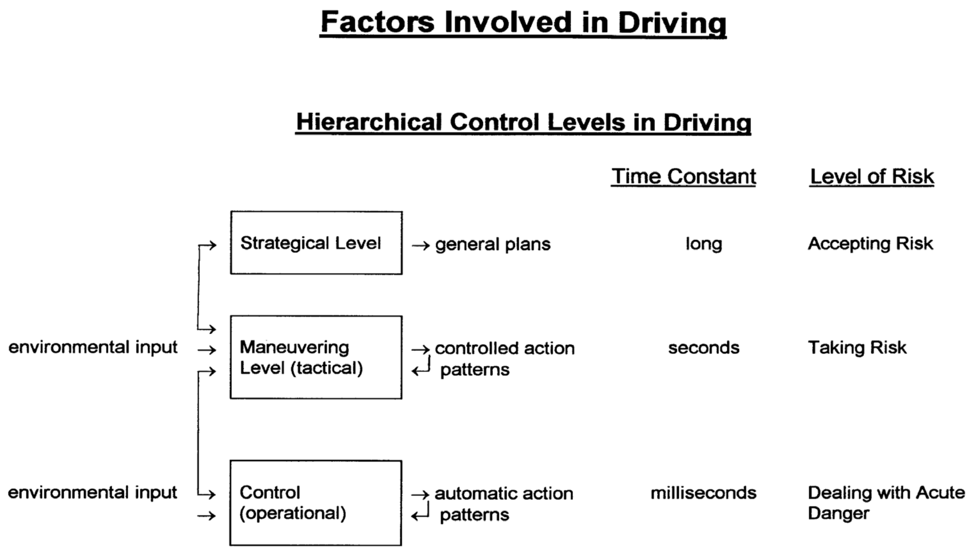

Fig. 1. Factors involved in driving according to Michon (1985).

2. The constellation of cognitive deficits observed in TBI survivors that may affect driving

The challenging problem that clinicians routinely face concerns the heterogeneous nature as well as the severity of cognitive deficits induced by a TBI (Schretlen & Shapiro, 2003). Individual differences are the hallmark of TBI. Further, cognitive recovery post TBI is not uniform across individuals and cognitive domains. Generally, TBI survivors exhibit deficits in attention, executive functions, processing speed, and memory (Hart et al., 2005; Lengenfelder et al., 2002; Madigan et al., 2000; Schretlen & Shapiro, 2003). Millis and colleagues (2001) found that reasoning and problem solving skills significantly differ between TBI survivors 5 years post injury. These cognitive and physical deficits are typically chronic and as expected, even 10 years post injury, TBI survivors may continue to demonstrate deficits in processing speed, memory, and executive function (Draper & Ponsford, 2008).

3. Assessment of TBI survivors using a generic approach

As indicated above, determining the capacity to drive post TBI poses a significant burden for rehabilitation professionals. To date, no commonly agreed upon best-practice guidelines are available to direct the assessment of driving ability post TBI and significant controversy exists regarding the most appropriate way to assess fitness to drive (Yale et al., 2003). The cognitive functions of TBI drivers are often assessed using 'generic' off-road tests that were not originally designed to assess driving competency and the specific cognitive requirements necessary for safe driving (e.g., Ball et al., 1988). The reliability, validity, and clinical effectiveness of these procedures have yet to be fully established. A recent systematic literature review indicated that studies have yet to provide evidence-based data that support the use of generic cognitive assessment tools to predict the driving abilities of TBI survivors (Classen et al., 2009). The lack of evidence-based data can be explained by at least four factors: 1) Generic cognitive/neuropsychological tests do not fully consider the heterogeneity of the cognitive deficits observed in TBI survivors and by the same token neglect to acknowledge the individual differences; 2) the lack of a sufficient generalizability between the cognitive functions assessed by these tests and those that are necessitated while driving; 3) Generic tests do not consider the continuous interaction between the cognitive processes involved in driving reflecting the need for the ability to shift and divide attention; and 4) the rather exclusive use of the on-road assessment to ultimately predict safe driving.

Current assessment procedures typically include a combination of off-road testing, including neuropsychological/cognitive tests and on-road testing. Simulator assessment is occasionally used (Cox et al., 2010; Lew et al., 2005) but its relevance will be detailed later in this chapter.

Off-road assessments are commonly used to assess cognitive, physical, and motor ability. These tests are often used as a primary screening assessment. They can also help identify the principal limitations of survivors and can help anticipate the difficulties they might have once behind the wheel. Typically, the first step in assessing TBI survivors' fitness to drive is through a neuropsychological exam (Côté, Syam, Vogel, & Cowper, 2007). Examples of neuropsychological tests include: the Trail Making test parts A and B, the Rey Complex Figure test, and the Clock Drawing test. Although these tests can discriminate between TBI survivors with different ability levels required for safe driving and are moderately correlated with driving ability (Marottoli et al., 1994), these tests alone cannot sufficiently determine fitness to drive (Schanke & Sundet, 2000; Classen et al., 2009) in all survivors, but can assist in estimating degree of recovery in order to prompt timing of further driving assessment. Another common test used to evaluate driving fitness is the Useful Field of View (UFOV; Owsley et al., 1991; Fisk et al., 2002). The UFOV assesses many important skills associated with safe driving, including visual processing speed and visual attention. It has been developed to assess fitness to drive in older drivers but has also been used to assess TBI survivors. The test has been found to be moderately associated with on-road driving performance (Myers et al., 2000; Novack et al., 2006). In fact Novack et al. (2006) found that the second subtest of the UFOV (divided attention subtest) did predict on-road driving performance of moderate to severe TBI individuals.

In sum, the results of cognitive tests can be used to determine whether someone is truly unable to drive when results demonstrate a significantly impaired ability. However, survivors for whom it is impossible to reach a decision about their driving based on the results of cognitive testing alone, need further clinical assessment, often in the form of an on-road driving assessment (Schanke & Sundet, 2000). The on-road driving assessment test may also be used to determine whether a potential driver can deploy compensatory strategies in order to overcome some of their limitations (Lew et al., 2009).

The on-road test which is typically administered by a driving rehabilitation specialist is the gold standard for driving assessment post TBI (Korner-Bitensky et al., 1994; Odenheimer et al., 1994). Although the on-road test demonstrates excellent face validity, some limitations have been raised (Lew et al., 2005). For instance, appropriate standardization between individuals and across assessment centres cannot always be achieved. Most importantly, the on-road test does not allow for the assessment of reactions in response to challenging or critical situations, impeding upon its predictive validity. This limitation is of most importance as TBI survivors most often demonstrate great difficulty in response to novel or challenging events (Couillet et al., 2000; Draper & Ponsford, 2008). Due to the nature of the on-road test, and the inability to assess driving behavior in response to more challenging events, there is a risk that TBI survivors could be granted license renewal, when in fact they may not be safe to drive. Few studies have assessed the predictive validity of the on-road test to real-world driving performance in people with TBI, which is necessary as drivers do not always drive as they do on the on-road test (Fox, Bowden, Smith, 1998; Lew et al., 2005).

4. A specificity-based approach: Unifying cognitive testing, driving assessment and retraining

The generic approach, as described above, operates in a highly structured sequential manner: tests of cognitive functions are administered first and are followed by the on-road test if necessary. On-road testing is often expensive, time consuming, and the safety of the driver and other road users is not always guaranteed. The on-road test is the final confirmation of driving ability. However, as mentioned previously, the generic approach may not provide sufficient information in regards to the specific limitations of the brain injury survivor. The content of the on-road driving assessment is not specifically adapted to the documented cognitive deficits of each individual, thus the observed relationship between test results and driving performance could be limited.

The importance of employing an approach that is customized to a TBI survivor’s symptom profile has been raised by Lew and colleagues (2005). Such an approach favours a flexible perspective to the assessment of driving safety that combines the cognitive assessment, the driving assessment, and perhaps the rehabilitation potential and needs of the individual. Ideally, the driving challenges of the brain injury survivor should be known even before cognitive testing occurs. Once the driving difficulties are circumscribed, the cognitive underpinnings of these errors should be identified, ideally leading to a specific 'cognitive' profile. A better characterization of the limitations of a TBI survivor could translate into an adapted retraining effort that could combine a cognitive retraining protocol within a driving context.

For the purpose of supporting the specificity-based approach, we will use the concept of attention to highlight the challenges associated with its assessment and how the proposed approach could lead to a more sophisticated understanding of the attention deficits of TBI survivors and how they might influence driving.

5. The specificity-based approach applied to deficits of attention in TBI

Attention can be broadly defined as the ability to receive and process information from the environment while filtering out irrelevant input (Trick et al., 2004). More recent models incorporate a strategic control dimension to attention (Whyte et al., in press). In such perspectives, sustaining attention to a task, inhibiting irrelevant input that induces distractions, shifting attention as a function of the changing goals and priorities of an individual, and manipulating currently processed information are also active attention processes (Whyte et al., in press). Within this context, the contribution of attention processes to safe driving is considerable. Most importantly, this conception of attention better incorporates the complexity of driving and the cognitive flexibility that it requires. It also allows one to explore more specifically why TBI survivors with attention deficits tend to have difficulty driving. Arguably, a TBI could disrupt several subcomponents of attention, given its diffuse nature, thereby altering a survivor's driving ability.

Attention is critical for safe driving. It is needed not only to respond to a continuously changing environment but also to allow one to rapidly and flexibly shift focus from one activity to another. A driver's lack of attention has been frequently cited as a major cause of motor vehicle accidents (Langham et al., 2002). More specifically, divided attention, which refers to the ability to simultaneously carry out two competing tasks (Van Zomeren & Brouwer, 1994), has been commonly considered to be central to safe driving (Trick et al., 2004). In TBI, impaired performance on tasks requiring divided attention has been documented (Lengenfelder et al., 2002). For example, Dockree et al. (2006) found that more mistakes were made by TBI survivors in a sustained attention task that also included a dual task, compared to the same sustained attention task that did not include a dual task.

An important element of the specificity-based approach consists of documenting the specific driving difficulties even before executing cognitive testing. Arguably, the on-road test cannot be used for that purpose; it is designed to assess driving safety not to document the specific difficulties of a TBI survivor. Moreover, due to safety reasons, the standard on-road driving assessment does not incorporate situations that would allow one to assess strategic control (e.g. ignoring distractor stimuli); and behavioral flexibility (reacting to surprising events). Simulator testing is a flexible, ecological tool that may be a valid replacement for the on-road test.

6. Using the simulator to uncover the driving limitations of TBI survivors

Simulator testing utilizes virtual reality technology to assess the driving behaviour of individuals. Driving simulation provides a convenient and safe method for assessing driving behaviors. Unlike the on-road test, the simulator allows for the assessment of a driver's behaviour in response to challenging or critical situations (Cyr et al., 2009), and further allows for standardized and objective testing across individuals (e.g., same conditions regardless of location, weather, traffic density and examiner).

Evidence indicating that simulator testing is a valid *substitute* for real-world driving is still lacking. However the results of recent studies do indicate that driving behaviour within a simulated context is similar to driving behaviour on-road (Lew et al., 2005; Bella, 2008) and can predict on-road driving behaviour (de Winter et al., 2009; Bedard et al., 2010) even five years post brain injury (Hoffman & McDowd, 2010). Indeed, the ability to test an individual's response to challenging situations may make simulated driving a more sensitive assessment technique in comparison to traditional on-road assessments (Lew et al., 2009). It is also likely that the variables examined within a simulator assessment differ substantially from those examined in a standard on-road assessment. For instance, variables such as speed maintenance, lane deviation, steering and pedal control can be quantified. This could eventually explain why the correlation between the results of simulator and on-road assessment are low or at best moderate (Lew et al., 2009). Arguably more research is needed to discern the validity between simulator and on-the-road studies versus meaningful outcomes such as violation and collision rates for TBI survivors after return to driving.

Another interesting feature of simulator testing is its flexibility. Indeed, simulator testing allows for the development of scenarios that can target specific aspects of attention. This can be achieved in at least two different ways. The first approach consists of developing scenarios that will incorporate situations that will require the execution of a set of responses that rely on a specific cognitive process. In a study by Bélanger, Gagnon, & Yamin (2009), older individuals were required to react to specific challenging situations. The situations varied in terms of speed of response, planning ability, and strategic control. Results indicated that older individuals were great planners and could react quickly to a challenging situation that required sudden braking (e.g., pedestrian crossing). Their capacity to anticipate a risky situation is a dominant feature of their driving style. Interestingly, when tested in a situation that required strategic control of attention (steering and braking), older adults tended to crash more often than younger drivers. The second approach consists of merging cognitive assessment and driving. This has been frequently done in the field by testing the capacity to divide attention while driving. A classic paradigm consists of assessing the ability to detect visual stimuli or to react to sound while driving (e.g., Cantin et al., 2009; Lengenfelder et al., 2002). In one such study, Cyr et al. (2009), assessed whether divided attention performance of TBI survivors while driving the simulator was correlated with the risk of crashing in response to challenging events. The results indicated that TBI survivors were more likely to crash, and further, crash rate was best predicted by the divided attention scores as assessed in the simulator. The divided attention scores were not moderated by reaction time test results nor by processing and attention scores from the UFOV test.

Attention control in TBI survivors can also be deduced from their visual exploration via an eye-tracking device coupled with a highly controlled simulator environment. Milleville-Pennel et al. (2010) recently assessed the visual exploration of TBI survivors while driving within a simulated context, and related these findings to neuropsychological test results.

Interestingly, TBI survivors exhibited a reduction in the number of visual zones explored as well as a reduction of the explored distance. Further, these TBI survivors also exhibited deficits in divided attention as assessed via the Test for Attentional Performance (Zimmermann et al., 2007).

The above research illustrates that the inclusion of a simulator protocol can provide a unique ecological opportunity for an in-depth cognitive assessment of safe driving in TBI survivors. The research to date is minimal but suggests that a driving simulator can help clinicians better determine survivors driving difficulties. Due to the heterogeneity of deficits in TBI survivors, assessment needs to be made on a case by case basis and the simulator assessment should be tailored to reflect a survivor's specific cognitive profile. Moreover, because errors in attention tend to be made primarily in relatively novel or complex situations and/or when demands on cognition are increased (e.g., dual task) (Lengenfelder et al., 2002), readiness to drive can only be fully determined in novel as well as complex driving environments. Evidently, driving simulators can be used in that regard. Their potential as an assessment tool is enormous (Lew et al., 2009) if used within the logic of the specificity-based approach. However, if simulator testing merely copied the on-road assessment it is unlikely that the results would lead to a better understanding of the unique challenges of a given individual; results would more closely resemble those yielded by the generic approach. Although time and money could be saved, the idea of replicating the on-road test in a simulator does not reflect what a simulator based assessment can ultimately deliver.

7. Closing the gap between assessment, rehabilitation and safety

Ponsford (2008) summarized that "despite the large number of attention rehabilitation studies conducted to date, there is still limited evidence of their success". Thus the issue appears to be one of specificity, not quantity. Indeed, recent research suggests that by creating more specific approaches to rehabilitation, such as the utilization of a training program focused on one specific impairment (i.e., one impaired attentional process), significant improvements can be made by TBI survivors. Strum and colleagues (2003) found that by implementing a *specific* re-training program designed to improve *specific* attention deficits (e.g., divided attention), TBI survivors improved significantly more when tested on that specific aspect of attention, compared to when TBI survivors received a general re-training program (Test for Attentional Performance). More recently, Coulliet et al. (2010) found that TBI survivors with divided attention deficits (as assessed by the Divided Attention subtest of the Test for Attentional Performance) improved significantly on tests of divided attention after receiving a specific rehabilitation program for divided attention. TBI survivors were trained on two tasks separately; once competency was reached on both tasks individually, TBI survivors were instructed to complete the two tasks simultaneously. The tasks consisted of both paper and pencil tests as well as computerized testing (e.g., go no-go task, verbal fluency, word sorting). The program consisted of six weeks of 1-hour individual training sessions, 4 times a week.

8. How can this idea of testing specific deficits translate into driving assessments and retraining?

The current assessment tools used to determine fitness to drive, although able to discern between differing driving abilities, do not necessarily assess specific deficits associated with driving. Based on the idea that specificity-based interventions are more effective rehabilitation tools compared to more general interventions, future research should assess whether a specificity-based approach can be more effective in determining fitness to drive post TBI. To that regard, Bouillon et al. (2006) have suggested that the content of a driving competency assessment should vary according to the specific diagnosis of the individual. Driving simulators also have the potential to be excellent training devices to help improve on-road driving performance by providing practice within a range of driving scenarios. Indeed, simulator training has been found to improve on-road driving abilities (Cox et al., 2010). In a randomized controlled trial, Akinwuntan and colleagues (2005) used the driving simulator as a training device to demonstrate that it can improve the rate of those who return to driving after stroke. More specifically, TBI survivors who received 5 weeks, (15-hour/week) of training in the simulator, were significantly more likely to pass a follow-up official pre-driving assessment and were legally allowed to resume driving, compared to TBI survivors who received driving-related cognitive tasks. Furthermore, simulator training may also improve complex neurocognitive skills. Rosen (2005) has likened the driving simulator to a mental "treadmill" as it challenges brain functioning across many levels and systems. Just as running on a treadmill utilizes several bodily systems (e.g., the respiratory and muscular systems), the driving simulator pushes several cognitive components (e,g., attention, vision) to work together.

The use of driving simulators may prove to be the most ideal method to asses and rehabilitate specific deficits associated with driving. For example, Kewman et al. (1985) developed a simulator based retraining procedure for TBI survivors to improve specific skills of functional significance involved in driving. The training consisted of exercises to improve attentional and visuomotor skills necessary for driving, focusing on visuomotor tracking and divided attention. Driving was broken down into simple components, and shaping procedures were then used to help participants gain the skill as they practiced. Such training resulted in better on-road driving performance, compared to the control group that receive no specific skill training, but rather just practiced driving.

A better understanding of the limitations of a TBI survivor can also lead to the selection of a more effective rehabilitation approach. Therefore, one could determine whether it is better to favor a compensatory retraining approach or one that emphasizes the retraining of the impaired cognitive functions (Boelen, et al., 2011; Lew et al., 2009).

In conclusion, the standard generic approach to driving assessment in TBI survivors could sometimes lead to inaccurate decisions regarding their driving safety. The specificity-based approach consists of developing an assessment and retraining procedure within a driving context that is ecological and customized to the individual's limitations. We believe that this approach should revolve around the simulator as an assessment/retraining tool. We used some research examples on attentional deficits and driving in TBI to demonstrate that this approach could potentially lead to more reliable decisions regarding driving safety. However, the specificity-based approach as well as the use of the simulator is definitely not limited to the assessment and rehabilitation of attention deficits. Other processes such as visual detection, speed of processing and even awareness deficits could be assessed within the simulator and examined within a specificity-based approach. The research in this area also has to generate evidence-based data to support its relevance. For instance, assessment results yielded by the generic and the specificity-based approaches should ultimately be validated against real world driving outcomes.

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