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Predictors of Driving Avoidance and Exposure Following Traumatic Brain Injury

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Abstract

Background—An estimated 40–60% of individuals who experience a moderate to severe Traumatic Brain Injury (TBI) return to driving. However, little is known about driving behavior post-TBI and how this may be related to demographic, injury, and outcome factors.

Methods—A total of 184 participants who experienced moderate to severe TBI were included in this study. Participants completed a telephone survey regarding return to driving and current driving behavior. Structural Equation Modeling (SEM) was used to analyze predicted relationships between demographic and injury-related variables with driving exposure and avoidance within 5 years of injury.

Results—The model indicated that participants who were older and female tended to avoid a greater number of challenging everyday driving scenarios. Participants that had more severe injuries and those with poorer performance on cognitive measures at the time of rehabilitation discharge were likely to drive less frequently and over less distances at follow up, though they did not avoid challenging driving situations.

Conclusions—Young males and those with more severe injuries may require additional attention regarding their driving behavior following TBI.

Introduction

An estimated 1.4 million Americans suffer a traumatic brain injury (TBI) each year¹. The physical, cognitive, and emotional difficulties associated with severe TBI often lead to significant lifestyle modifications such as loss of employment, reduced social contact, and driving cessation. The reported rates of return to driving among individuals who have experienced a moderate to severe TBI range from 40–60%^{2,3}. The ability to drive an automobile is of particular importance as it has been associated with multiple aspects of functional independence and psychosocial well-being. Specifically, driving cessation has been correlated with lower rates of employment⁴, community integration⁵, and life satisfaction⁶. Windsor et al.⁷ found that loss of driving ability was related to increased rates of depression among older adults. This association has also held despite the availability of

alternate means of transportation⁸. These results suggest that the psychosocial effects of loss of driving ability go beyond the inherent utility of accessing the community. Driving an automobile has been identified as a symbol of self-efficacy and personal freedom with loss of this ability associated with feelings of dependence and loss of self-esteem⁹.

Among TBI survivors, return to driving was rated among the most desired across activities they could not currently perform⁶. Similarly, Rapport et al.⁵ found that 48% of non-drivers in a TBI sample had strong desires to return to driving. For many brain injured adults, there are a variety of barriers that may limit or prevent opportunities to return driving including lack of financial resources and the availability of a motor vehicle. In addition, decisions made by family members, caregivers, and significant others are the most common source limiting driving among those who wish to do so^{10,11}. However, Coleman et al.¹⁰ found that the perceptions of driving fitness by significant others are only modestly related to actual driving ability. These results suggest that many individuals who are capable of returning to driving and thus greater community integration and psychosocial well-being may be denied the chance due to such well-meaning misperceptions about driving fitness.

Cognitive and sensorimotor limitations also play a significant role in driving cessation and may be mediated by the individual's self-assessment or awareness of deficits⁵. Rapport et al.⁵ found those who assessed themselves as fit to drive, despite poor cognitive and/or physical abilities, were more likely to view caregivers and significant others as the primary barrier to driving. Conversely, those with greater awareness of the effects of their injuries were more likely to view their deficits as the cause of driving cessation⁵. This study also found that drivers showing little awareness of the residual effects of their injury were at greater risk for motor vehicle crashes. Albeit, those with better awareness or who participated in on-road driving assessment showed no difference in risk than non-TBI drivers.

For those who do return to driving, findings regarding increased risk for crashes or other moving violations have been mixed. Haselkorn¹² found no increased risk of motor vehicle crashes for individuals post-TBI compared to control participants with no history of brain injury or recent hospitalizations of any kind; however, TBI survivors were more likely to receive moving violation citations. In a more recent study, individuals 6 to 9 years post-TBI were found to be twice as likely to be involved in a motor vehicle crash when compared to the general population¹³.

Studies have found visuospatial abilities, processing speed, attentional processes, and executive skills to be useful constructs in predicting fitness to drive^{10,14}. It is important to note that a safe return to driving is not solely a function of the combination of one's physical and cognitive attributes. The recognition of one's abilities and appropriate self-regulation can improve driving safety by avoiding challenging and potentially dangerous situations. Lundqvist and Alinder¹⁵ (2007) found that self-perception of driving ability differed among individuals with acquired brain injuries (ABI) who passed or failed an on-road driving test. Unlike participants who passed the on-road evaluation, those who failed over-estimated their driving ability. This occurred despite equivalent cognitive abilities among the two groups. Thus Lundqvist and Alinder proposed that more accurate self-assessment may have

contributed to passing the on-road test by enabling individuals to modify their behavior in accordance with their abilities to optimize driving performance.

While the previously mentioned study¹⁵ examined a combined TBI and stroke group, Schanke et al.¹³ looked at how these two groups compare in terms of modifying driving behavior. They found that only the stroke group drove fewer miles than pre-injury and avoided challenging driving conditions. In this study, participants had already passed physical and neuropsychological assessments prior to return to driving. Thus, it is possible that many cognitive and sensorimotor factors that would impact driving performance had already been removed from the sample.

Driving behavior has been studied in greater detail among older adults. Older adults have been shown to modify driving in relation to sensorimotor and cognitive impairment¹⁶. Baldock et al.¹⁷ reported that older adults may self-regulate by avoiding situations in which they have less confidence. However, avoidance was not related to actual driving ability as measured by on-road tests. This finding suggests that while self-awareness may lead to behavior modification, the ability to match one's abilities to the demands of the environment is a key component to appropriate self-regulation.

Understanding the pattern of return to driving after TBI and the predictors of such return may allow individuals, aided by clinicians, to develop safe parameters to resume driving as opposed to an all or nothing approach. An initial step in this process involves better identification of characteristics that lead to avoidance and decreased exposure in driving situations. Among older drivers, Lyman et al. found cognitive decline was associated with decreased exposure in terms of average miles driven¹⁸. Furthermore, they found that functional decline was associated with decreased exposure in terms of frequency of driving. In a causal model of driving avoidance and exposure among older adults, Vance et al.¹⁹ found that poorer cognitive ability is a particularly salient predictor of driving restriction, as were poorer health, older age, and female gender.

The aim of the present study was to develop a causal model of post-TBI driving behavior in terms of driving avoidance and exposure based on injury factors, functional motor abilities, cognitive abilities, and demographic characteristics. These predictor variables have been studied and reported separately in the previously cited research involving individuals with TBI, stroke, and older adults. Among individuals with TBI, these studies primarily looked at how these variables related to return to driving and driving ability following injury. The current study combines these variables into a parsimonious model that looks at specific aspects of driving behavior following TBI. In particular, this study assessed driving exposure in terms of self-reported frequency of driving and distance driven per week. Avoidance of specific driving situations was also analyzed as a proposed measure of restriction of driving behavior. Structural equation modeling (SEM) was used to determine causal models for avoidance and exposure post-TBI. It was hypothesized that injury, demographic, and initial rehabilitation outcome variables would predict post-TBI driving behavior in the context of the proposed model. The full predicted model, which is based on the literature reviewed, can be seen in Figure 1.

Methods

Participants

Data from a total of 184 individuals who experienced a TBI were included in this study. All participants had previously agreed to participate in the Traumatic Brain Injury Model Systems (TBIMS) data base, a multicenter, longitudinal study of traumatic brain injury funded by the National Institute on Disability and Rehabilitation Research (NIDRR). Participants were recruited for the TBIMS data base during inpatient rehabilitation at Spain Rehabilitation Center (SRC).

Inclusion criteria for this study were consistent with the TBIMS inclusion criteria. Participants must be 16 years of age or older and have sustained a TBI (penetrating or non-penetrating) as evidenced by loss of consciousness, focal brain lesion on neuroimaging, or abnormal neurological exam. They must have received medical care in a TBIMS affiliated hospital within 24 hours of injury and must be transferred directly from acute hospitalization to a TBIMS affiliated comprehensive rehabilitation program. In addition to the TBIMS inclusion criteria, participants must have driven an automobile during the month prior to phone interview.

Demographic and injury-related data for the study sample can be found in Table 1. In summary, 70.1% were male with a racial makeup of 75.0% Caucasian and 25.0% African American participants. Average age at the time of injury was 34.9 years with a range of 16 to 78. On average, the sample was moderately to severely injured as indicated by a mean Glasgow Coma Scale (GCS) ²⁰ score of 8.7. In the present sample, a total of 59 participants were chemically paralyzed during the course of emergency medical treatment and had no recorded GCS score.

General Experimental Procedures

By agreeing to participate in the TBIMS data base, participants were contacted by phone at 1, 2, and 5 years post-injury to complete a follow up assessment. At each follow up time point, participants were asked to provide information regarding a number of outcome variables including employment, social activity, physical functioning, etc. TBIMS data was gathered from participants and/or relatives/caregivers. Within this database, information regarding demographics, injury related variables, and outcomes from acute rehabilitation were also available. For this study, variables of interest from the TBIMS database included race, gender, age at time of injury, injury severity as measured by the duration of post-traumatic amnesia (PTA), and functional motor ability as measured by the Motor Scale of the Functional Independence Measure (FIM) ²¹, and time since injury. The GCS was not used in data analysis due to the large amount of missing data as previously mentioned.

In addition to standard follow up questions associated with the TBIMS data base, participants as well as caregivers/family members also completed a survey of driving behaviors that included items that addressed return to driving, miles driven in a typical week, and driving situations avoided. The primary outcome variables of interest for this study were: 1.) Driving exposure defined as the average frequency of driving and number of miles driven per week; and 2.) Driving avoidance defined as the total number of common

driving situations avoided. Outcome variables were based on participant report at the time of follow up interview. Predictor variables, both observed and latent, as well as outcome variables are described below and are presented in a path diagram in Figure 1.

SEM Model and Measures

Observed Demographic Variables—Race, Gender, and Age were extracted from the TBI Model Systems database. Race was based on self-report of the participant. In this study participant responses fell into two categories – Caucasian or African American (coded 1 and 2 respectively). In a study by Arango-Lasprilla et al.²² functional outcomes, including the Functional Independence Measure (FIM), were significantly different among Caucasian versus minority groups. Gender was coded 1 for female and 2 for male participants. Age refers to the age of the participant at the time of their head injury.

Injury Severity—Injury severity was measured by the participants' duration of post-traumatic amnesia (PTA) and was extracted from the TBIMS data base. The duration of PTA was defined as the number of days from the date of injury until the participant demonstrated orientation. This was indicated by two consecutive administrations in which the person achieved threshold performance on one of two validated orientation instruments (the Galveston Orientation and Amnesia Test²³ or the Orientation Log²⁴). Injury severity has been found to be predictive of both cognitive and functional ability following TBI²⁵. In particular, individuals with greater durations of post-traumatic amnesia have been found to perform worse on functional indicators including the FIM and Disability Rating Scale (DRS)²⁶.

Cognitive Functioning—Measures of cognitive abilities completed during rehabilitation included parts A and B of the Trail Making Test (TMT) and the Digit Span subtest of the Wechsler Adult Intelligence Scale – Third Edition (WAIS-III). Studies have demonstrated that various measures of executive function and general cognitive ability are significant predictors of functional outcomes as measured by the DRS^{27–29}. Part A of the TMT is a measure of attention and processing speed that incorporates visual scanning as well as graphomotor and attentional skills. Part B of the TMT adds additional demands of executive abilities in the form of set shifting and mental flexibility³⁰. This task has been shown to be related to multiple outcomes in a moderate to severe TBI population such as on road driving performance,³¹ overall cognitive improvement over time,³² as well as community integration and employment³³. Performance is measured by the time in seconds needed to complete each part of the test.

The Digit Span subtest of the WAIS- III is a commonly used measure of basic auditory attention and working memory across multiple clinical populations. There are two sections of the subtest, Digits Forward and Digits Backward. Poor performance of the Digit Span test, particularly the Digits Backward component, has been identified as a marker of cerebral disorder following TBI^{32,34}.

Functional Motor Ability—Functional motor ability was measured using the FIM Motor subscale. The FIM is a measurement of rehabilitation outcome across 6 domains: self-care,

sphincter control, transfers, locomotion, communication, and social cognition^{35, 36}. For the present study, the FIM Motor score, ranging from 13 to 91, was used as a measure of functional motor ability that may be related to driving ability. The FIM Motor score is composed of items in the areas of self-care (eating, grooming, bathing, dressing, and toileting), sphincter control (bowel and bladder management), transfers (bed, chair, toilet, and bath), and locomotion (walking using a wheelchair, and climbing stairs). This measure was completed by healthcare professionals at the time of rehabilitation discharge from SRC.

Outcomes - Driving Avoidance and Exposure—The driving questionnaire used in the current study consists of 11 questions that assess participants' driving status as well as a wide variety of driving behaviors. These include the frequency of driving an automobile in the past month, the average distance driven per week, and avoidance of common driving situations. The survey also has items regarding reasons for driving, moving violations, and confidence in driving post-injury. The questionnaire was completed by the injured participant as well as a family member or caregiver when available. Only data collected from injured participants were used for this study.

Driving exposure was based on the frequency of driving during the past month and the average distance driven per week. Driving frequency was categorized as occurring multiple times per day, once per day, multiple times per week (less than daily), once per week, every other week, and once per month. Average distance per week was categorized as less than 20 miles, 20–50 miles, 50–75 miles, 75–100 miles, and 100 or more miles. Frequency and distance were standardized using *z* scores and summed to form a composite score of overall driving exposure.

Driving avoidance was based on the total number of common situations that the participant endorsed as being avoided. The possible avoided situations were driving alone, at night, in heavy traffic, when the weather is bad, on the highway, in a city, long distances (> 30 miles), and other. Scores for avoidance were entered into the model as raw scores based on the number of positive responses to avoidance items with a possible range of 0–8.

This questionnaire was developed based on a review of studies using non-validated surveys. As a means of validating participant responses, they were compared to the responses from family/caregivers. Responses from both parties were available in 48.4% of cases with correlations as follows: distance driven Pearson's $r = .83$, $p < .001$; driving frequency Pearson's $r = 0.78$, $p < .001$; total situations avoided Pearson's $r = .93$, $p < .001$. Responses were an exact match between participants and significant others at a rate of 85.5% for frequency driven, 77.1% for distance driven, and 81.3% for total number of avoided situations. Significant others providing information included parents (51.6%), spouses (25.8%), siblings (12.9%), children (7.5%), and friends/significant others (2.2%).

Data Analysis

Structural equation modeling (SEM) was used to determine causal pathways from demographic and post-injury variables to driving behavior at follow up. Model specification was based on a theoretical framework developed by available research on driving following TBI (see Figure 1). No study has directly investigated variables related to driving avoidance

and exposure post-TBI. Therefore, the current model incorporates results from research mentioned previously that describe relationships between the model variables and return to driving or driving ability in the TBI population as well as models of driving avoidance and exposure among older adults. Data from the TBI Model Systems database and the driving questionnaire were tested using SEM to assess the fit with the proposed theoretical model. SEM allows for the assessment of multiple relationships simultaneously resulting in a more accurate reflection of the dynamic relationship that multiple variables have on specific outcomes.

The variables Age, PTA, and FIM Motor scores were entered as continuous variables. Race and gender were analyzed as categorical/dichotomous variables and coded as previously mentioned. Cognitive variables gathered through assessments (TMT parts A and B, Digit Span) were analyzed using standard scores with a mean of 100 and standard deviation of 15. Standard scores were derived from normative data based on age (Digit Span³⁷) or age and race (TMT³⁸). For participants who were unable to complete either part of the TMT, the lowest score available was imputed. This was entered as a standard score of 25 (T score equal to 0). Unlike the TMT, not all participants attempted to complete the Digit Span subtest. This was due to the individualized, flexible battery of cognitive tests administered prior to discharge from SRC. For these individuals regression analysis based on existing test scores from both parts of the TMT were used to impute values. This occurred for a total of 10 cases (5.4%). Significant Pearson correlations were found among cognitive variables as a means of validating the overall latent variable.

As previously mentioned, driving surveys were completed at different time points across participants such that they were completed at either 1, 2, or 5 years post injury. This variable, time since injury, was unrelated to all other variables and had no impact, positive or negative on the overall model. As such, it was removed from the model as extraneous.

Using the previously mentioned variables, a baseline model was constructed in which all variables and all available paths were entered. Multiple goodness of fit indices were used including the Goodness of Fit Index (GFI), the Comparative Fit Index (CFI), the Incremental Fit Index (IFI), and the Root Mean Square Error of Approximation (RMSEA). Values for goodness of fit indices range from 0–1 with indices of 0.90 or greater indicating a good model fit. The RMSEA is an indicator of the overall amount of error in the model. Values below 0.1 are generally considered acceptable.

Results

Of the initial 364 participants who completed the driving survey, a total of 206 (56.6%) met inclusion criteria by resuming driving prior to the month before completing the questionnaire. This percentage of individuals who return to driving following injury is consistent with the 40–60% estimate previously mentioned². Among the 206 drivers who completed the questionnaire, a total of 22 participants were excluded due to insufficient, available data. The majority of these participants were either discharged prior to cognitive testing or were unable to participate in any substantial assessment at the time of discharge from acute rehabilitation. The data from the remaining 184 participants (see Table 1) were

analyzed for univariate and multivariate outliers as well as multicollinearity. Two multivariate outliers were identified, both of whom avoided no driving conditions, but experienced longer durations of PTA. This result is not inconsistent with other outcomes observed clinically and thus remained in the dataset. Skewness and kurtosis were detected; therefore, the data were analyzed by normalizing the data using the LISREL transformation option to correct for this³⁹.

The initial baseline model was constructed in which all variables and all paths were analyzed. The resulting model demonstrated good model fit across multiple indices (GFI = 0.97, CFI = 0.94, IFI = 0.95, RMSEA = 0.07). Similarly, the full model was constructed in which paths were specified in accordance with the theoretical framework previously discussed (Figure 1). Again the model demonstrated good fit (GFI: 0.96, CFI: 0.94, IFI: 0.95, RMSEA: 0.06). Several paths in this model were non-significant. To arrive at the final model, non-significant paths were trimmed one at a time based on t value. This was done by removing the least significant path (lowest t value) and recalculating model fit. This process was repeated for each non-significant path until a trimmed model was evident with only significant paths ($p < .05$) remaining.

The path diagram for the final trimmed model can be seen in Figure 2. Again, the model demonstrated good overall fit (GFI = 0.95, CFI = 0.92, IFI = 0.92, RMSEA = 0.06). This model indicated that individuals who were older and female tended to avoid a greater number of challenging everyday driving scenarios. Interestingly, injury severity, as well as factors that have been shown to be related to driving ability such as functional motor ability and cognition, did not show a significant effect on driving avoidance.

The trimmed model indicated two significant paths predicting driving exposure. Within this model, individuals that had less severe injuries as measured by PTA and those with better performance on cognitive measures at the time of rehabilitation discharge were likely to drive more frequently and over greater distances. In addition, the predicted relationship between injury severity and cognitive performance was evident such that those with greater durations of PTA performed worse on cognitive testing prior to rehabilitation discharge. PTA was also associated with functional mobility in that more severe injuries resulted in decreased mobility per the FIM Motor subscale.

Discussion

The purpose of this study was to construct a parsimonious model predicting driving avoidance and exposure in light of demographic, cognitive, physical, and injury related variables. Both the full model based on a theoretical framework as well as the trimmed model demonstrated good fit. From this model, several findings emerged both in terms of the variables that were predictive of driving avoidance and exposure as well as those that were not.

First, only demographic factors, specifically age and gender, were found to be related to driving avoidance. Participants who were older and female avoided a greater number of driving situations than younger males. This finding would be expected based on knowledge

of driving behavior, particularly in terms of young males being more likely to engage in risk-taking behavior⁴⁰. This is also consistent with a previous study using a similar design by Vance et al.¹⁹. This may suggest that young males may be less likely to modify their driving behavior due to a higher threshold for taking risks or a poorer appreciation of actual risks of their continued driving.

A second outcome was that, as expected, individuals with less severe injuries and those who performed better on the initial cognitive assessment exhibited greater driving exposure at follow up. One possible explanation for this may be that less severe injuries and better early cognitive recovery has been shown to be predictive of multiple outcomes including return to work and community integration that may influence a need for greater driving exposure²⁹. However, cognitive performance in the acute phase post-injury was not significantly predictive of driving avoidance. Rapport et al.⁴ (2008) indicated the presence of a subset of TBI survivors who desire to return to driving despite significantly lower cognitive abilities than survivors who have resumed driving. This group may have less awareness of their abilities and are primarily limited in driving by social barriers such as family members or significant others. Similarly, previous studies have found that TBI survivors who failed an on road driving test often overestimated their driving ability. Applying these conclusions to the current study, there may be a similar group who had lower cognitive ability acutely post-injury who has returned to driving with limited awareness and subsequently do not avoid challenging driving conditions.

Third, injury severity was predictive of cognitive ability, motor functioning, and driving exposure in this model. Thus, individuals with a shorter duration of PTA were more likely to drive at a higher rate in terms of frequency and distance. However, similar to cognitive variables in this model, individuals with more severe injuries did not avoid a greater number of challenging driving situations.

There were several limitations to this study. Most notably, outcome variables were based on an unpublished, unvalidated questionnaire of driving behavior. While attempts to validate the accuracy of participant responses were made based on corroborative information from a significant other, there may be some degree of response bias as is the case with self-report measures. In addition, the overall sample size was relatively low given the number of parameters in this SEM model.

The results obtained from this model may have implications for rehabilitation specialists. Specifically, acknowledging individuals who drive further, more often, and without restrictions presents a possible risk group that may require further attention. Young males require additional attention with regard to driving after rehabilitation discharge as they are more likely to return to driving³ and less likely to modify driving behavior following injury. In addition, those with more severe injuries and poorer initial cognitive recovery may not avoid challenging situations representing an additional risk group. Attention to these groups who do not modify driving behavior may limit the number of TBI survivors who resume driving despite limited ability to do so or allow for advice on modification of driving behavior that may limit crash risk for these and other motorists. Future research that examines how these variables relate to perceived and actual driving ability may further

guide clinicians in identifying individuals who would benefit from additional assessment and intervention before returning to driving.

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Figure 1.

Full Model

PTA: Posttraumatic Amnesia, FIM: Functional Independence Measure

Figure 2.

Final Model

→ Significant paths; - - - Non-significant paths

PTA: Posttraumatic Amnesia, FIM: Functional Independence Measure

Table 1

Sample characteristics (n=184)

Variable	n	%	Mean(SD)	Range
Gender				
Female	55	29.9		
Male	129	70.1		
Race				
Caucasian	138	75.0		
African American	46	25.0		
Age			34.9(14.9)	16–78
PTA (days)			25.1(15.9)	0–87
Trails A (standard score)			69.8(18.1)	25–119
Trails B (standard score)			60.4(26.9)	25–123
Digit Span (scaled score)			7.1 (3.4)	2–14
FIM Motor (rehabilitation discharge)			59.1(11.1)	13–82
Driving Avoidance			1.5(1.9)	0–8
Driving Exposure (composite z-score)			0.0(0.9)	–2.4–2.2

Table 2

Fit Measures for the Baseline, Full, and Trimmed Models

Model	$\chi^2(df)$	p	GFI	CFI	IFI	RMSEA
Baseline	28.0(14)	0.01	0.96	0.93	0.94	0.07
Full	38.4(21)	0.01	0.95	0.92	0.93	0.07
Trimmed	38.4(21)	0.01	0.95	0.92	0.93	0.07

Notes: GFI: Goodness of Fit Index; CFI: Comparative Goodness of Fit Index; IFI: Incremental Goodness of Fit Index; RMSEA: Root Mean Square Error of Approximation