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Assessing Changes in Self-Reported Driving Ability After Mild Traumatic Brain Injury

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ASSESSING CHANGES IN SELF-REPORTED DRIVING ABILITY AFTER MILD TRAUMATIC BRAIN INJURY

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ABSTRACT

The ability to safely drive a car requires intact cognitive functioning across a variety of domains, many of which are adversely affected following a moderate-to-severe traumatic brain injury (TBI). Mild traumatic brain injury (mTBI) impacts similar cognitive facets, albeit to a less severe extent, and preliminary evidence suggests that mTBI may also have a deleterious effect on driving abilities immediately following injury. However, changes in driving ability over the course of recovery from mTBI have not been adequately examined. The present study addressed this dearth in the literature through examination of self-reported driving ability in 18 participants with a recent mTBI and 25 orthopedic injury (OI) comparison participants both immediately following injury and at two-week follow-up. Participants were recruited from a local emergency department, at which they completed self-report measures of driving ability and an assessment of post-concussive symptoms (PCS). Participants also completed the driving ability self-report at two-week follow-up. Participants with an mTBI reported more driving problems than those with an OI and both groups increased in driving problems reported from baseline to follow-up. Greater PCS was associated with more driving problems at follow-up. Results indicate a possible deleterious effect of injury on driving ability. Implications for future work and clinical practice are discussed.

INTRODUCTION

Overview of Traumatic Brain Injury

In the United States, approximately 2.5 million individuals are diagnosed with a traumatic brain injury in emergency departments (ED) each year (Faul, Xu, Wald & Coronado, 2010; Finkelstein, Corso & Miller, 2006). A traumatic brain injury is an insult to the brain resulting from an external force. Traumatic brain injury can be broadly broken down into two injury severity sub-groups: moderate-to-severe TBI (TBI) and mild traumatic brain injury (mTBI). Differential diagnoses of TBI and mTBI differ on several injury characteristics, namely presence and duration of loss of consciousness and duration of amnesia. Both TBI and mTBI are associated with impairments in a variety of cognitive domains including processing speed, complex attention and executive functioning, with TBI generally considered to be more detrimental to cognitive functioning both in severity of symptoms as well as their persistence over time (e.g., Mazaux, Masson, Levin, Alaoui, Maurette,& Barat, 1997; Millis et al., 2001; Fleminger & Ponsford, 2005; Konrad et al., 2011). Impaired cognitive performance in these domains has been shown to impede higher-order abilities that most individuals depend upon to live independently (e.g., Richardson, Nadler & Malloy, 1995; Twamley et al., 2002; Aretouli & Brandt, 2010).

Traumatic Brain Injury and Driving Ability

Of those higher-order abilities frequently affected, driving is perceived to be among the most vital to maintaining an independent lifestyle (Burkhardt, 1999; Ragland, Satariano & MacLeod, 2005). Driving ability relies on intact cognitive functioning across numerous domains, many of which are impaired in those with a history of TBI (Macciocchi, Barth, Alves, Rimel & Jane, 1996; Echemendia, Putukian, Mackin, Julian & Shoss, 2001; Belanger & Vanderploeg,

2005; Rohling, Binder, Demakis, Larrabee, Ploetz & Langhinrichsen-Rohling, 2011; Dougan, Horswill & Geffen, 2014). Moreover, compared to those without history of TBI, individuals with a history of TBI have been shown to perform worse in several facets of driving, including poor speed and steering control, higher accident rates, difficulties performing divided-attention tasks while driving, and impaired spatial area monitoring (Brooke, Questad, Patterson & Valois, 1992; Brouwer & Withaar, 1997; Fisk, Schneider & Novack, 1998; Coleman, Rapport, Ergh, Hanks, Ricker & Millis, 2002; Lew, Poole, Lee, Jaffe, Huang & Brodd, 2005; Novack, Banos, Alderson, Schneider, Weed, Blankenship & Salisbury, 2006; Novack et al., 2010; Neyens & Boyle, 2012). As a result of these deficits, approximately half of TBI patients fail re-licensing tests following their injury (Brouwer & Withaar, 1997). Detriments to driving ability in patients with TBI may be assessed via self-report (e.g., the Driving Behavior Questionnaire: Reason, Manstead, Stradling, Baxter & Campbell, 1990; the Driving Habits Questionnaire: Owsley, Stalvey, Wells & Sloane, 1999; the Fitness to Drive Screening Measure: Winter, Classen, Bedard, Lutz, Velozo, Lanford & Drumback, 2011) or more objective measures such as on-road driving tests, driving simulators or computerized assessments (e.g., Owsley, Ball, Sloane, Roenker & Bruni, 1991; Korteling & Kaptein, 1996; Lew et al., 2005).

Prevalence and Symptomatology of Mild Traumatic Brain Injury

Mild traumatic brain injuries (mTBI), or concussions, represent between 70-90% of all traumatic brain injuries in the United States, contributing to the $60 billion annually spent on rehabilitation and treatment for TBI as well as lost productivity (Cassidy et al., 2004). According to the American Congress of Rehabilitation Medicine (ACRM), a mTBI is defined as a blow to the head resulting in a loss of consciousness of no longer than 30 minutes, posttraumatic amnesia of no longer than 24 hours, or a Glasgow Coma Scale of 13-15 at 30 minutes post-injury

(American Congress of Rehabilitation, 1993). Given its high prevalence and associated costs, studies examining the frequency of symptoms and signs of mTBI are necessary in order to better determine the services that they would most benefit from upon release from the ED.

In recent years, research has begun to elucidate the symptomatic, cognitive and neural underpinnings of mTBI. mTBI results from a biomechanical force to the brain, resulting in functional (e.g., ionic shifts, metabolic changes, neurotransmission impairment) or microstructural injury (i.e., axonal injury detected by advanced imaging techniques such as diffusion tensor imaging) to neural tissue without macroscopic neural damage (McCrory et al., 2009). These changes cause have been theorized as responsible for very acute symptoms that are common following mTBI, such as headache, confusion and dizziness (Giza & Hovda, 2014). Physical symptoms (e.g., impaired balance control, vision) (Guskiewicz, Perrin, Gansneder, 1996; Guskiewicz, Riemann, Perrin & Nashner, 1997; Riemann & Guskiewicz, 2000; Cifu et al., 2015) and emotional signs (e.g., irritability) (e.g., McCrory & Johnston, 2002; Hutchison et al., 2009; Mainwaring et al., 2010; Putukian, 2011) may also be present following mTBI. Though a mTBI is generally considered to be less impairing than a moderate-to-severe TBI, individuals with a recent mTBI are likely to show deficits across similar cognitive domains to that of individuals with TBI, such as working memory, processing speed and complex attention (e.g., Macciocchi, Barth, Alves, Rimel & Jane, 1996; Echemendia, Putukian, Mackin, Julian & Shoss, 2001; Belanger & Vanderploeg, 2005; Rohling, Binder, Demakis, Larrabee, Ploetz & Langhinrichsen-Rohling, 2011; Dougan, Horswill & Geffen, 2014). In addition to examining the acute effects of mTBI, longitudinal studies have also started to explore its long-term consequences. While symptoms and cognitive deficits associated with mTBI are typically transient, between 10-33% show persisting cognitive problems for over two weeks post-injury

(e.g., Rimel, Giordani, Barth, Boll & Jane, 1981; Moser, Schatz & Jordan, 2005; Willer & Leddy, 2006; De Beaumont, Lassonde, Leclerc & Theoret, 2007; Catena, van Donkelaar & Chou, 2009; Yang, Hua, Tu & Huang, 2009). Further, although concerns about the role of psycholegal issues and malingering in mTBI assessment remain, some individuals (i.e., a "miserable minority") may continue to show post-injury cognitive and emotional symptoms for several months post-injury (e.g., Ruff, Camenzuli & Mueller, 1996; Ruff, 2005; Barlow, Crawford, Stevenson, Sandhu, Belanger & Dewey, 2010). These longer-term deficits may be detrimental to the recovery of driving capacities, the capability of returning to work and other higher-order abilities (Brouwer & Withaar, 1997; Benedictus, Spikman & van der Naalt, 2010). A broad array of symptoms assessed immediately following injury, commonly referred to as post-concussive symptoms (PCS), may predict these poor longer-term cognitive and functional outcomes. Common PCS may include impaired cognition (e.g., working memory: Wood & Rutterford, 2006), physical capabilities (e.g., balance control: Lau, Collins & Lovell, 2011) and emotional symptoms (e.g., Rush, Malec, Moessner & Brown, 2004). Despite these findings, more work is necessary to determine the role of acute PCS in recovery.

Mild Traumatic Brain Injury and Driving Ability

Compared to moderate-to-severe TBI, the literature regarding self-reported and objectively-measured driving performance in the mTBI population is more limited, as are clinical methods of assessing fitness-to-drive in this population (Baker, Unsworth & Lannin, 2015). However, what evidence does exist suggests a detrimental effect of mTBI on driving ability. As many as 93% of individuals report at least one difficulty within a few days post-injury that has an effect on their everyday activities, with fatigue and reduced concentration reported as having the strongest effect on driving ability (Bottari, Lamothe, Gosselin, Gelinas & Ptito, 2012).

Furthermore, almost three-quarters of individuals with recent mTBI report accommodating their driving techniques or developing new strategies to compensate for problems with driving post-injury. These accommodations include both strategic alterations (e.g., reduced time spent driving, not driving at night) and tactical changes (e.g., not conversing with passengers while driving, taking breaks, reducing speed) (Bottari et al., 2012). However, others have failed to identify differences in self-reported driving ability between those with and without a mTBI in the prior 24 hours (Preece, Geffen & Horswill, 2010).

Prior work further hints that in addition to driving difficulties shortly after injury, individuals with mTBI also report longer-term problems with driving. Individuals with a history of mTBI have been shown to be at higher risk of self-reported collisions when behind the wheel, even after a period of several years between mTBI and collision have elapsed (Schneider & Gouvier, 2005; Bernstein & Calamia, Under Review). These individuals also report engaging in a higher frequency of aberrant driving behaviors and driving in an aggressive manner that risks the safety of themselves and other drivers (Bernstein & Calamia, in prep.). Additionally, pilot findings suggest that veterans with a history of mTBI several month-to-years prior and co-morbid PTSD diagnosis must employ strategies on the road to overcome their perceived driving difficulties (Hannold, CLassen, Winter, Lanford & Levy, 2013).

Congruent with studies of self-reported driving ability, those examining driving ability via objective measures have similarly found that mTBI is associated with impaired driving. Preece, Horswill and Geffen (2010) found that, compared to orthopedic injury comparisons, individuals recruited from an emergency department with a recent mTBI (i.e. less than 24 hours) performed more poorly on a computerized hazard perception task. The hazard perception task utilized by Preece and colleagues has been conceptualized as a driver's active search of the road

in front of them, and poor performance on the task has been linked to higher on-road crash rates in prior studies (McKenna & Horswill, 1999; Wells, Tong, Sexton, Grayson & Jones, 2008; Darby, Murray & Raeside, 2009).

Similar to performance on the hazard perception task, studies utilizing simulated driving tasks have also identified a deleterious effect of mTBI on driving. In a study of veterans with a history of mTBI and PTSD and healthy controls, Classen, Levy, Meyer, Bewernitz, Lanford and Mann (2011) found that the veterans made more speeding and adjustment-to-stimuli errors. In a separate simulated driving study examining distractedness via a dual-task paradigm, Neyens, Boyle and Schultheis (2015) noted that individuals with recent mTBI had to spend more time looking at the secondary task (i.e., a coin-counting task) in order to obtain the same level of performance on the coin-counting task as those without mTBI. This led to more glances away from the road, which has been associated with poorer driving outcomes in other studies (Harbluk, Noy, Trbovich & Eizenman, 2006; Owens, McLaughlin & Sudweeks, 2011). Collectively, these suggest that mTBI is associated with poorer performance on measures related to safe driving, though work with larger samples and more ecologically valid driving measures are necessary.

Despite both preliminary evidence suggesting a deleterious effect of mTBI on driving ability as well as the medical community's recommendation to abstain from driving for days to weeks following mTBI, most individuals report no intention of reducing driving in the days post-injury and many return to driving without clinical evaluation of capacity to drive (Preece, Geffen & Horswill, 2013). This lack of adherence to medical recommendations may be partially explained by patients' misconceptions of the severity of their injury and the effects it has on their cognitive capacities (e.g., Gouvier, Prestholdt & Warner, 1988; Swift & Wilson, 2001;

McKinlay, Bishop & McLellan, 2011; Weber & Edwards, 2012; Bloodgood et al., 2013). These disparities between individuals' perceptions and their actual abilities would be in parallel with those of individuals with moderate-to-severe TBI, which have been shown to overestimate the effect that their condition has on their driving abilities (Fleming, Strong & Ashton, 1996).

Taken as a group, past work indicates that mTBI may be associated with poorer driving outcomes immediately following injury as well as in the longer-term (i.e., several years post-injury). However, little work has assessed changes in self-reported driving ability between immediately post injury and early on in the course of recovery (i.e., when symptoms have stabilized but remain present). Given that individuals do not report problems driving immediately following injury, yet do so in the years following, such work is necessary to help identify when these problems are first realized (Preece et al., 2010; Bernstein & Calamia, in prep.). Additionally, while prior studies have examined predictive relationships between acute mTBI-associated symptoms and recovery of cognitive functioning, the relationship between acute mTBI symptoms and recovery of driving ability in the short-term remain unclear. An appreciation for the extent to which these symptoms are related to changes in driving ability may help influence return-to-driving protocols and increase safety on the roads for all drivers.

The goals of the current study were to (1) compare changes in self-reported driving ability over the course of recovery between participants with a recent mTBI and those with a recent orthopedic injury (OI), and (2) examine whether post-mTBI PCS predict changes in self-reported driving ability within the mTBI group. The inclusion of an OI group allows for a comparison group that controlled for the general effects of injury, a common practice in previous case-control TBI and mTBI studies (e.g., Sheedy, Geffen, Donnelly & Faux, 2006; Woodrome et al., 2011; Ettenhofer & Barry, 2012). It was hypothesized that (1) compared to those without a

recent mTBI, participants with a recent mTBI would report increases in both overall aberrant driving behaviors as well as aggressive driving behaviors (i.e., behaviors that endanger others on the road) over the course of recovery, and (2) individuals with greater post-injury PCS severity would report larger increases in overall aberrant driving behaviors and aggressive driving behaviors from immediately post-injury to follow-up.

METHODS

Participants

The current study served as part of a larger study examining predictors (e.g., PCS, emotional functioning, personality factors) of recovery of cognitive and driving-related abilities after mTBI. For purposes of the current study, a total of 43 participants were recruited from the emergency department (ED) at a large, southern medical center that also serves as one of the area's level II trauma centers. Of these, 18 participants (41.9%) were identified as having recently experienced a mTBI, and 25 participants (58.1%) were identified as having recently experienced another non brain-related injury (i.e., an orthopedic injury (OI)). mTBI was defined according to criteria set out by the ACRM and described previously in this manuscript (i.e., loss of consciousness of less than 30 minutes, posttraumatic amnesia of less than 24 hours, or a Glasgow Coma Scale of 13-15 at 30 minutes post-injury). mTBI and OI participants were recruited based on common mechanisms of injury according to the Centers for Disease Control, including falls, assaults, struck by/against an object and motor vehicle accidents (Faul, Xu, Wald & Coronado, 2010).

Inclusion criteria included that participants be 18 years of age or older and native English speakers. Exclusion criteria include current inarceration, inability or unwillingness to give consent, or presenting with a more severe head injury or other condition that requires immediate medical treatment.

Measures

Self-Reported Driving Ability. Self-reported driving ability was assessed using the shortened Driving Behavior Questionnaire (DBQ). The DBQ is a 24-item paper-and-pencil measure of self-reported driving errors, lapses in attention while driving and aggressive driving

behaviors (Reason, Manstead, Stradling, Baxter & Campbell, 1990). Respondents report the frequency with which they engage in these behaviors on a scale of 1 (Never) to 6 (Nearly All The Time). The DBQ has demonstrated high validity as a predictor of simulated driving performance as well as real-world crash risk (Schwebel, Severson, Ball & Rizzo, 2006; Helman & Reed, 2015). The DBQ has also demonstrated adequate test-retest reliability (i.e., .61 for entire scale, .50-.76 across subscales) (Parker, Reason, Manstead & Stradling, 1995; Ozkan, Lajunen & Summala, 2005).

Post-Concussive Symptoms. The Sport Concussion Assessment Tool (SCAT2) is a sideline concussion evaluation tool measuring concussion-related signs and symptoms, cognition, balance and coordination (McCrory, Meeuwisse, Johnston, Dvorak, Aubry, Molloy & Cantu, 2009). Signs and symptoms are measured via a 22-item self-report in which common indicators of concussion (e.g., headache, “pressure in head”, feeling slowed down, etc.) are reported on a 0 (“none”) to 6 (“severe”) scale. Cognition is assessed using the Standardized Assessment of Concussion, a brief measure of orientation, immediate and delayed memory (McCrea, Randolph & Kelly, 2000). Balance is examined using the Balance Error Scoring System, which assesses the ability to maintain double-leg, single-leg and tandem stances for twenty seconds each with eyes closed (Guskiewicz, 2001; Guskiewicz, Ross & Marshall, 2001). Consciousness is assessed using the Glasgow Coma Scale (GCS) (Jones, 1979). The GCS measures level of awareness by assessing eye movements, verbal responses and motor responses to external stimuli. Scores across these facets are summed to produce an overall symptom score out of a maximum of 100 points, with higher scores suggesting fewer symptoms. While the psychometric properties of the SCAT2 as a measure of global post-injury functioning have not been examined in an injured population, its individual components have separately demonstrated

validity in the assessment of cognitive and behavioral impairments in individuals after a mTBI (Barr & McCrea, 2001; Valovich McLeod, Barr, McCrea & Guskiewicz, 2006; Shehata, Wiley, Richea, Benson, Duits & Meeuwisse, 2009). Components of the SCAT2 have also shown fair to good test-retest reliability (.46 to .83) (Valovich McLeod et al., 2006).

Procedure

This study employed a follow-up design so as to allow for examination of changes in self-reported driving ability between immediately post-concussion and at two-week follow-up. A two-week follow-up window was chosen as many individuals were assumed to remain symptomatic at this time point, but also to have resumed driving, thus allowing for collection of retrospective self-reported driving data regarding the previous week (e.g., Ryan & Warden, 2003; McCrea et al., 2003). At baseline, participants were screened for possible study inclusion using the hospital's online ED tracking system after presenting to triage. A study investigator or trained research assistant completed informed consent with participants within a designated room at the ED. Informed consents included a form allowing participants to provide their contact information to allow for follow-up data collection. All measures were administered in the order presented above. Participants completed baseline study measures while waiting to be seen by an ER physician. Therefore, participants did not always have time available to complete all measures. Due to this constraint, demographic information was not collected at baseline from all participants. This information will be extracted from medical records at a future time.

At follow-up, participants were contacted by study investigators and completed the DBQ orally. This study was approved by all relevant institutional review boards.

Analyses

To assess changes in self-reported driving ability between the mTBI and OI groups, a 2-by-2 repeated-measures multivariate analysis of variance (MANOVA) with groups as a between-subjects factor and time as a within-subjects factor was used. For any differences found via the MANOVA (group, time or group-by-time interaction), follow-up analyses of variance (ANOVAs) were used to determine for which specific DBQ subscales these differences were significant. Multiple linear regressions were also used to examine whether baseline DBQ scores and PCS (i.e., SCAT2 total scores) predicted follow-up DBQ scores.

RESULTS

Table 1 displays demographic variables within groups. Across the entire sample, participants were an average of 36.8 years of age (SD = 13.7). The sample was 37.2% male, 41.9% female and 20.9% did not have gender recorded. A total of 39.5% of the sample was Caucasian, 20.9% were African-American, and an additional 65.1% did not have race recorded.

Table 1. Sample Demographics

	mTBI, mean (SD) or n (%)	OI, mean (SD) or n (%)
Age	34.0 (12.4)	40.1 (14.8)
Gender		
Male	7 (38.9%)	9 (36.0%)
Female	11 (61.1%)	7 (28.0%)
Not Reported/Missing	0 (0.0%)	9 (36.0%)
Education		
Less than High School Diploma	2 (11.1%)	1 (4.0%)
High School Diploma	4 (22.2%)	0 (0.0%)
1-3 Years of College	4 (22.2%)	4 (16.0%)
	mTBI, mean (SD) or n (%)	OI, mean (SD) or n (%)
College Diploma	4 (22.2%)	7 (28.0%)
Post Graduate Degree	0 (0.0%)	3 (12.0%)
Not Reported/Missing	4 (22.2%)	10 (40.0%)
Race		
Caucasian	9 (50.0%)	8 (32.0%)
African-American	5 (27.8%)	4 (16.0%)
Asian-American	0 (0%)	0 (0.0%)
Not Reported/Missing	4 (22.2%)	13 (52.0%)
Ethnicity		
Hispanic or Latino	2 (11.1%)	12 (48.0%)
Not Hispanic or Latino	12 (66.7%)	1 (4.0%)
Not Reported/Missing	4 (22.2%)	12 (48.0%)
Cause of Injury		
Vehicular Accident	11 (61.1%)	-
Sport	6 (33.3%)	-
Fight	1 (5.6%)	-
Loss of Consciousness		
Yes	5 (27.8%)	-
No	13 (72.2%)	-
Post-Traumatic Amnesia		
Yes	17 (94.4%)	-
No	1 (5.6%)	-

A small portion (7.0%) of participants reported being of Hispanic or Latino ethnicity, however a larger percentage (37.2%) did not have ethnicity recorded. The sample represented a range of educational backgrounds, with 7.0% having less than a high school education, 9.3% having a high school diploma, 18.6% having 1-3 years of college, 25.6% holding a college degree, and 7.0% having a post-graduate degree. A total of 32.6% of participants did not have their educational level recorded, Independent-samples t-tests revealed no differences between groups in age, and chi square analyses revealed no group differences in gender, education, race or ethnicity (all $p > .05$). Within the mTBI group, a majority of participants (61.1%) received their injury as a result of a motor vehicle accident, while a smaller number of individuals experienced theirs as a result of a sport (33.3%) or fight (5.6%). A minority of mTBI participants (27.8%) reported experiencing a loss of consciousness after injury, however the vast majority (94.4%) reported post-traumatic amnesia. Table 2 displays scores within each group on all outcome measures.

Table 2. Scores on Outcome Measures

Measure	mTBI Mean (SD)	OI Mean (SD)
DBQ Total		
Baseline	40.0 (8.8)	30.7 (7.4)
Follow-Up	44.5 (8.1)	32.7 (4.6)
DBQ Total Change	4.5 (5.0)	2.0 (5.2)
DBQ Lapses		
Baseline	14.6 (4.6)	10.8 (3.0)
Follow-Up	16.1 (4.7)	11.5 (2.4)
DBQ Lapses Change	1.5 (3.5)	.7 (2.7)
DBQ Errors		
Baseline	12.0 (3.2)	9.6 (2.4)
Follow-Up	12.8 (2.9)	9.8 (1.9)
DBQ Errors Change	.8 (1.8)	.3 (1.6)
DBQ Violations		
Baseline	13.4 (5.0)	10.4 (3.7)
Follow-Up	15.6 (3.7)	11.4 (3.1)
DBQ Violations Change	2.2 (2.9)	1.0 (3.0)
SCAT2 Total	60.7 (19.8)	83.7 (10.0)
Symptom Severity Score	13.3 (7.9)	7.2 (8.1)

The MANOVA did not reveal a significant effect of time-by-group on any DBQ subscale scores, all $p > .05$. A significant effect was found for both group, $F(3,39) = 8.32$, $p < .001$, and time, $F(3,39) = 5.32$, $p < .01$, on the DBQ subscale scores.

To follow-up on significant group and time effects from the MANOVA, ANOVAs were used to assess effects on total DBQ scores and individual DBQ subscales. A significant effect was found for both time, $F(1,41) = 16.62$, $p < .001$, and group, $F(1,41) = 25.91$, $p < .001$, on DBQ total scores. A significant effect was found for both time, $F(1,41) = 12.13$, $p < .01$, and group, $F(1,41) = 10.88$, $p < .01$, on DBQ Violations scores. A significant effect was found for group, $F(1,41) = 12.83$, $p < .01$, on DBQ Errors scores, and an effect for time trended toward significance, $F(1,41) = 3.93$, $p = .05$. A significant effect was found for both time, $F(1,41) = 5.51$, $p < .05$, and group, $F(1,41) = 17.44$, $p < .001$, on DBQ Lapses scores. The ANOVAs revealed no time-by-group effect on DBQ total scores or any individual DBQ subscale scores, all $p > .05$.

Table 3 displays correlations among outcome measures. Within the entire sample, baseline DBQ scores were correlated with follow-up DBQ scores, and both baseline and follow-up DBQ scores were correlated with SCAT2 performance. Multiple linear regressions revealed associations between PCS and follow-up DBQ scores after controlling for the effects of baseline DBQ scores. Specifically, greater PCS predicted higher follow-up DBQ total scores, $F(2,40) = 57.51$, $R^2 = .74$, $\beta = -.26$, $p < .01$. Greater PCS also predicted higher follow-up DBQ Violations, $F(2,40) = 37.59$, $R^2 = .65$, $\beta = -.29$, $p < .01$. PCS did not predict follow-up DBQ Lapses or Errors scores, both $p > .05$.

Table 3. Correlations Among Measures

	1	2	3	4	5	6	7	8	9	10
1. Baseline DBQ Total	-									
2. Follow-Up DBQ Total	.83**	-								
3. Baseline DBQ Lapses	.80**	.70**	-							
4. Follow-Up DBQ Lapses	.64**	.82**	.73**	-						
5. Baseline DBQ Errors	.76**	.76**	.53**	.62**	-					
6. Follow-Up DBQ Errors	.62**	.78**	.48**	.53**	.82**	-				
7. Baseline DBQ Violations	.79**	.54**	.36	.21	.40**	.26	-			
8. Follow-Up DBQ Violations	.69**	.76**	.40**	.34*	.41**	.43**	.76**	-		
9. SCAT2	-.38*	-.54**	-.45**	-.49**	-.30	-.34*	-.17	-.41**	-	
10. Symptom Severity	.20	.25	.10	.22	.31*	.35	.12	.07	-.18	-

Note: * indicates significance at the $p < .05$ level, ** indicates significance at the $p < .01$ level.

DISCUSSION

TBI has been shown to have a deleterious effect on driving ability as well as on several cognitive domains tantamount to safe driving (Fisk et al., 1998; Coleman et al., 2002; Lew et al., 2005; Novack et al., 2006; Novack et al., 2010; Neyens & Boyle, 2012). mTBI constitutes the vast majority of TBIs and prior studies suggest that mTBI impairs several of the same cognitive abilities as TBI (Cassidy et al., 2004; Macciocchi et al., 1996; Echemendia et al., 2001; Belanger & Vanderploeg, 2005; Rohling et al., 2011; Dougan et al., 2014). While these deficits are transient for most individuals, a sizable minority continues to experience symptoms several months post-injury (Ruff et al., 1996; Ruff, 2005; Barlow et al., 2010). The literature indicates that individuals with recent mTBI (i.e., within 24 to 48 hours) are at heightened risk for poorer driving performance, both as measured subjectively (i.e., self-reports) and objectively (i.e., driving records, driving simulator performance) (Schneider & Gouvier, 2005; Preece et al., 2010; Neyens, Boyle and Schultheis, 2015; Classen et al., 2011). Others have noted that mTBI is associated with poorer driving outcomes in the longer-term post-injury (i.e., months to years post-injury) (Bernstein & Calamia, Under Review; Bottari et al., 2012). However, less is known about the effects of mTBI on changes in driving ability within weeks of injury when the patient is still recovering from the effects of their injury. Furthermore, few have examined whether post-concussive symptoms may predict changes in driving ability following mTBI.

The present study utilized a case-control follow-up design to assess changes in self-reported driving ability following mTBI. This methodology represented an improvement over previous work in this area, which frequently relies on single-time point, cross-sectional comparisons (e.g., Classen et al., 2011; Neyens, Boyle & Schultheis, 2015) in order to make inferences about the effects of mTBI on cognitive abilities and driving ability, and thus does not

control for the fact that individuals with mTBI may differ from both OI patients and healthy controls even prior to injury. Furthermore, the inclusion of OI patients allowed for the controlling of effects that non-head-related injuries may have on cognitive functioning and driving ability (e.g., Bazarian, Wong, Harris, Leahey, Mookerjee & Dombovy, 1999; Erlanger, Kutner, Barth & Barnes, 1999).

At odds with hypotheses, changes in driving ability did not differ between individuals with mTBI and those with orthopedic injuries. However, within the mTBI group, DBQ scores increased from baseline to post-injury, which is congruent with prior work suggestive of a detrimental effect of mTBI on driving ability and capacities related to safe driving (Schneider & Gouvier, 2005; Preece et al., 2010; Neyens, Boyle and Schultheis, 2015; Classen et al., 2011). Moreover, while differences in change scores between groups was not significant, participants with mTBI demonstrated a larger increase in raw scores across all three subscales over time relative to the OI group. Lack of between-group differences in change scores may be at least partially attributable to higher baseline DBQ scores reported by the mTBI group relative to the OI group. Findings related to differences between groups in baseline DBQ scores conflict with those of Preece and colleagues (2010), who despite differences in Hazard Perception Test performance between groups at 24 hours post-injury, did not detect differences in their self-reported pre-injury abilities on either the DBQ Violations or Errors subscales. This contrast in findings may be the result of differences between studies in their respective mTBI samples' causes of injury; specifically, whereas in the present study over 60% of mTBI participants suffered their injury due to a motor vehicle accidents, only 12% of mTBI participants reported motorvehicle accident as their cause of injury in the Preece study. Thus, relative to Preece's sample, mTBI participants in the current study may have been more likely to engage in aberrant

driving behaviors even prior to their injury, hence why they were involved in an accident (Mesken, Lajunen & Summala, 2002; Parker, West, Stradling & Manstead, 1995). Furthermore, a number of risk factors that put individuals at increased likelihood for experiencing a mTBI and influence outcomes post-injury are also correlated with poorer driving ability, including aggression and impulsivity (Carroll et al., 2004; Ruff et al., 1996; Chliaoutakis et al., 2002; Owsley, McGwin Jr. & McNeal, 2003). Findings related to changes in DBQ scores within the OI group also conflict with prior literature, which has generally indicated a lack of change in cognition over time in these individuals, as the effects of these types of injuries generally do not have a substantial impact on brain functioning (Schretlen & Shapiro, 2003; Levin et al., 2008). Despite this, some literature has indicated that symptoms common after mTBI may also be experienced by those with OI and even those free of injury (Gouvier et al., 1988; Gunstad & Suhr, 2002; McCrea, 2008), and OI patients with certain types of injuries (i.e., patients exposed to a decelerating force) have been shown to have slower processing speed following those injuries (De Monte & Geffen, 2005).

Within groups, a significant effect of time was also found for both the mTBI and OI groups with regard to total DBQ scores and both the Violations and Lapses subscales, while the Errors subscale trended toward significance ($p = .05$). These results suggest that individuals in both groups experienced an increase in aberrant driving behaviors from immediately post-injury to two-week follow-up. Given that prior work suggests that cognitive deficits following mTBI typically dissipate within three to seven days post-injury (Bleiberg et al., 2004), it is possible that driving ability following mTBI remains impaired even after cognitive faculties have returned to baseline. Alternatively, mTBI participants in the present study may have over reported the extent of their driving difficulties at this time point, while more objective measures of driving may have

revealed no differences from their pre-injury capacities. Recent work also indicates that some self-reported driving problems (i.e., DBQ Violations) become less frequent with greater time since mTBI; however, it is worth noting that other facets of driving have not demonstrated this temporal effect (Bernstein & Calamia, Under Review). Interestingly, although aggressiveness has been shown to increase following mTBI (Kerr, Evenson, Rosamond, Mihalik, Guskiewicz & Marshall, 2014), mTBI participants also demonstrated increases in scores on the DBQ Lapses subscale, perhaps hinting at changes in attention/concentration that frequently follow mTBI and are among the longest-lasting residual effects (Ettenhofer & Barry, 2012; Catale, Marique, Closset & Meulemans, 2009; van der Naalt, van Zomeren, Sluiter & Minderhoud, 1999). With respect to increases in DBQ scores over time in the OI group, and psychological symptoms similar to those experienced by those with mTBI have been found to develop in those with OI (albeit to a lesser severity) in the aftermath of injury (Ettenhofer & Barry, 2011). As a result, it is possible that OI participants experienced increased cognitive symptoms (e.g., fatigue, headache) or emotional symptoms (e.g., irritability) following injury that may have impeded their driving capacities (Curran, Ponsford & Crowe, 2000). These symptoms may been linked to poorer driving outcomes in other clinical populations (Bernstein, DeVito & Calamia, Under Review; Fonda, Wallace & Herzog, 2001; Shahar, 2009).

Consistent with hypotheses, immediately post-injury PCS was associated with follow-up total DBQ scores as well as DBQ Violations scores. These results are consistent with a small body of literature indicating that PCS following mTBI, and especially impaired performance in various cognitive domains, following injury may help predict severity of outcomes after mTBI. In particular, Stokx and Gaillard (1986) found that both reaction time and driving ability may be impaired in those with concussion even two years post-injury (Stokx & Gaillard, 1986), while

more recent work suggests that processing speed may predict performance on the Hazard Perception Test (Preece et al., 2010). Research in other clinical populations (e.g., multiple sclerosis, dementia) further suggests that cognitive performance in such areas as visuospatial abilities, reaction time, processing speed and executive functioning are linked to driving performance (Reger et al., 2004; Lincoln & Radford, 2008). As expected, the relationship between PCS and DBQ total scores appeared to be driven by associations with the DBQ Violations subscale, indicating that individuals with greater PCS were more likely to deliberately drive in a manner that put others in harm's way. In contrast, PCS did not predict follow-up DBQ Lapses or Errors scores, suggesting that when controlling for the effects of baseline driving abilities, PCS does not significantly contribute to unintentional driving mistakes that follow injury. These results are consistent with prior work suggesting that aggression and other emotional symptoms that impair driving ability may increase with heightened injury severity both in those with mTBI and orthopedic injuries (Kerr et al., 2014; Curran, Ponsford & Crowe, 2000), and a similar trend has been found in other populations (Bernstein, DeVito & Calamia, Under Review).

Limitations

The present study was limited by its small sample size, which may have contributed to a lack of differences in group-by-time effects on driving ability. Additionally, the reliance on self-report measures may have caused some participants to attempt to underreport the frequency of their driving behaviors; however, it is likely that such an effect would be seen in both groups and thus not contribute to differences between them. The DBQ has also demonstrated negligible effects of reporter bias (Lajunen & Summala, 2003), further suggesting that DBQ scores accurately reflected participants' true beliefs about their present driving abilities.

Although the present study built on prior mTBI driving literature through its utilization of both a test-retest methodology and recruitment of both those with mTBI and OI, there are issues with both these aspects of the study design that warrant attention. As participants were only assessed at two weeks post-injury, it is unclear when during the course of recovery participants began to perceive their driving abilities as becoming worse. Future work should follow-up with participants on a more regular basis to better comprehend this recovery timeframe. Additionally, although recruitment of patients with OI allowed for a comparison group that controlled for the effects of injury on driving ability, cause of injury was only recorded in the mTBI group as this information was specifically collected when assessing whether individuals reporting a head injury met criteria for mTBI. Given the broad array of physical impediments that characterize those with OI (e.g., leg injury, arm injury, finger injury), it is unclear how well the OI group accurately represents the effects of OI broadly, and it is possible that most may have had a specific kind of injury. As recruitment is still ongoing for this study, medical records will be examined at the conclusion of recruitment to determine whether groups differed in mechanism of injury. Similarly, several demographic variables (e.g., age, education) were not recorded for a sizable minority of participants, and this information will also be collected from the hospital's medical records when recruitment has finished.

Despite efforts to assess performance validity and obtain information regarding participants' prior mTBI history, time constraints during evaluations limited the present study's ability to collect data on these variables. As a result, sub-optimal effort in one or both groups during SCAT2 testing may prevented detection of relationships between PCS and changes in driving ability (Lange, Iverson, Brooks & Rennison, 2010), while the cumulative effects of prior

mTBI on abilities related to driving ability cannot be ruled out in either group (De Beaumont et al., 2007; Rabadi & Jordan, 2001).

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APPENDIX
LSU IRB APPROVAL

ACTION ON PROTOCOL APPROVAL REQUEST

Institutional Review Board
Dr. Dennis Landin, Chair
130 David Boyd Hall
Baton Rouge, LA 70803
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TO: Matthew Calamia
Psychology

FROM: Dennis Landin
Chair, Institutional Review Board

DATE: May 17, 2016

RE: **IRB#** 3729

TITLE: Assessing Concussion in the Emergency Department: Clinical Symptoms, Cognitive Performance and Biological Indicators

New Protocol/Modification/Continuation: New Protocol

Review type: Full ___ Expedited _X_ **Review date:** 5/11/2016

Risk Factor: Minimal ___X___ Uncertain _____ Greater Than Minimal_____

Approved_____X_____ **Disapproved**_____

Approval Date: 5/16/2016 **Approval Expiration Date:** 5/15/2017

Re-review frequency: (annual unless otherwise stated)

Number of subjects approved: 260

LSU Proposal Number (if applicable):

Protocol Matches Scope of Work in Grant proposal: (if applicable) _____

By: Dennis Landin, Chairman _____

PRINCIPAL INVESTIGATOR: PLEASE READ THE FOLLOWING –
Continuing approval is CONDITIONAL on:

1. Adherence to the approved protocol, familiarity with, and adherence to the ethical standards of the Belmont Report, and LSU's Assurance of Compliance with DHHS regulations for the protection of human subjects*
2. Prior approval of a change in protocol, including revision of the consent documents or an increase in the number of subjects over that approved.
3. Obtaining renewed approval (or submittal of a termination report), prior to the approval expiration date, upon request by the IRB office (irrespective of when the project actually begins); notification of project termination.
4. Retention of documentation of informed consent and study records for at least 3 years after the study ends.
5. Continuing attention to the physical and psychological well-being and informed consent of the individual participants, including notification of new information that might affect consent.
6. A prompt report to the IRB of any adverse event affecting a participant potentially arising from the study.
7. Notification of the IRB of a serious compliance failure.
8. **SPECIAL NOTE: When emailing more than one recipient, make sure you use bcc.**

**All investigators and support staff have access to copies of the Belmont Report, LSU's Assurance with DHHS, DHHS (45 CFR 46) and FDA regulations governing use of human subjects, and other relevant documents in print in this office or on our World Wide Web site at http://www.lsu.edu/irb*

VITA

John Philip Kelly Bernstein was raised in Lexington, Massachusetts. He graduated with a Bachelor of Science in Brain and Cognitive Sciences with Highest Research Honors and a Bachelor of Arts in Psychology with Distinction and High Research Honors from the University of Rochester in 2015. In college, he completed two theses examining the utility of a test of visual scanning in the assessment of the effects of concussion and chronic partial sleep restriction.

Upon graduating, John enrolled as a doctoral student at Louisiana State University in Fall of 2015 to pursue his Doctorate of Philosophy in Clinical Psychology. His research interests include the recruitment, assessment and functional outcomes of those with Major Neurocognitive Disorders, including traumatic brain injury and Alzheimer's Disease, as well those with sleep-related disorders such as insomnia.

ADDENDUM

RESULTS

Due to an error that occurred when preparing the data for analysis, the sample reported on in the original analyses included participants whose outcome measure data was partially imputed. As a result, to assess whether results were robust when only complete cases were considered, analyses were re-conducted on solely those participants in the sample with complete DBQ and SCAT2 data. This analysis included 12 mTBI participants and 15 OI participants.

Table 1 displays demographic variables within groups. Across the entire sample, participants were an average of 38.7 years of age (SD = 14.1). The sample was 44.4% male and 55.6% female. A total of 51.9% of the sample was Caucasian, 22.2% were African-American, and an additional 25.9% did not have race recorded.

Table 1. Sample Demographics

	mTBI, mean (SD) or n (%)	OI, mean (SD) or n (%)
Age	35.55 (12.8)	41.2 (15.1)
Gender		
Male	4 (33.3%)	8 (53.3%)
Female	8 (66.7%)	7 (46.7%)
Not Reported/Missing	0 (0.0%)	0 (0.0%)
Education		
Less than High School Diploma	1 (8.3%)	1 (6.7%)
High School Diploma	3 (25.0%)	1 (6.7%)
1-3 Years of College	3 (25.0%)	3 (20.0%)
College Diploma	2 (16.7%)	7 (46.7%)
Post Graduate Degree	0 (0.0%)	1 (6.7%)
Not Reported/Missing	3 (25.0%)	2 (13.3%)
Race		
Caucasian	5 (41.7%)	9 (60.0%)
African-American	4 (33.3%)	2 (13.3%)
Asian-American	0 (0%)	0 (0.0%)
Not Reported/Missing	3 (25.0%)	4 (26.7%)

(table cont'd.)

	mTBI, mean (SD or n (%)	OI, mean (SD or n (%)
Ethnicity		
Hispanic or Latino	1 (8.3%)	0 (0.0%)
Not Hispanic or Latino	5 (41.7%)	12 (80.0%)
Not Reported/Missing	6 (50.0%)	3 (20.0%)
Cause of Injury		
Vehicular Accident	8 (66.7%)	-
Sport	4 (33.3%)	-
Fight	0 (0.0%)	-
Loss of Consciousness		
Yes	4 (33.3%)	-
No	8 (66.7%)	-
Post-Traumatic Amnesia		
Yes	12 (100.0%)	-
No	0 (0.0%)	-

A small portion (3.7%) of participants reported being of Hispanic or Latino ethnicity, however a larger percentage (33.3%) did not have ethnicity recorded. The sample represented a range of educational backgrounds, with 7.4% having less than a high school education, 14.8% having a high school diploma, 22.2% having 1-3 years of college, 33.3% holding a college degree, and 3.7% having a post-graduate degree. A total of 18.5% of participants did not have their educational level recorded. Independent-samples t-tests revealed no differences between groups in age, and chi square analyses revealed no group differences in gender, education, race or ethnicity (all $p > .05$). Within the mTBI group, a majority of participants (66.7%) received their injury as a result of a motor vehicle accident, while a smaller number of individuals experienced theirs as a result of a sport (33.3%). A minority of mTBI participants (33.3%) reported experiencing a loss of consciousness after injury, however all (100.0%) reported post-traumatic amnesia.

Table 2 displays scores within each group on all outcome measures. The MANOVA did not reveal a significant interaction effect of time-by-group on any DBQ subscale scores, all $p > .05$. A significant effect was found for group on the DBQ scores, $F(3, 23) = 3.65$, $p < .05$. The effect of time on the DBQ scores was non-significant, $p > .05$.

Table 2. Scores on Outcome Measures

Measure	mTBI Mean (SD)	OI Mean (SD)
DBQ Total		
Baseline	43.5 (7.8)	35.0 (8.2)
Follow-Up	46.3 (7.8)	37.4 (6.7)
DBQ Total Change	2.8 (4.6)	2.4 (7.1)
DBQ Lapses		
Baseline	15.3 (4.9)	12.9 (3.8)
Follow-Up	16.4 (4.7)	14.0 (3.9)
DBQ Lapses Change	1.1 (3.4)	1.1 (3.8)
DBQ Errors		
Baseline	12.9 (3.4)	11.1 (2.6)
Follow-Up	13.4 (3.2)	11.3 (2.0)
DBQ Errors Change	.5 (1.8)	.3 (2.2)
DBQ Violations		
Baseline	15.3 (5.0)	11.1 (4.6)
Follow-Up	16.5 (3.8)	12.1 (3.3)
DBQ Violations Change	1.3 (2.7)	1.0 (3.8)
SCAT2 Total	74.7 (20.2)	72.5 (16.8)
Symptom Severity Score	12.9 (8.5)	13.0 (8.1)

Follow-up ANOVAs were used to assess effects on total DBQ scores and individual DBQ subscales; these effects were explored with time in addition to group to be consistent with original analyses. A significant effect was found for time on DBQ total score, $F(1, 25) = 4.85$. The effect of time on all DBQ subscales were non-significant, all $p > .05$. A significant effect was found for group on DBQ total score such that the mTBI group reported greater overall aberrant driving behaviors, $F(1, 25) = 10.37$. Additionally, a significant effect was found for group on DBQ violations such that the mTBI group reported intentionally engaging in more frequent aberrant behaviors that risked the safety of others, $F(1, 25) = 8.37$. The effects of group on DBQ lapses and errors were non-significant, $p > .05$.

Table 3 displays correlations among outcome measures. Within the entire sample, baseline total DBQ scores were correlated with follow-up total DBQ scores, and baseline DBQ

subscales were correlated with their respective follow-up subscales. DBQ scores were not associated with SCAT2 performance.

Table 3. Correlations Among Measures

	1	2	3	4	5	6	7	8	9	10
1. Baseline DBQ Total	-									
2. Follow-Up DBQ Total	.76**	-								
3. Baseline DBQ Lapses	.72**	..61**	-							
4. Follow-Up DBQ Lapses	.51**	.79**	.67**	-						
5. Baseline DBQ Errors	.64**	.67**	..34**	.49**	-					
6. Follow-Up DBQ Errors	.44*	.68**	.29**	.39*	.78**	-				
7. Baseline DBQ Violations	.75**	.41*	.21	.03	.23	.05	-			
8. Follow-Up DBQ Violations	.71**	.74**	.33	.28	.33	.30	.77**	-		
9. SCAT2	-.24	-.18	-.07	-.03	-.01	.10	-.33	-.41	-	
10. Symptom Severity	-.25	-.08	-.26	-.06	-.03	.09	-.19	-.16	.57**	-

Note: * indicates significance at the $p < .05$ level, ** indicates significance at the $p < .01$ level.

DISCUSSION

Results of the re-conducted analyses were largely similar to those of the original analyses. A notable exception pertains to a lack of group differences on the DBQ Lapses and Errors subscales. Specifically, although in the original analyses the mTBI group reported greater DBQ Lapses and DBQ Errors scores, these effects were not found in the re-done analyses. However, the mTBI group continued to exhibit higher DBQ Total scores and DBQ Violations scores. This change in results suggests that differences in total scores were largely driven by the mTBI group's higher frequency of deliberately engaging in driving behaviors that risked the safety of others. Such findings may partially be explained by prior work indicative of greater emotional symptoms in those with recent mTBI (Cunningham, Brison & Pickett, 2011). Given the intentional nature of the behaviors captured by the Violations subscale, it is possible that participants in the mTBI group drove in a more aggressive manner following their injury; these behaviors would not have been evident on the other DBQ subscales. Alternatively, decreased power as a result of the smaller sample size may explain lack of group differences in the re-done analyses.

Additionally, in the re-done analyses, no significant correlations were found between PCS and DBQ scores (both total scores and all subscales) at either baseline or follow-up, which stands in contrast with significant associations observed in the original analyses with regard to total DBQ scores and several subscale scores. Given the smaller sample size, it is possible that reduced individual differences among patients in PCS at both time points resulted in a lack of correlation with DBQ scores. While certain PCS are especially common following mTBI (e.g., headache), others are less so, and may be observed even in OI patients (McAllister & Arciniegas, 2002).

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