Driving after Childhood TBI: The Impact of Distraction

Final Grant Report

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Introduction

Traumatic Brain Injury (TBI) is a significant public health concern, one of the leading causes of morbidity and mortality in childhood, and one of the most common sources of acquired disability in children. Virtually no research has been completed with adolescent drivers with a history of TBI, however they are at especially high risk for driving impairments given the constellation of incomplete neural development, inexperience, and the neuropsychological consequences of TBI. Although there have been studies that look at return to driving for adults with TBI, this fails to address the concern related to acquiring new skills for teens with a history of TBI early in childhood as well as the increased executive dysfunction in teens with TBI. While public health initiates have had a positive impact on teen driving safety, teens remain the most at risk group of drivers. Further a better understanding of which groups of teens are at most risk for negative driving outcomes as well as the mechanisms that increase driving risk is the next step in developing targeted safety initiatives and interventions.

We are proposing a project that will examine the driving performance of teens with a history of TBI in comparison to their non-injured peers. Because distracted driving is an increasing phenomenon, we will also examine the impact of distraction on the driving performance of teens with a history of TBI. We also aim to explore the role that experience plays in the driving performance of our teens as well as the possible underlying mechanisms for observed deficits including various aspects of executive functioning (planning, processing speed, visual attention, selective attention, divided attention, etc.).

This study is the first to examine the driving performance of teens with a history of TBI. The aims of the study were to 1) Compare the driving performance of teens with a history of TBI to the driving performance of teens without a history of TBI, and 2) Examine the impact of cell phone use (conversation and texting) on teen driving performance

Executive Summary

Background

Traumatic brain injury is a significant public health concern, and the leading cause of morbidity and mortality in childhood, and the most common source of acquired disability in children (Thurman, 2014). Many of the acquired deficits after TBI are cognitive and behaviorally related including memory deficits, difficulties with executive functioning (i.e., difficulties with attention, organization, slowness in completing tasks, etc.), inflexible thinking, and externalizing behaviors (Anderson, Brown, Newitt & Holle, 2011; Anderson, Godfrey, Rosenfeld, & Catroppa, 2012; Karver et al. 2012; Fay et al., 2009). Understanding how pediatric TBI impacts everyday functioning in adolescence and young adulthood (i.e. driving) is of great importance for identifying barriers to achieving key developmental milestones. Learning to drive and becoming an independent driver is an important rite of passage and promotes social engagement for all adolescents; however, given the potential catastrophic consequences of motor vehicle crashes (MVCs), is not something that should be undertaken without additional consideration for teens with a history of TBI.

MVCs result in an estimated 32,788 deaths (NHTSA, 2011) and 2.8 million injuries per year (CDC, 2011), and teen drivers, especially newly licensed drivers, contribute disproportionately to the rates of MVCs (Lee, 2007; McKnight & McKnight, 2003; Williams, 2003). Initiatives and laws directed at teens have reduced MVC rates, but there is a clear need for additional work to identify teens most at risk for driving-related impairment. One step in developing additional safety interventions/initiatives is understanding the mechanisms that increase the risk for specific groups of young drivers. Unfortunately, virtually no published research has examined the driving performance of novice drivers with a history of TBI, although there is a small but concerning literature reporting on the driving performance of adults following TBI. While the adult literature helps to shed lights on the impact of TBI on driving performance, it fails to address the increased risk of young/novice drivers.

A contributing factor to driving errors by AYAs is the increasing use of mobile electronics (e.g., cell phones) during driving. Engaging in phone tasks (e.g., talking, texting, wayfinding) results in behaviors such as looking away from the road, taking hands off the steering wheel, or directing attention away from driving. Such instances of distracted driving are cited as one of the primary causes of MVCs (Neyens & Boyle, 2008; Kass, Cole & Stanny, 2007; Beede & Cass, 2006). Distraction is particularly problematic for novice drivers, who are at a 4-fold increased risk for being involved in MCs resulting in injuries when talking on a cell phone (McEvoy et al., 2005).

Virtually no research has been completed with adolescent drivers with a history of TBI, however, they are at especially high risk for driving impairments give the constellation of incomplete neural development, inexperience, and the neuropsychological consequences of TBI. Additionally, the task of driving is different for teens as they are novice drivers and allocate more cognitive resources to attention and decision making. This study has the potential to add to our understanding of distracted driving among teens with and without TBI. Information gained from the proposed study could be used to inform and improve current interventions and driver's education programs. Finally, information gleaned from this study is likely to impact clinical practice with teens with a history of TBI. Knowing the risks associated with impairment in driving performance as well as the mechanisms of risk is likely to improve injury prevention measures with this population and contribute greatly to public health safety initiatives.

Participants

A total of 50 adolescents between the ages of 16-24 with a valid driver’s license were recruited to participate in the study. This age range was targeted in order to evaluate the population of drivers most at risk for the deficits in driving performance. 15 participants had a history of moderate to severe TBI were recruited from the Head Injury Research Center at Cincinnati Children’s Hospital Medical Center. The TBI participants had a history of moderate (GCS 9-12 or >12 accompanied by abnormal neuroimaging) or severe (GCS <=8) injury. All potential participants had a valid driver’s license. Those with recent injuries must have completed their hospital or rehabilitation care and have returned to driver, or be approved by medical professionals to return to driving to be eligible. 25 age and gender matched non-injured control participants were recruited from the community.

A total of 71 individuals with TBI were screened for eligibility. 13 were ineligible due to not having a license, 21 were not able to be scheduled within the time constraints of the study, and 13 were not interested in participating after being screened. At completion of enrollment a total of 25 adolescents and young adults with TBI, and 25 age and gender matched controls participated in the study. The sample characteristics for each group and the study as a whole are presented in the table below.

Table 1. Participant demographic information

	TBI (n=25)	Control (n=25)	Total (n=50)

Age in years, mean (std. dev)	19.05 (1.74)	19.12 (1.88)	19.09 (1.80)
Sex, n (%) male	15 (60%)	15 (60%)	30 (60%)
Race	1 (4%)	6 (24%)	7 (14%)
Months of driving experience	30.13 (21.05)	30.76 (22.43)	30.46 (21.55)
Cell phone use with driving (ever)	20 (80%)	16 (64%)	36 (72%)

Participants were given the option to complete all study activities in a single visit or across two separate visits. One participant with TBI was lost to follow-up before completing the simulated drive, and simulator data from 11 participants (6 uninjured controls and 5 with TBI) where lost due to technical difficulties, resulting in complete simulator data from 19 uninjured controls and 19 individuals with a history of TBI.

Methodology

During a baseline visit, all participants and their parents (when appropriate) provided informed consent. Parents and adolescents completed the Kiddie Schedule for Affective Disorders and Schizophrenia for School-Age Children – Present and Lifetime Version (KSADS-PL) and the Behavior Rating Inventory of Executive Functioning (BRIEF). Parents (or participants if ≥ 18 years of age) completed a demographic form which gathered background information, injury information (for those in the TBI sample), and psychosocial and medical history. Adolescents also reported months of driving experience and whether they engaged in cell phone use while driving. Participants then completed the simulated. All participants completed an identical 40 minute simulated drive. The first 10-minutes (40,000 ft.) was an adjustment period during which participants became more comfortable with the driving simulator. The remaining 30 minutes (120,000 ft.) were divided into 3 separate (but continuously driven) 10-minute (40,000 ft.) sections. During each period, participants were engaged in a cell phone conversation, a text message exchange, or no distraction. The order of these three conditions was randomized and counterbalanced across participants and each order of conditions occurred equally across groups. During each of the three experimental conditions, one unexpected event occurred (car suddenly pulling in from of the driver or a pedestrian suddenly crossing the street in front of the vehicle). The data were summarized by calculating the maximum, mean, and standard deviation (SD) of speed in miles per hour, and SD of lateral position in feet for each section. Finally, if the vehicle made contact with the deployed object (car or pedestrian), a crash was coded.

The primary dependent variables in our analyses were mean speed, maximum speed, standard deviation of lateral position (variability), standard deviation of speed (variability), and braking reaction time. Separate 2 (TBI vs. Control) x 3 (Conversation vs. Texting vs. No distraction) mixed models were used to assess hypotheses. A p-value of less than .05 were interpreted as statistically significant. These models were used to assess the following aims:

Specific Aim #1: Compare the driving performance of teens with a history of TBI to that of teens with TBI.

Primary Hypothesis #1: Participants with TBI will exhibit a deficit in performance on simulated driving tasks in comparison to uninjured control participants. It is expected that individuals with TBI will display greater maximum and mean speed, greater speed variability, greater lane position variability, and increased braking RT than non-injured controls.

Specific aim #2: Examine the impact of distraction on adolescent driving performance.

Primary Hypothesis #2: Distraction (conversation and texting) will have a detrimental impact on the driving performance of all participants. It is expected that individuals engaged in a cell phone use will exhibit greater maximum and mean speed, greater speed variability, greater lane position variability, and increased braking RT compared to their performance while not engaged in cell phone use. Further, individuals will demonstrate a greater impairment in the aforementioned variables during the texting condition in comparison to the conversation condition.

Primary Hypothesis #3: Cell phone use (Conversation and texting) will have a greater detrimental effect on the simulated driving performance of adolescents with TBI than non-injured controls.

Exploratory analyses:

In addition to the dependent variables discussed above, we also conducted analyses examining the effect of executive functioning (UFOV, Processing speed from WASI, BRIEF-GEC, and DKEFS) on driving performance. Group differences on the BRIEF were examined via independent samples t-tests (TBI vs. Control). Exploration of their indirect role as underlying mechanisms for impairment on dependent driving variables will then be examined via analyses of mediation using bootstrapping. In order to examine the mediating effect of these variables on the effect of distraction condition (a repeated measures variable), we first computed change scores comparing each pair of conditions. We then completed regression analyses, exploring the effect of the mediating variable on the change in dependent variable. Significant medication was determined if the regression models demonstrated a significant relationship between mediator and change in driving outcome.

Finally, months of driving experience was examined as a possible moderator. Months of driving experience will be entered as an interaction term (i.e., group*months, distraction*months, group*distraction*months) into the models described above to assess moderation.

Conclusions

There was no significant effect of injury on driving performance. While there was a significant effect of distraction on mean speed and lane position variability, there was no significant TBI by distraction condition interaction on any of the outcome variables suggesting that distraction influenced performance similarly for all individuals regardless of injury history. Mediation analyses revealed that selective attention mediated the effect of distraction condition on mean speed, maximum speed, and speed variability. This highlights the notion that while distracted driving is related to poor outcomes for all individuals, there may be a subgroup of individuals who may be at greater risk for poor outcomes.

Information/Qualifications (Principal and Co-Investigators) Investigators and Research Setting

Investigative Team

Principal Investigator: Megan Narad, PhD is a clinical psychology fellow in the Division of Physical Medicine and Rehabilitation at Cincinnati Children's Hospital Medical Center. Megan completed her graduate training at the University of Cincinnati. Throughout her training, she has developed an interest in examining the real world implications of deficits in executive functioning, injury prevention, and intervention development. She received a dissertation award for the American Psychological Association to partially fund her dissertation project which looked at the impact of distracted driving on the driving performance of teens with ADHD. This study demonstrated that not only did teens with ADHD demonstrate greater driving impairment (with and without distraction) than teens without ADHD; it also suggested that visual attention was one of the primary mechanisms for this impairment. Dr. Narad received the 2013 Society of Pediatric Psychology/Centers for Disease Control Injury Prevention Student Research Award for the resulting manuscript. Based on this new knowledge the investigative team is currently working on developing a safety intervention designed to improve driver's visual attention to the roadway, thereby improving their driving performance. This history and collaboration with the investigative team will be integral to the implementation of the work within this application.

Shari Wade, PhD. – Co-Investigator and fellowship mentor to Dr. Narad). Dr. Wade is a research professor at CCHMC. She has published more than 100 peer-reviewed articles related to the recovery from pediatric TBI. She has examined how the family dynamic related to this recovery and has more recently looked at the relationship of neuroimaging to neuropsychological recovery following pediatric TBI. She has also collaborated with other cents nationally to evaluate neurocognitive recovery after pediatric TBI as it related to family and various psychosocial parameters. Because of Dr. Wade's expertise in neurocognitive and psychosocial parameters related to the recovery from pediatric TBI, she is an integral part of successful completion of this project. Her expertise in behavioral and family outcomes augments Dr. Narad's strengths as well as the expertise of the other co-investigators on the team. Her active studies as well as precious studies with children with TBI will serve as a source of patients interested in research, and her expertise in recruitment methods and relationships with other divisions in the institution who serve children with a history of TBI will greatly aid in recruitment of participants. Finally, in addition to her active mentorship of Dr. Narad, she will provide her expertise on the long term behavioral sequella of pediatric TBI to the project and aide with data interpretation and dissemination of findings.

Dean Beebe, PhD. – Co-Investigator. Dr. Beebe is a professor of pediatrics at the University of Cincinnati College of Medicine, Director of the Neuropsychology Program in the Division of Behavioral Medicine and Clinical Psychology at Cincinnati Children's Hospital Medical Center, and Co-director of the Driving Simulation Lab at CCHMC. His research program, which investigates the daytime effects of inadequate sleep, has been continuously funded by the NIH and other granting agencies since 2000, with the past 10 years focused on adolescents. Dr. Beebe has also completed an EMS funded study examining the role of sleep restriction on the driving performance of teens.

Research Environment

Cincinnati Children's Hospital Medical Center. CCHMC is committed to providing its investigators excellent space, state of the art computer resources, and ongoing administrative statistical support. CCHMC has shown strong success in research activities and currently ranks 3rd in NIH funding among tertiary pediatric centers in the United States. US News & World Report recognized CCHMC as one of the best children's hospitals, and ranked the Department of Pediatrics at CCHMC and the University of Cincinnati College of Medicine as the 3rd best pediatric program at a medical school in 2010. Further, CCHMC also has the only level I Pediatric Trauma Center in the area. The CCHMC vision is to be a leader in improving child health and the institution has developed excellent resources to pursue this vision.

Head Injury Research Center. The Head Injury Research Center, housed in the Division of Physical Medicine and Rehabilitation (PM&R), provides a unique opportunity for subject recruitment. PM&R also has a 14-bed inpatient medical rehabilitation program that is accredited by the Commission on Accreditation of Rehabilitation Facilities (CARF). Within the Head Injury Research Center, Dr. Wade (Co-I) was awarded a Rehabilitation Research and Training Center (RRTC) Grant for Pediatric Traumatic Brain Injury Interventions in October of 2009. This grant from the National Institute on Disability and Rehabilitation Research represents the first and only federally-funded center for childhood TBI. This center includes researchers and clinicians at the forefront of the pediatric TBI field with studies examining interventions to improve outcomes for children and families following pediatric TBI, medication trials to mitigate impairments, as well as genetic and imaging studies to further understand the functional outcomes of these children.

Driving Simulation Lab. The driving simulation lab is house within the Division of Behavioral Medicine & Clinical Psychology at CCHMC, and co-directed by Drs. Beebe and Epstein. The simulator is run on a software platform designed by Systems Technology Incorporated (STI; www.stismdrive.com) that allows for both pre-made and programmable driving scenarios. STI has over 40 years of experience with driving simulation, and their systems are widely used in academic, industry and military use. The system has 3 driving displays, a 135-degree driver field of view with integrated rear-view and side mirrors, a full sized steering wheel with dynamics based feedback, full sized foot pedals, and a fixed base, adjustable full-size car seat. The simulator is also equipped with a high definition digital camera to record behaviors of the driver.

Review of Literature

Impact of Pediatric Traumatic Brain Injury

Traumatic brain injury (TBI) is a significant public health concern resulting in 52,000 deaths, 275,000 hospitalizations, and 1.3 million emergency department visits annually (Faul, Wald, & Coronado, 2010). Specifically in children, TBI results in 2,685 deaths, 37,000 hospitalizations, and 435,000 emergency department visits yearly in the United States (Faul, Xu, Wald, & Coronado, 2010), making it one of the leading causes of morbidity and mortality in childhood, and the most common source of acquired disability in children (Thurman, 2014). The age groups at highest risk for TBIs are those 0-4 years old and 15-19 years old. Even injuries occurring at an early age can have a persistent impact with the CDC estimating that at least 5.3 million Americans have a life-long or long-term need for help with performing activities of daily living following TBI (Faul, Xu, Wald, & Coronado, 2010). Survivors of pediatric TBI may have persistent impairments that delay their achievement of developmental milestones such as learning to drive during adolescents (Babikian et al., 2009). Despite these potential delays, adolescents with TBI express the desire to drive like their peers (Di Battista et al., 2014).

Many of the acquired deficits after TBI are cognitive and behaviorally related including memory deficits, difficulties with executive functioning (i.e. difficulties with attention, organization, slowness in completing tasks, etc.), inflexible thinking, and externalizing behaviors (Anderson, Brown, Newitt & Holle, 2011; Anderson, Godfrey, Rosenfeld & Catroppa, 2012; Karver et al., 2012; Fay et al., 2009). Further complicating recover is that expression of these impairments is highly variable in terms of whether or not the individual experiences the impairment or when in their recovery the impairment becomes apparent (Schwartz, et al., 2003). Therefore, while a child injured early in life may not experience impairing deficits in executive functioning acutely following injury, these difficulties may present themselves later in adolescence. Understanding how pediatric TBI impacts everyday functioning in adolescence and transitioning to adulthood is of great importance for identifying barriers to achieving key developmental milestones such as graduation and employment. One significant milestone for nearly all adolescents is learning to drive. Learning to drive and becoming an independent driver is an important rite of passage and promotes social engagement for all adolescents; however, given the potential catastrophic consequences of motor vehicle crashes (MVCs), it is not something that should be undertaken without additional consideration for teens with a history of TBI.

Teen Drivers as a Public Safety Concern

Motor vehicle safety is a significant area of public health concern. MVCs result in an estimated 32,788 deaths (NHTSA, 2011) and 2.8 million injuries per year (CDC, 2011). Teen drivers, especially newly licensed drivers, contribute disproportionately to the rates of MVCs (Lee, 2007; McKnight & McKnight, 2003; Williams, 2003). In fact, adolescents are 4 times more likely to be involved in MVCs than drivers older than 20 years of age (Insurance Institute for Highway Safety, 2011), and MVCs are the number 1 cause of death for teens in the United States (Ozer, MacDonald, & Irwin, 2002), with 41% of all teen (13-19) deaths attributable to car accidents (Shope & Bringham, 2008). Initiatives and laws directed at teens have reduced accident rates, but there is a clear need for additional work to identify teens most at risk for driving-related impairment. One step in developing additional safety interventions/initiatives is understanding the mechanisms that increase the risk for specific groups of young drivers.

Incomplete neural development is thought to contribute, in part, to the increased risk for MVC among teens (Casey, Jones, & Hare, 2008). In particular the prefrontal cortex, the locus of executive functioning, is not fully matured until as late as 25 years of age (Keating, 2007; Keating & Halpern-Feisher, 2008; Steinberg et al., 2006). Driving is a complex task that requires integration of a number of EF skills including planning, concentration, inhibition, problem solving, and appropriate responses to events. Further, the most cited reason for MVCs is driver inattention (Neyens & Boyle, 2008; Braitman et al., 2008). EF is critical for safe driving (Giedd, 2008), and biologically mediated deficits in cognitive development appear to contribute to risky driving behaviors and poor driving outcomes.

Inexperience is thought to exacerbate the effects of developmental/neural immaturity. Research shows that teens are at the highest risk for MVC within the first 6 months of becoming independently licensed (Lee, 2007; McKnight & McKnight, 2003; Williams, 2003). While accident rates for this population drop dramatically within the first year of independent driving (Williams, 2003), teen drivers remain the highest at-risk MVCs, as their driving skills are not yet automatic, thereby making them more vulnerable to distractions.

Current Knowledge Regarding Driving after TBI

A majority of adults with TBI return to driving within 5 years of their injury (Novak et al., 2010; Tamietto, et al., 2006). Further, research with adults recovering from TBI cites the return to driving as a pivotal benchmark in recovery that promotes social re-engagement, maintenance of steady employment, and improved life satisfaction (Johnston, Goverover, & Dijkers, 2005; Kreutzer et al., 2003; Novak et al., 2010). Studies with adult survivors of TBI report that this group remains at higher risk for driving-related impairments even years after returning to drive (Pietrapian et al., 2005); however, findings from other studies regarding neuropsychological predictors of post injury driving behavior are mixed (Tamietto et al., 2006). While some investigations report minimal impact of neuropsychological abilities, other researchers have identified attention, processing speed, working memory and perceptual motor skills as important predictors of driving performance (Tamietto et al., 2006). There are some instances where individuals with a history of TBI are prohibited from driving (i.e., seizures, visual impairment, mediation, etc.), but little is known about the driving performance of those who do return to driving or who learn to drive after childhood TBI.

The Role of Distraction

Distracted driving, behavior performed while driving that involves taking one's eyes off the road (visual), hands off the wheel (manual), or mind off driving (cognitive), is one of the primary causes of most MVCs (Neyens & Boyle, 2008). As the technological world continues to grow, the number of factors diverting a driver's attention away from the task of driving is increasing as well. Although many contextual factors contribute to distracted driving, cell phone-related distracted driving fatalities are an ever-increasing phenomenon and account for an estimated 18% of all distraction related driving deaths (NHTSA, 2011). Moreover, 77% of drivers reported engaging in cell phone conversations (Tison et al., 2011), 81% of young adults write text messages while driving, and 92% read text messages while driving (Atchley, et al., 2011). The detrimental impact of cell phone use of driving performance has been well documented (Kass, Cole, & Stanny, 2007; Beede & Cass, 2006). In simulated drives, individuals engaged in a cell phone conversation missed twice as many traffic signals (Strayer & Johnston, 2011), displayed decreased vehicle control (Drews, Pasupathi, & Strayer, 2008), and displayed significantly slower braking reaction times compared to their performance with no distraction or while listening to the radio (Consiglio et al., 2003). Moreover, distraction is thought to compound the effects of novice drivers with teens being at a four-fold increased risk of being involved in MVCs resulting in injuries when talking on a cell phone (McEvoy et al., 2005). Given the extreme prevalence of cell phone use while driving, examining the impact of distraction on the driving performance on teens with a history of TBI is of critical importance. In light of the difficulties with divided attention and management of cognitive demands experienced by teens with a history of TBI, it is highly likely that cell phone use while driving will impair the driving ability of teens with a history of TBI, it is highly likely that cell phone use while driving will impair the driving ability of teens with a history of TBI over and above the observed detrimental effects of cell phone use among drivers without a history of TBI.

Addressing a Gap in the Research

Virtually no research has been completed with adolescent drivers with a history of TBI, however, they are at especially high risk for driving impairments given the constellation of incomplete neural development, inexperience, and the neuropsychological consequences of TBI. Although there have been studies that look at return to driving for adults with TBI, this fails to address the concern related to acquiring new skills for teens with a history of TBI early in childhood as well as the increased executive dysfunction in teens with TBI (Babikian & Asarnow, 2009). Additionally, the task of driving is different for teens as they are novice drivers and allocate more cognitive resources to attention and decision-making. Further, in remains unclear what specific aspects of EF are most related to safe driving performance. Further evidence and understanding of the aspects of executive functioning that contribute to driving impairment will contribute greatly to prevention/intervention efforts aimed at reducing deaths and injuries associated with teen crashes.

Brief Review of the Status of Topic in Ohio, Surrounding States, and Nationally

The state of Ohio is not exempt from these facts regarding teen driving safety. Significant public health initiatives to improve the driving safety of teens, including increased education and graduated driver licensing laws (GDL), have contributed to the reduction of MVCs and MVC-related fatalities. However teen drivers around the US and in Ohio continue to have the highest accident and MVC-related death rate of any age group and are more likely to be at fault than any other age groups (Ohio Department of Public Safety, 2014).

Data and Information Issues and Considerations

Approach

This study employed a mixed (between- and within-groups) design to examine the impact of cell phone use of simulated driving performance of teens with and without a history of TBI. A total of 50 adolescents (25 with TBI and 25 uninjured controls) aged 16-25 years of age with a valid driver's license, participated in the study. Participants were given the option to complete all study activities in a single visit or across two separate visits. Participants were first screened where they were comprehensively assessed for symptoms of inattention, interviewed about driving history as well as history of injury, and completed a number of EF measures. Their driving performance was then assessed in the driving simulator lab where they completed one 40-minute simulated drive, half of which (20 minutes) was competed while engaged in cell phone-related distraction (10-minutes hands free conversation; 10-minutes text message exchange).

Participants

A total of 50 participants (25 TBI, 25 uninjured control) aged 16-25 years of age, all with a valid driver's license participated in the study. Participants were given the option to complete all study activities in a single visit or across two separate visits. One participant with TBI was lost to follow-up before completing the simulated drive, and simulator data from 11 participants (6 uninjured controls and 5 with TBI) were lost due to technical difficulties, resulting in complete simulator data for 19 uninjured controls and 19 individuals with a history of TBI. Participants in the TBI group had been hospitalized for a moderate-severe TBI in the past, and all were required to have been approved to return to driving by their medical provider prior to their participation in the study. Participants in the uninjured control group were required to have fewer than 3 total *Diagnostic and Statistical Manual of Mental Disorders* (Fifth Edition) symptoms of ADHD, as assessed by the Kiddie Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime Version (KSADS-PL; Kaufman et al., 1997). Table 1 provides the demographic information. All study procedures where approved by the Institutional Review Board.

Screening Visit

The screening portion took place that the Traumatic Brain Injury Research Center at CCHMC. After providing informed consent and assent, all participants were assessed to gather information regarding current level of functioning in the areas of inattention, executive functioning, and processing speed. Participants also completed a number of self-report measures and a brief neuropsychological battery during this time.

Measures

Kiddie Schedule for Affective Disorders and Schizophrenia for School-Age Children – Present and Lifetime Version (K-SADS-PL; Kaufman, Birmaher, Brent, et al., 1997) - This semis-structured diagnostic interview was completed with the parent (when appropriate) as well as the teen, and was used to assess for the presence of any Axis-I diagnoses for all participants.

Driving History Questionnaire (DHQ) – This is a brief self-report questionnaire that asks about previous accidents, citations, and risky driving behavior. The purpose of this questionnaire was to collect information and the individual's driving history.

Wechsler Adult Intelligence Scale (WAIS-IV; Wechsler, 2008) – The WAIS-IV Processing Speed Index has been designed for individuals ages 16 and over, and will provided a measure of processing speed and sustained attention.

Delis-Kaplan Executive Function System – Trail Making (DKEFS; Delis, Kaplan, & Kramer, 2001) – This is a test of executive functions such as flexibility of thinking, inhibition, problem solving, planning, impulse control, concept formation, abstract thinking, and creativity in verbal and spatial modalities. Specifically, the Trail Making tasks assess flexibility of thinking on a motor task.

Useful Field of View Task (UFOV; Ball & Owsley, 1993) – This is a computerized visual task which results in 3 subscales: Processing Speed, Divided Attention, and Selective Attention. Performance on this task has been correlated with a number of important real-world functions including MVC (Myers, Ball, Kalina, Roth, & Goode, 2000). Further this task has been shown to differentiate between those with a history of TBI and those without a history of TBI (Calvanio, Williams, Burke et al., 2004; Fisk, Novack, Mennemeier & Roenker, 2002).

Behavior Rating Inventory of Executive Functioning (BRIEF; Gioia, Isquith, et al., 2013) – Parent report of teen behaviors and teen self-report were collected. The BRIEF assesses various domains of executive functioning including behavioral regulation, metacognition, inhibitory self-control, flexibility, as well as a global executive functioning composite.

Driving Assessment

The driving assessment consisted of a 43 minute simulated drive (3-minute practice drive and 40-minute experimental drive). All participants completed an identical simulated driving consisting of a three-minute practice drive, and a 40-minute experimental drive. The first 10-minutes of the experimental drive will serve as an adjustment period with no engagement in a conversation or text message exchange. The remaining 30-minutes were divided into three 10-minute blocks. During each block, participants will be engaged in 1) hands-free cell phone conversation, 2) text message exchange, or 3) no distraction. The no distraction, conversation, and texting conditions were counterbalanced across subjects, and the order of distraction condition were randomized and occurred equivalently across injury groups.

All drives were completed in a driving simulator housed at CCHMC, and developed in coordination with Systems Technology Incorporated. The roadway consisted of two lanes separated by a dashed yellow line, and proceeds through urban, suburban, and rural settings. All drives consisted of sections of straight and curving roadways with other vehicles in the driver’s lane as well as the opposite lane of travel. In addition, there are a number of stop signs, and traffic lights presented throughout the drive and speed limits signs are posted along the roadway. On three occasions (1 per distraction condition) the simulator was programmed to present an unexpected event requiring the driver to respond appropriately (cut-off by another driver, unexpected entry of pedestrian onto roadway, and responding to slow drivers ahead of them). Participants were told that they would receive telephone calls and text messages that they would need to respond to during the drive.

The no distraction condition was a 10-minute period when participants drive without interruption or distraction. The conversation and texting conditions were completed using a texting enable cell phone equipped with a hands-free headset. The content of these exchanges were guided and structured using questions from the Book of Questions (Stock, 1985). Questions ranged from simple questions (i.e., what is your favorite food?) to more complex situational questions or moral dilemmas (i.e., imagine that you found a wallet on the side of the road with $5000 and no name or address inside, what would you do with it?). This paradigm was selected in order to evoke as much of a conversation-like experience as possible. Questions presented in the texting condition were similar to those in the conversation condition; however, questions were altered in order to limit both the question length and response to 160 characters, as this is the character limit for most text messages. During all manipulations, the experimenter was separated from the participant and simulator by a room divider with no view of the simulator, so as not to induce a passenger-like interaction (Charlton, 2009).

Driving performance data was collected during the entire 40-minute drive. These data included speed, lateral position, and braking reaction time in response to unexpected events in the roadway. The simulator experience describe above allowed us to gather driving performance data during a variety of driving situations. While there may be some limitations to the use of simulators to evaluate driving performance, the use of a simulator provides accurate and ecologically valid information (Lee, Cameron, & Lee, 2003). Specifically, the STI system has demonstrated ecologically validity in predicting the real world driving performance of healthy adults (Shechtman, Classen, Awadzi, & Mann, 2009), older adults (Lee, Cameron & Lee, 2003), adults with a history of brain injury (Lew et al., 2005), and young drivers with ADHD (Narad et al., 2013). Further the simulator allowed us to present driving situations that would be impossible and unethical to produce in the real world setting with this high-risk population.

Analyses

Group differences (TBI vs Control) were examined via independent samples t-tests for all executive functioning measures (WAIS-PS, DKEFS-trails, UFOV, parent and self-reported BRIEF). Chi-Square models examined the group differences in frequencies of negative driving outcomes as reported on the DHQ.

Separate linear mixed models examined the effect of group (TBI vs. Control), distraction (Conversation vs. Texting vs. No Distraction), and their interaction for each driving outcome (mean speed, maximum speed, speed variability, lane position variability). A p-value of less than .05 was interpreted as statistically significant.

Mediation was explored for Group and Condition effects. In order to examine the impact of the mediating variables on the group effects, indirect effects were examined separately for each condition, in the method proposed by Hayes (Hayes, 2012). The indirect effects of group via self-reported BRIEF, parent-reported BRIEF, DKEFS-trail making, Useful Field of View - processing speed, Useful Field of View – divided attention, Useful Field of View – selective attention, WASI – Processing speed index were estimated using bias corrected bootstrap intervals using 5,000 bootstrap samples in PROC PROCESS in SAS. Significant mediation was determined if the 95% confidence interval surrounding the indirect effect did not include zero, indicating that this indirect effect was significantly different than zero.

When examining mediation on the distraction condition effect, we needed to modify our analytic plan to accommodate the fact that the condition variable were repeated measures variables. Judd et al (Judd, Kenny, & McClelland, 2001) suggest examining the relationship between change scores to assess for mediation when the independent and/or mediating variables are repeated measures. We therefore computed change scores comparing each pair of conditions (no distraction – texting, no distraction – conversation, conversation – texting). A regression analyses assessing the relationship between the mediator and change in driving outcomes was used to assess mediation of the Condition effect. Significant mediation was determined if the mediator was a significant predictor of the change score in the outcome variable.

Analysis of the Researcher's Findings

Group Differences

Driving History Questionnaire – There were no group differences on any of the behaviors or consequences assessed by the driving history questionnaire (See below), suggesting no significant effects on self-reported risky driving behaviors or negative driving consequences.

Table 2. Negative Driving Consequences

	TBI (n=25)	Control (n=25)	Total (n=50)	Group Difference
Accident	8 (32%)	10 (40%)	18 (36%)	N/A
Pulled over	11 (44%)	9 (36%)	20 (405)	N/A
Warning	5 (20%)	7 (28%)	12 (24%)	N/A
Fines	4 (16%)	7 (28%)	11 (22%)	N/A
Points	1 (4%)	1 (4%)	2 (4%)	N/A
Suspended	0 (0%)	0 (0%)	0 (0%)	N/A
Class hours	2 (8%)	0 (0%)	2 (4%)	N/A

Table 3. Risky driving behaviors

	TBI (n=25)	Control (n=25)	Total (n=50)	Group Difference
Driving without a seatbelt	5 (20%)	7 (28%)	12 (24%)	N/A
Expired tags	2 (8%)	1 (4%)	3 (6%)	N/A
Driving without a license	1 (4%)	1 (4.17%)	2 (4.08%)	N/A
Driving without insurance	0 (0%)	1 (4%)	1 (2%)	N/A
Illegal parking	7 (28%)	5 (20%)	12 (24%)	N/A
Making illegal turns	10 (40%)	9 (36%)	19 (38%)	N/A
Speeding	22 (88%)	22 (88%)	44 (88%)	N/A
Failure to stop	11 (44%)	9 (36%)	20 (40%)	N/A
Failure to yield	8 (32%)	3 (12%)	11 (22)	N/A
Tailgating	7 (28%)	9 (36%)	16 (32%)	N/A
Reckless driving	2 (8%)	4 (16%)	6 (12%)	N/A
Driving within 1 hour of drinking alcohol	1 (4%)	3 (12%)	4 (8%)	N/A
Driving within 1 hour of consuming a substance	0 (0%)	2 (8%)	2 (4%)	N/A

WAIS-PSI – Mean PSI score did not significantly differ between TBI (M=102.38, SD = 14.12) and control (M = 103.20, SD = 11.86) participants (t(47) = .22, p = .83).

DKEFS-Trails. No group differences were noted on any of the DKEFS-Trails scale scores (See Below).

Table 4. DKEFS-Trails scores

	TBI	Control	Group Difference
Visual Scanning	10.67 (2.41)	11.28 (1.97)	t(47) = .98, p = .33
Number Sequencing	10.63 (2.57)	11.32 (2.21)	t(47) = 1.02, p = .31
Letter Sequencing	11.63 (2.22)	11.52 (2.89)	t(47) = -.14, p = .89
Number Letter Switching	9.75 (2.75)	10.88 (1.60)	t(47) = 1.73, p = .09
Motor Speed	11.71 (1.43)	11.20 (2.36)	t(47) = -.91, p = .37
Number Letter Sequencing	11.83 (2.53)	12.20 (2.92)	t(47) = .47, p = .64

Useful Field of View Task – No statistically significant group differences were noted on any of the subscale scores (see below).

Table 5. Useful Field of View Task Scores

	TBI	Control	Group Differences
Processing Speed	22.50 (1.68)	21.72 (2.67)	t(45) = -1.18, p=.24
Divided Attention	23.14 (.64)	25.08 (7.20)	t(45) =1.26, p=.21
Selective Attention	36.27 (24.38)	35.12 (14.24)	t(45) =-.20, p=.84

Behavior Rating Inventory of Executive Functioning – Participants with TBI had significantly great scores, reflective of greater dysfunction, on parent-reported Behavioral Regulation, Metacognition, and GEC as well as self-reported Metacognition and GEC than non-injured controls (see below).

Table 6. Parent and Self-Reported BRIEF Scores.

	Parent-Report		
	TBI	Control	Group differences
Behavior Regulation	52.53 (12.65)	48.34 (6.10)	t(26) = -2.38, p .03
Metacognition	54.13 (12.64)	45.77 (8.04)	t(26) = -2.05, p .05
GEC	53.60 (13.32)	44.38 (7.76)	t(26) = -2.19, p .04
	Self-Report		
Behavioral Regulation	53.22 (10.00)	48.88 (9.45)	t(46) = -1.54, p .13
Metacognition	55.26 (10.91)	48.48 (9.77)	t(46) = -2.27, p .03
GEC	54.87 (10.48)	48.52 (9.85)	t(46) = -2.16, p .04

Driving Outcomes

See Table 7 for means and standard deviations as well as model results for all measured simulated driving outcomes. Of note, there was no significant effect of injury (TBI vs. Control) on any of the simulated driving outcomes. A significant main effect of distraction was noted for mean speed and standard deviation of lateral position. Adolescents had a greater mean speed during the conversation condition compared to the texting condition (t(186) = 3.46, p = .001). Additionally, adolescents demonstrated greater lane position variability during the texting condition than both the conversation condition (t(186) = 4.01, p<.0001) and no distraction condition (t(186) = 2.27, p = .02). There was no significant TBI by Distraction interaction on any outcome variable, suggesting that distraction influenced the performance of all individuals in a similar fashion regardless of injury history.

Table 7. Model Results for Simulated Driving Outcomes

Mean Speed

	Control	TBI	TBI effect	Distraction effect	TBI*Distraction
No Distraction	47.49 (4.15)	47.84 (5.23)	F(1,186) = .11, p = .74	**F (2,186) = 5.98, p = .003**	F(2,186) = 1.45, p= .24
Conversation	46.27 (4.50)	47.60 (6.72)			
Texting	46.21 (6.57)	46.05 (6.29)			

Max speed

	Control	TBI	TBI effect	Distraction effect	TBI*Distraction
No Distraction	56.79 (6.41)	59.00 (10.69)	F(1,186) = 1.27, p = .26	F(2,186) = 1.59, p = .21	F(2,186) = 1.55, p = .22
Conversation	54 (6.96)	58.84 (13.59)			
Texting	55.72 (6.57)	57.99 (11.36)			

SD Speed

	Control	TBI	TBI effect	Distraction effect	TBI*Distraction
No Distraction	4.07 (1.44)	5.04 (2.73)	F(1,186) = 2.35, p = .13	F(2,186) = 1.87, p= .16	F(2,186) = .14, p = .87
Conversation	4.16 (1.72)	5.28 (3.30)			
Texting	4.63 (2.08)	5.47 (2.73)			

SD lateral position

	Control	TBI	TBI effect	Distraction effect	TBI*Distraction
No Distraction	1.09 (.27)	1.17 (.42)	F(1,186) = 1.44, p = .23	**F(2,186) = 8.1, p = .0004**	F(2,186) = .24, p = .79
Conversation	1.01 (.24)	1.12 (.33)			
Texting	1.15 (.35)	1.29 (.47)			

Braking Reaction Time

	Control	TBI	TBI effect	Distraction effect	TBI*Distraction
No Distraction	1828.06 (2095.14)	1403.39 (1792.19)	F(1,65) = 2.07, p = .15	F(2,65) = 1.49, p = .23	F(2,65) = .44, p = .65
Conversation	2360.29 (2661.28)	1411.41 (886.18)			
Texting	1862.27 (1911.38)	1110.78 (554.72)			

Mediation analyses of group effects. The indirect (mediating) effects parent and self-reported BRIEF, DKEFS trail making task, Useful Field of View Task, and WASI-PSI were explored for all driving outcomes. No statistically significant findings were revealed suggesting that none of the selected variables mediated TBI vs Control group differences (Table 8).

Table 8. Results of Bootstrapping Analyses Examining the Mediating Effects of Proposed Mediators on TBI (TBI vs. Control) effects.

		Mean Speed			
No Distraction		*B*	*SE*	*BootLLCI*	*BootULCI*
	Self-Report GEC	0.36	0.62	-0.7	1.8
	Parent GEC	-0.21	0.31	-0.96	0.26
	DKEFS	0.02	0.26	-0.82	0.22
	UFOVPS	0.41	0.69	-0.27	2.31
	UFOVDA	-0.13	0.28	-0.7	0.47
	UFOVSA	0.03	0.39	-1.18	0.48
	WAIS-PSI	0.07	0.33	-0.47	1
Conversation		*B*	*SE*	*BootLLCI*	*BootULCI*
	Self-Report GEC	0.53	0.8	-0.86	2.33
	Parent GEC	0.45	1.34	-1.47	3.96
	DKEFS	0.02	0.38	-1.11	0.48
	UFOVPS	0.11	0.41	-0.35	1.31
	UFOVDA	-0.55	0.79	-1.96	1.16
	UFOVSA	0.15	0.82	-1.27	2.1
	WAIS-PSI	0.13	0.44	-0.77	1.13
Texting		*B*	*SE*	*BootLLCI*	*BootULCI*
	Self-Report GEC	-0.1	0.68	-1.45	1.39
	Parent GEC	-0.17	0.77	-1.84	1.33
	DKEFS	-0.01	0.33	-0.9	0.48
	UFOVPS	0.26	0.5	-0.24	1.62
	UFOVDA	-0.41	0.57	-1.57	0.65
	UFOVSA	0.01	0.47	-1.48	0.43
	WAIS-PSI	0.11	0.43	-0.81	1.03
		Maximum Speed			
No Distraction		*B*	*SE*	*BootLLCI*	*BootULCI*
	Self-Report GEC	0.62	1.19	-1.25	3.52
	Parent GEC	1.31	1.92	-1.37	6.11

	DKEFS	0.02	0.58	-1.89	0.45
	UFOVPS	0.27	0.74	-0.34	2.47
	UFOVDA	-0.96	0.76	-2.5	0.89
	UFOVSA	0.23	1.29	-2.63	2.73
	WAIS-PSI	0.34	0.79	-1.02	2.22
Conversation		*B*	*SE*	*BootLLCI*	*BootULCI*
	Self-Report GEC	1.34	1.52	-1.1	4.83
	Parent GEC	2.15	3.81	-1.33	13.22
	DKEFS	0.13	0.77	-2.13	1.27
	UFOVPS	-0.2	0.77	-1.57	1.54
	UFOVDA	-1.54	1.78	-4.76	2.15
	UFOVSA	0.42	2.13	-2.77	5.76
	WAIS-PSI	0.39	0.97	-1.63	2.52
Texting		*B*	*SE*	*BootLLCI*	*BootULCI*
	Self-Report GEC	0.42	1.14	-1.91	2.76
	Parent GEC	-0.24	1.2	-2.03	2.94
	DKEFS	-0.02	0.55	-1.61	0.68
	UFOVPS	0.28	0.58	-0.26	1.92
	UFOVDA	-0.92	1.05	-3.11	0.87
	UFOVSA	0.08	0.9	-2.81	0.94
	WAIS-PSI	0.05	0.62	-1.27	1.5
SD Speed					
No Distraction		*B*	*SE*	*BootLLCI*	*BootULCI*
	Self-Report GEC	0.1	0.29	-0.39	0.78
	Parent GEC	0.45	0.61	-0.45	1.94
	DKEFS	0.004	0.12	-0.38	0.12
	UFOVPS	-0.07	0.14	-0.29	0.3
	UFOVDA	-0.23	0.19	-0.6	0.25
	UFOVSA	0.07	0.35	-0.57	0.83
	WAIS-PSI	0.06	0.17	-0.23	0.47
Conversation		*B*	*SE*	*BootLLCI*	*BootULCI*
	Self-Report GEC	0.32	0.38	-0.31	1.22
	Parent GEC	1.1	1.2	-0.13	4.39
	DKEFS	0.03	0.17	-0.46	0.27
	UFOVPS	-0.1	0.21	-0.54	0.29
	UFOVDA	-0.44	0.39	-1.12	0.57
	UFOVSA	0.11	0.53	-0.58	1.5
	WAIS-PSI	0.16	0.3	-0.51	0.76
Texting		*B*	*SE*	*BootLLCI*	*BootULCI*

	Self-Report GEC	0.37	0.31	-0.22	1.05
	Parent GEC	0.23	0.52	-0.22	1.73
	DKEFS	0.04	0.17	-0.39	0.33
	UFOVPS	-0.001	0.1	-0.19	0.25
	UFOVDA	-0.37	0.32	-1.09	0.03
	UFOVSA	0.03	0.22	-0.62	0.32
	WAIS-PSI	0.05	0.19	-0.27	0.51
		SD Lateral Position			
No Distraction		*B*	*SE*	*BootLLCI*	*BootULCI*
	Self-Report GEC	0.08	0.06	-0.01	0.2
	Parent GEC	0.03	0.08	-0.11	0.21
	DKEFS	-0.01	0.02	-0.08	0.02
	UFOVPS	-0.01	0.02	-0.05	0.04
	UFOVDA	-0.001	0.01	-0.02	0.02
	UFOVSA	0.005	0.04	-0.1	0.05
	WAIS-PSI	0.004	0.02	-0.04	0.05
Conversation		*B*	*SE*	*BootLLCI*	*BootULCI*
	Self-Report GEC	0.04	0.04	-0.05	0.12
	Parent GEC	-0.003	0.07	-0.14	0.16
	DKEFS	0.001	0.02	-0.05	0.03
	UFOVPS	-0.02	0.03	-0.07	0.03
	UFOVDA	-0.01	0.02	-0.04	0.03
	UFOVSA	0.003	0.02	-0.06	0.04
	WAIS-PSI	0.001	0.02	-0.04	0.04
Texting		*B*	*SE*	*BootLLCI*	*BootULCI*
	Self-Report GEC	0.09	0.06	-0.01	0.23
	Parent GEC	0.04	0.11	-0.1	0.36
	DKEFS	-0.01	0.03	-0.1	0.03
	UFOVPS	-0.03	0.04	-0.12	0.03
	UFOVDA	0.007	0.01	-0.02	0.04
	UFOVSA	0.0005	0.03	-0.1	0.03
	WAIS-PSI	-0.004	0.03	-0.06	0.05
		Braking RT			
No Distraction		*B*	*SE*	*BootLLCI*	*BootULCI*
	Self-Report GEC	89.22	437.42	-911.14	877.65
	Parent GEC	-517.69	53.99	-1730.93	235.54
	DKEFS	14.85	166.14	-118.79	521.05
	UFOVPS	-394.25	473.69	-1597.2	176.98

	UFOVDA	182.84	222.19	-139.91	719.77
	UFOVSA	21.52	215.57	-440.93	436.42
	WAIS-PSI	-190.91	285.38	-896.38	264.48
Conversation		*B*	*SE*	*BootLLCI*	*BootULCI*
	Self-Report GEC	-199.8	729.49	-1750.98	1268.74
	Parent GEC	-1232.29	1901.02	-7481.07	868.03
	DKEFS	-81.95	344.95	-745.22	777.48
	UFOVPS	31.12	352.42	-387.49	974.39
	UFOVDA	540.08	493.78	-106.21	1778.33
	UFOVSA	-110.75	225.01	-498.15	402.16
	WAIS-PSI	-83.36	354.85	-866.03	619.85
Texting		*B*	*SE*	*BootLLCI*	*BootULCI*
	Self-Report GEC	-577.66	687.36	-2297.42	289.85
	Parent GEC	112.9	179.59	-184.68	526.76
	DKEFS	0.51	141.87	-86.61	446.38
	UFOVPS	-282.62	482.54	-1644.06	130.71
	UFOVDA	146.51	208.15	-28.44	696.49
	UFOVSA	-2.15	106.56	-199.24	213.04
	WAIS-PSI	51.6	233.33	-202.43	722.18

Note. BootLLCI = Lower bound of 95% confidence interval, BootULCI = Upperbound of 95% confidence interval.

Mediation of Distraction Condition Effect

The effect of condition on mean speed was mediated by UFOV selective attention, particularly during the conversation and texting conditions (see Table 9). Specifically, greater UFOV selective attention scores were associated with lower no distraction – conversation mean speed difference scores suggesting a greater increase in mean speed during conversation condition with increased selective attention scores. Additionally, greater UFOV selective attention scores were associated with increased conversation – texting mean speed difference scores suggesting that greater selective attention is associated with a greater decline in speed during the texting condition compared to the conversation condition.

The effect of condition on maximum speed was also mediated by UFOV selective attention (see Table 9). Greater UFOV selective attention was associated with a greater slowing during the texting condition compared to the no distraction condition and conversation condition, and a greater increase in max speed during the conversation condition compared to the no distraction condition.

The effect of condition on speed variability mediated by UFOV selective attention and WASI Processing Speed Index. Lower UFOV selective attention score was associated with greater increase in speed variability during the texting condition compared to the no distraction condition. The opposite was true for the conversation condition such that lower selective attention score was associated with similar or less change in variability during the conversation condition compared to the no distraction condition, and similar or greater variability during the conversation condition compared to the texting condition. Finally processing speed mediated the change in speed variability during the conversation condition compared to the no distraction condition such that greater processing speed was associated with similar or less variability during the conversation condition.

Table 9. Results of analyses examining the mediating effect of proposed mediators on distraction condition effects.

Mean Speed				
No distraction - Text	*B*	*SE*	*F*	*P*
SR_GEC	0.07	0.05	1.76	0.19
P_GEC	-0.03	0.08	0.12	0.73
DKEFS	-0.09	0.22	0.17	0.69
UFOVPS	0.23	0.24	0.86	0.36
UFOVDA	-0.11	0.09	1.36	0.25
UFOVSA	0.01	0.03	0.23	0.64
WASI-PSI	0.02	0.05	0.14	0.71
No Distraction - Conversation	*B*	*SE*	*F*	*P*
SR_GEC	-0.04	0.06	0.34	0.56

P_GEC	-0.13	0.12	1.27	0.28
DKEFS	0.02	0.25	0	0.95
UFOVPS	0.41	0.27	2.28	0.14
UFOVDA	-0.14	0.11	1.63	0.21
UFOVSA	**-0.09**	**0.03**	**10.59**	**0.003**
WASI-PSI	0.03	0.06	0.38	0.54
Conversation - Text	*B*	*SE*	*F*	*P*
SR_GEC	0.11	0.06	3.25	0.08
P_GEC	0.1	0.12	0.72	0.41
DKEFS	-0.11	0.25	0.18	0.67
UFOVPS	-0.19	0.28	0.44	0.51
UFOVDA	0.03	0.11	0.06	0.81
UFOVSA	**0.1**	**0.03**	**15.61**	**0.0004**
WASI-PSI	-0.02	0.06	0.08	0.78
Max Speed				
No distraction - Text	*B*	*SE*	*F*	*P*
SR_GEC	0.03	0.09	0.11	0.74
P_GEC	0.22	0.16	1.92	0.19
DKEFS	-0.11	0.36	0.09	0.77
UFOVPS	-0.03	0.41	0	0.95
UFOVDA	0.02	0.16	0.02	0.88
UFOVSA	**0.11**	**0.04**	**6.74**	**0.01**
WASI-PSI	-0.14	0.08	3.27	0.08
No Distraction - Conversation	*B*	*SE*	*F*	*P*
SR_GEC	-0.13	0.1	1.47	0.23
P_GEC	-0.13	0.21	0.41	0.53
DKEFS	0.34	0.41	0.66	0.42
UFOVPS	0.6	0.46	1.72	0.2
UFOVDA	-0.17	0.18	0.86	0.36
UFOVSA	**-0.14**	**0.05**	**9.46**	**0.004**
WASI-PSI	0.04	0.09	0.15	0.7
Conversation - Text	*B*	*SE*	*F*	*P*
SR_GEC	0.16	0.12	1.62	0.21
P_GEC	0.35	0.26	1.79	0.2
DKEFS	-0.44	0.48	0.84	0.37
UFOVPS	0.63	0.54	1.34	0.26
UFOVDA	0.19	0.21	0.81	0.37
UFOVSA	**0.25**	**0.04**	**32.36**	**<.0001**
WASI-PSI	-0.18	0.11	2.81	0.1
Standard Deviation of Speed				
No distraction - Text	*B*	*SE*	*F*	*P*
SR_GEC	-0.03	0.03	1.16	0.29

P_GEC	0.06	0.06	1.08	0.31
DKEFS	0.1	0.1	0.92	0.34
UFOVPS	-0.1	0.12	0.73	0.4
UFOVDA	-0.05	0.04	1.41	0.24
UFOVSA	**0.03**	**0.01**	**5.17**	**0.03**
WASI-PSI	-0.005	0.02	0.04	0.83
No Distraction - Conversation	*B*	*SE*	*F*	*P*
SR_GEC	-0.03	0.03	1.1	0.3
P_GEC	-0.07	0.05	1.76	0.2
DKEFS	0.06	0.1	0.4	0.53
UFOVPS	0.04	0.11	0.12	0.73
UFOVDA	-0.07	0.04	2.89	0.1
UFOVSA	**-0.03**	**0.01**	**6.77**	**0.01**
WASI-PSI	**0.05**	**0.02**	**5.1**	**0.03**
Conversation - Text	*B*	*SE*	*F*	*P*
SR_GEC	-0.001	0.03	0	0.97
P_GEC	0.13	0.07	3.37	0.09
DKEFS	0.03	0.13	0.07	0.79
UFOVPS	-0.14	0.15	0.87	0.36
UFOVDA	0.02	0.06	0.12	0.74
UFOVSA	**0.06**	**0.01**	**18.44**	**0.0001**
WASI-PSI	-0.05	0.03	3.51	0.07
Standard Deviation of Lane Position				
No distraction - Text	*B*	*SE*	*F*	*P*
SR_GEC	-0.001	0.006	0.1	0.76
P_GEC	-0.0006	0.007	0.01	0.94
DKEFS	-0.009	0.02	0.18	0.67
UFOVPS	0.02	0.03	0.44	0.51
UFOVDA	0.004	0.01	0.15	0.7
UFOVSA	0.003	0.003	1.12	0.3
WASI-PSI	-0.002	0.005	0.18	0.68
No Distraction - Conversation	*B*	*SE*	*F*	*P*
SR_GEC	0.001	0.004	1.9	0.18
P_GEC	0.003	0.006	0.26	0.61
DKEFS	0.02	0.02	1.12	0.3
UFOVPS	0.01	0.02	0.21	0.65
UFOVDA	-0.003	0.008	0.14	0.71
UFOVSA	0.001	0.002	0.23	0.64
WASI-PSI	0.001	0.004	0.03	0.87
Conversation - Text	*B*	*SE*	*F*	*P*

	SR_GEC	-0.008	0.006	1.43	0.24
	P_GEC	-0.004	0.01	0.15	0.71
	DKEFS	-0.03	0.02	1.29	0.26
	UFOVPS	0.008	0.03	0.07	0.79
	UFOVDA	0.007	0.01	0.37	0.55
	UFOVSA	0.002	0.003	0.35	0.56
	WASI-PSI	-0.003	0.006	0.24	0.63
Braking Reaction Time					
No distraction - Text		*B*	*SE*	*F*	*P*
	SR_GEC	68.69	41.71	2.71	0.12
	P_GEC	-30.61	41	0.56	0.48
	DKEFS	-97.3	215.75	0.2	0.66
	UFOVPS	109.9	196.8	0.31	0.59
	UFOVDA	-25.8	61.63	0.17	0.68
	UFOVSA	2.72	18.52	0.02	0.89
	WASI-PSI	35.67	41.16	0.75	0.4
No Distraction - Conversation		*B*	*SE*	*F*	*P*
	SR_GEC	-2.77	48.24	0	0.96
	P_GEC	98.06	56.85	2.98	0.15
	DKEFS	16.23	151.98	0.01	0.92
	UFOVPS	-176.27	178.07	0.98	0.34
	UFOVDA	11.47	43.67	0.07	0.8
	UFOVSA	12.76	13.46	0.9	0.36
	WASI-PSI	-30.5	27.35	1.24	0.28
Conversation - Text		*B*	*SE*	*F*	*P*
	SR_GEC	23.51	77.16	0.09	0.77
	P_GEC	-139.69	71.84	3.78	0.09
	DKEFS	-216.7	237.86	0.83	0.38
	UFOVPS	227.81	218.23	1.09	0.31
	UFOVDA	-32.79	70.41	0.22	0.65
	UFOVSA	-5.33	20.69	0.07	0.8
	WASI-PSI	52.34	37.26	1.97	0.18

Months of Driving as a Moderator

To examine if months of driving experience moderated injury group or distraction condition effects, models discussed above were rerun to include the injury group by months of driving experience interaction and distraction condition by months of driving experience interaction. Months of driving experience did not moderate the effects on any of the driving outcomes.

Conclusions

No injury group differences were noted on the driving behavior questionnaire, suggesting no injury related differences on self-reported risky driving behaviors or negative driving consequences. Future studies may benefit from collecting official driving records to examine these factors in a less biased way. The TBI group had greater executive dysfunction than the non-injured control group as noted by greater difficulties with behavioral regulation, metacognitive skills, and global executive functioning as reported on the parent-report BRIEF. Adolescents also reported greater difficulties with metacognitive skills and global executive functioning as reported on the self-report BRIEF. No other group differences were noted on any of the selected measures of executive functioning.

No significant injury group differences were noted on any of the simulated driving outcomes, suggesting that in general, individuals with a history of TBI perform similarly to those with no history of TBI. Significant distraction effects were noted on select driving outcomes such that a greater mean speed was noted during the conversation condition compared to the texting condition, and greater lane position variability (poorer vehicle control) was noted during the texting condition compared to the no distraction and conversation condition. No significant TBI by distraction condition interaction was noted on any of the simulated driving outcomes suggesting that distraction influenced the performance of all individuals similarly regardless of injury history.

None of the identified executive functioning variables significantly mediated the effect of injury group on simulated driving outcomes. Selective attention, as measured by the useful field of view task, mediated condition effects. Interestingly, greater selective attention was associated with greater slowing (mean speed and maximum speed) and greater speed variability during the texting condition, while lower levels of selective attention were associated with fewer changes in driving outcomes during the texting condition. May suggest that those with lower levels of selective attention may not recognize the potential effects of texting related distraction, and thus may not adjust their driving behavior in response to the distraction appropriately. In contrast, lower levels of selective attention were associated with greater no distraction – conversation difference scores suggesting that lower levels of selective attention was associated with greater slowing (mean speed and maximum speed) and lower levels of speed variability during the conversation condition compared to the control condition. This may reflect that those with greater selective attention skills are better able to manage the cognitive distraction of a cell phone conversation, while those with poorer selective attention may demonstrate greater impact of this type of cell phone related distraction. Finally, months of driving experience did not moderate the effect of injury group or distraction condition on simulated driving outcomes.

While the lack of significant findings are surprising, especially the lack of TBI-related deficits, it may be related to the selected sample. The sample studied was exclusively adolescents and young adults. Future research would benefit from including older drivers with and without a history of pediatric TBI, to explore how the driving performance of these adolescents/young adults compared to more experienced adult drivers, and whether TBI-related deficits emerge over time. One potential hypothesis may be that while driving performance of uninjured individuals improves with time/experience, those with a history of moderate to severe TBI may fail to achieve these gains/improvements.

Recommendations

We continue to analyze data from this study. In the coming months, we will continue to explore mediating and moderating variables, and their influence on driving performance. While there were no specific TBI-related deficits noted in the present study, selective attention, a potential area of impairment following TBI, was noted to be a contributing factor to speed control during distraction conditions. Continued monitoring of executive functioning, including attention, following moderate to severe TBI to identify potential developing issues, and intervene early to prevent/treat potential areas of impairment.

Further, distraction related deficits included a decline in vehicle control (increased variability in lane position) during the texting condition compared to the no distraction and conversation condition among all participants regardless of injury history. These findings, together with previous findings strongly support distracted driving laws limited/restricting the use of cell phones while driving. This is especially true for texting while driving, or any form of distraction that involves cognitive, visual, and manual distraction (such as reading/responding to emails). However, impairment in speed monitoring/control was noted in during the conversation condition for those with lower levels of selective attention. All participants utilized a hands free head set for this condition, suggesting that it is more than just handling/looking at the phone that results in driving related impairment, but for a subgroup of individuals, simply being engaged in a conversation can provide a cognitive distraction enough to impair speed regulation. Finally, mediation analyses revealed that those with lower levels of selective attention may be more prone to distraction-related deficits, particularly related to speed regulation. While we support laws regulating/restricted distracted driving for all drivers, additional education regarding the role of attention and its relation to additional impairment may also be helpful in helping drivers understand the mechanism of distraction-related impairment.

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