PILOT DATA ON THE BEHAVIOR RATING INVENTORY OF EXECUTIVE FUNCTION (BRIEF) AND PERFORMANCE MEASURES OF EXECUTIVE FUNCTION IN PEDIATRIC TRAUMATIC BRAIN INJURY (TBI)

By

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Executive dysfunction has been reported in several studies of pediatric traumatic brain injury (TBI). Research using the Behavior Rating Inventory of Executive Function (BRIEF) in pediatric TBI has focused on cases of severe TBI evaluated several years post-injury, and little is known about the relationship between the BRIEF and traditional tests of executive function. Furthermore, previous studies did not explore individual BRIEF scales and instead used global composite scores from the BRIEF. The current study presents pilot data examining ratings of individual scales of the BRIEF and performance on traditional tests of executive functioning for an acute pediatric TBI sample with a range of severity. These data are compared to an orthopedic control group within the first year of recovery.

CHAPTER 1
INTRODUCTION

Traumatic brain injury (TBI) occurs when the brain is injured as the result of an external mechanical force (Loring, 1999). Injuries can be sustained in a variety of ways, such as a direct blow, acceleration-deceleration movements of the brain within the skull cavity, or from the penetration of the brain via an external object. Primary causes of TBI are motor vehicle accidents, falls, and interpersonal violence. Measurements of severity of injury include the Glasgow Coma Scale's (GSC) rating of eye, motor and verbal responsiveness (Teasdale and Jennett, 1974) and other behavioral, physiological and radiological evidence in addition to GSC ratings, such as abnormal MRI or CT findings, loss of consciousness duration, and post-traumatic amnesia.

Yeates (2000) summarizes a number of neuropathological and pathophysiological changes that occur following TBI. Primary injuries, i.e. injuries that result directly from the trauma itself, consist of contusions, skull fractures, and mechanical injuries to blood vessels and nerve fibers. Secondary injuries include brain swelling, increased intracranial pressure, epidural and subdural hematomas, and seizures. Neurochemical changes consist of the excessive production of free radicals, disruption of cellular calcium homeostatis, and the excessive release of excitatory neurotransmitters.

The National Center for Injury Prevention and Control, Center for Disease Control and Prevention (CDC) reports that approximately 1.5 million people sustain a traumatic brain injury (TBI) each year in the United States. The CDC reports that this estimate is 8 times greater than the number of individuals diagnosed with breast cancer and 34 times greater than the number of new cases of HIV/AIDS. Furthermore, the CDC estimates that the number of people who experience long-term disability associated with a TBI ranges from 80,000 to 90,000 (CDC, 2003).

TBI leads to an estimated 3,000 deaths, 29,000 hospitalizations and 400,000 emergency room visits each year for children under the age of 14 (Langlois and Gotsch, 2001). Kraus (1995) estimated that the average annual incidence of closed head injury is 180 per 100,000 children in children less than 15 years of age. With regards to TBI severity, Yeates (2000) highlighted data provided by the National Pediatric Trauma Registry and the United States National Coma Data Bank. Information from these sources suggests that 76% to 85% of all TBIs are mild in nature, with the remaining cases of TBI being evenly distributed between moderate and severe TBI.

In children and adolescents, traumatic brain injuries can produce dysfunction across a number of domains, including alertness and orientation, intellectual functioning, language skills, nonverbal skills, attention, memory, executive functions, motor skills, academic achievement, behavioral and emotional adjustment (Yeates, 2000). Executive function has become an area of study within the TBI literature in recent years. Executive function research has not been as heavily published in the TBI literature as some cognitive domains, such as memory and attention. Yeates (2000) explains that this may be in part due to the complex and multifaceted nature of the construct. However, despite the challenges of studying executive function, several research groups have pursued the study of executive functions in children with TBI.

What exactly are “executive functions”? The construct of executive function encompasses a heterogeneous sample of behaviors. Baron (2004) summarizes a range of definitions for executive function that have been put forth by various researchers. One definition explains executive function as an ability that helps one to maintain an appropriate mental set in order to achieve a future goal. Another explanation describes executive functions as the mechanisms used in order to optimize performance in situations requiring the simultaneous operation of several different cognitive processes. Other definitions of executive function include the following abilities: flexible thought and action, planning and sequential processing of complex behaviors, simultaneously attendance to multiple sources of information, resistance to distracting and interfering stimuli from the environment, the ability to sustain certain behaviors over prolonged periods, and the inhibition of inappropriate behaviors.

Baron (2004) provides an encompassing list of sample subdomains implicated in executive function. These include set shifting, problem solving, abstract reasoning, planning, organization, goal setting, working memory, inhibition, mental flexibility, initiation, attentional control, and behavioral regulation. Typical measures of executive function used in neuropsychological research include the Wisconsin Card Sorting Task, Trail Making Test, various motor sequencing tasks (e.g., Go-No Go), Stroop Color and Word Test, Booklet Category Test, n-back tasks, and verbal fluency.

Baron (2004) highlights research by Stuss and Benson (1986), who suggest that executive functions are higher cognitive functions that serve to integrate other more basic cognitive functions, such as memory, attention, and perception. Stuss and Benson list among these higher functions the ability to set goals, anticipate, plan, monitor results, and incorporate feedback. They also outline that the prefrontal cortex and interconnected regions serves as the neuroanatomical substrates for executive function.

Given that the domains encompassed by the construct of executive function are implicated in a variety of day-to-day tasks, it is clear that executive dysfunction could cause a number of problems in everyday life. A few examples of executive function in daily life include the following: being able to hold a goal in mind and perform a series of actions to reach that goal, having the ability to inhibit inappropriate behavior so that one does not offend another person during personal interactions, and adequately being able to switch one's attention among several tasks as necessary. With diminished executive function, one would struggle to adequately complete academic and occupational tasks as well as appropriately maintain interpersonal relationships.

Researchers have evaluated the development of executive function skills in children. Two examples of such research include Welsh and colleagues (1991) and Levin and colleagues (1991). Welsh, Pennington, and Grossier (1991) examined children's performance on a variety of executive function measures. Participants were 100 children ages 3 to 12 years of age. Test measures consisted of verbal fluency, motor sequencing, visual search, the Wisconsin Card Sorting Task, the Tower of Hanoi, and Matching Familiar Figures Test. The authors found that adult-level performance was achieved at three different ages within development. Children were able to perform the visual search and Tower of Hanoi 3-disc task at adult levels by age 6. By age 10, adult-level performance was displayed for the Matching Familiar Figures Test and the Wisconsin Card Sorting Test. Adult-levels performance was reached for the TOH 4-disc, verbal fluency and motor sequencing by adolescence.

Levin et al. (1991) evaluated 52 normal children ages 7 to 15 years using a wide range of executive function measures. The testing battery consisted of the Wisconsin

Card Sorting Test, California Verbal Learning-Children's Version, Word Fluency, Animal Naming, Design Fluency, the Twenty Questions task, the Go-No Go task, the Tower of London, and Delayed Alternation. Children were divided into three groups by ages, 7- to 8-year-olds, 9- to 12-year-olds, and 13- to 15-year olds, in order to determine developmental change across the measures. With the exception of one test (Delayed Alternation), developmental changes were found on all of the measures. Large gains were found for various Wisconsin Card Sorting Test measures between the 7- to 8- and 9- to 12-year-old groups. At this developmental shift, concept formation (measures by the number of categories obtained) and problem-solving efficiency increased. In contrast, the percentage of perseverative errors decreased with age. A developmental difference was also found between the 7- to 8-year-olds and the 9- to 12-year-olds for false positive errors on the Go-No Go Task. Further improvements in performance were demonstrated up through ages 13 to 15 years for the California Verbal Learning Test, Twenty Questions, and the Tower of London.

Research on executive function has extended into clinical populations, with investigators utilizing a number of assessment measures with which to characterize various neurological and psychiatric populations. Several research groups have examined executive function in pediatric TBI. Studies in TBI have used neuropsychological performance-based measures, behavioral reports completed by an adult rater (e.g., parent), or a combination of these two types of assessment methods.

With regards to performance-based measures of executive function, Levin et al. (1994) evaluated the Tower of London task performance in children with traumatic brain injury. The Tower of London involves planning skills since the task requires the participant to rearrange beads on three vertical rods to match a model. Task complexity is determined by the minimum number of moves necessary to solve the problem. The examiner reminds the child of the rules if he or she breaks a rule, such as picking up more than one bead at a time. The authors found that children who had suffered a severe TBI tended to break the rules despite reminders from the examiner. This tendency for rule breaking was particularly notable in children between the ages of 6 and 10 at the time of the assessment. Levin and colleagues also found that the initial planning time on the Tower of London decreased with age and was prolonged in children who had sustained a severe TBI. Such results suggest that task efficiency improved with age and was inversely related to greater injury severity.

Levin et al. (1997) assessed performance in a pediatric TBI sample ages 5 to 18 for three performance measures of executive function. The Twenty Questions Test, the Tower of London, and the Wisconsin Card Sorting Test (WCST) were given to 151 children who sustained a head injury of varying severity approximately 3 years earlier and 89 control subjects. The authors also examined a subset of this population involved in a longitudinal study involving assessments at 3 and 36 months post-injury. In the cross-sectional study, Levin et al. (1997) found that the severity of head injury adversely affected performance on all three executive function tests. The severe TBI group showed more inefficient strategies on the Twenty Questions Test, asking more questions than either the mild TBI or control groups and asking questions that were less efficient in allowing them to generate a correct answer. For the WCST, the severe TBI patients had the lowest percent of conceptual responses and attained the fewest categories relative to controls. Compared to both the mild TBI and control groups, the severe TBI group displayed the highest percent of perseverative errors. On the Tower of London, the severe TBI group solved a lower percentage of problems within three trials and had a greater number of broken rules than the mild TBI and control groups. Within the severe TBI group, young children who sustained a severe head injury had greater impairment for solving the Tower of London relative to older severe TBI children. The young severe TBI children demonstrated an increased tendency to break rules, and they also had more difficulty solving Tower of London problems that were more complex. In the longitudinal study, all three executive function measures showed improved performance over three years, although there was a ceiling effect for the Tower of London. This improvement over time was larger for children who had sustained a severe head injury.

Slomine et al. (2002) evaluated executive function performance in 68 children ages 7 to 15 with moderate to severe TBI 1 year post-injury as part of a structural neuroimaging study. The authors used the WCST, the Tower of Hanoi, and the letter fluency test. Children who had sustained a TBI at a younger age displayed more perseverative errors on the WCST and worse performance on the letter fluency test. Slomine and colleagues (2002) concluded that the risk for impairment on measures of executive function is increased for children injured at a younger age.

Levin et al. (2002) assessed working memory differences in 44 normal controls, 54 mild pediatric TBI, and 26 severe TBI cases several years post-injury utilizing two different n-back working memory paradigms. The first paradigm was a letter identification (semantic) task in which subjects had to identify whether a specific target letter, e.g., “X,” had been presented a certain number of trials back from the current letter presentation. The second paradigm was a phonological working memory paradigm for which subjects had to identify whether a particular letter that rhymes with a particular target, e.g., “C” for the letter “Z,” had been presented a certain number of trials back from the current rhyme. Both paradigms had varying memory load (ranging from 0 to 3 letters or rhymes back from the current presentation item). The correct detection of targets as well as false alarms were measured for each task. Levin et al. (2002) found that memory load and age significantly affect the detection of targets and false alarms in both tasks. The identification of targets increased with age at testing across all memory load conditions. Performance worsened for all subjects as memory load increased, with the number of false alarms increasing and the number of targets detected decreasing with increased load. TBI severity interacted with memory load for false alarms on the rhyme task. The severe TBI group had more false alarms than either the mild TBI patients or normal children on the 0-back condition. Mild TBI patients displayed more false alarms than controls on the 0-back condition. For the 2-back condition, the severe TBI group displayed more false alarms than the mild TBI group. The authors also found that the rhyme condition was more difficult than the letter identification task. The authors concluded that TBI often results in impaired working memory and diminished inhibition in children.

Behavioral report of executive function has begun to be used in more recent years as a measure of executive in the everyday environment. Most studies involving behavioral report of executive function in pediatric TBI have utilized the Behavior Rating Inventory of Executive Function (BRIEF; Gioia, Isquith, Guy, and Kenworthy, 2000). The BRIEF is a relatively new instrument designed to assess executive function behaviors in the home and school environment for children ages 5 to 18. Parent, teacher, and self-report scales are available. The authors designed the instrument to be used with children having a wide range neurological, psychiatric, developmental, and medical conditions in order to assess executive dysfunction in a more ecologically valid way. The Parent Form of the BRIEF contains 86 items that have been divided into eight theoretically and empirically derived clinical scales that are purported to measure different aspects of executive functioning: Inhibit, Shift, Emotional Control, Initiate, Working Memory, Plan/Organize, Organization of Materials, and Monitor. Exploratory factor analysis for the Parent Form produced two Composite Index scores. The Initiate, Working Memory, Plan/Organize, Organization of Materials, and Monitor scales were determined to make up the first Composite Index (labeled Metacognitive Index by the authors), and the second Composite Index (labeled Behavioral Regulation Index) is comprised of the Inhibit, Shift, and Emotional Control scales. A Global Composite Index is also provided by the BRIEF and consists of the total score across all of the clinical scales. Figure 1 outlines the scales that comprise the BRIEF.

Clinical Scales	**Composite Indices**	
Inhibit Shift Emotional Control	Behavioral Regulation Index	Global Composite Index
Initiate Working Memory Plan/Organize Organization of Materials Monitor	Metacognitive Index	

Figure 1. BRIEF scales

The authors of the BRIEF provided preliminary information in the BRIEF manual for the pediatric TBI population. They compared parent ratings of the eight BRIEF scales across four groups of children consisting of 33 children with mild/moderate TBI, 34 children with severe TBI, 35 orthopedic controls, and 35 normal controls (Gioia et al., 2000). The severe TBI group had significantly worse scores on the Inhibit, Shift, Emotional Control, Initiate, Working Memory and Plan/Organize scales as compared to healthy controls, suggesting global executive dysfunction. The authors reported that children with severe TBI also had significantly worse scores on the Working Memory scale in comparison to children in the mild/moderate TBI group and orthopedic controls.

Gioia, Isquith, Kenworthy, and Barton (2002) evaluated the individual BRIEF scales for groups of moderate and severe TBI children and normal controls within a larger study examining profiles of everyday executive function across a variety of acquired and developmental disorders. The authors used BRIEF data provided by Mangeot, Armstrong, Colvin, Yeates, and Taylor (2002), and the sample included 33 moderate TBI, 34 severe TBI, and 208 children from the BRIEF normative sample. Gioia et al. (2002) found that the severe TBI children were rated as having more executive dysfunction than controls for the Inhibit, Shift, Initiate, Working Memory and Plan/Organize scales. Severe and moderate TBI were not significantly different from one another on any of the scales, and the moderate TBI group was not significantly different than the control group for any of the scales. It should be noted that for the Severe TBI sample, the mean T-scores for Working Memory and Plan/Organize were in a borderline clinical range (63.5 and 62.0, respectively), with fairly large standard deviations. This finding suggests that a subset of the children surpassed the clinical cutoff designated for the BRIEF scales (T-score $\geq$ 65).

Studies involving executive function in pediatric TBI have also examined a combination of performance and behavioral report measures in order to assess the relationship between behavioral ratings and neuropsychological performance measures of executive function. Proctor, Wilson, Sanchez, and Wesley (2000) studied the correlation between executive function and working memory for eight adolescents with closed head injury and eight controls. Executive functioning was measured using a respondent report known as the Profile of Executive Functioning (Pro-Ex), and working memory was assessed with a recognition task. When all subject data was grouped together, a positive linear correlation was found for the Pro-Ex and the recognition task. Severity of injury influenced test performance for both the Pro-Ex and the recognition measure, with a significant group effect found for the recognition measure. The authors concluded that a relationship can exist between a measure of daily executive functioning and working memory performance, and they emphasize the clinical importance of assessing executive functions within a TBI population.

Mangeot et al. (2002) examined executive functioning in moderate and severe TBI using the BRIEF as a measure of everyday executive functioning within the context of a study examining family functioning and adaptive behavior following TBI. The research sample consisted of 33 severe TBI, 31 moderate TBI, and 34 orthopedic controls who were evaluated approximately five years post-injury. The TBI sample in this study was the same one used by Gioia et al. (2002) to examine the various clinical scales of the BRIEF. Mangeot and colleagues (2002) compared the BRIEF's two Composite Index

Scores (the Behavioral Regulation Index and Metacognitive Index) and its Global Executive Composite to several performance-based measures of executive functioning, including Consonant Trigrams, the Rey-Osterriech Complex Figure, Word Fluency, Contingency Naming, and the Underlining test. They found that while the 3 BRIEF Index scores were correlated with the Consonant Trigrams test, none of the three BRIEF Index scores correlated with any of the other performance measures of executive function. The authors also found that the largest deficits in parent-reported executive functions existed in the severe TBI group. The authors suggested that the BRIEF and performance measures of executive function possibly measure different aspects of the executive function construct. The authors implied that the BRIEF scales may have more ecological validity and therefore may be measuring constructs within the domain of executive function differently than performance measures.

Vriezen and Pigott (2002) examined executive functioning in 48 moderate to severe TBI cases that were, on average, two-and-a-half years post injury. The used the BRIEF as a measure of everyday executive functioning and compared the BRIEF's two Composite Index Scores (the Behavioral Regulation Index and Metacognitive Index) and its Global Executive Composite to several performance-based measures of executive functioning, including the Wisconsin Card Sort Test, the Trail Making Test and verbal fluency. They found that none of the three BRIEF scores correlated with any of the three objective measures of executive function. Vriezen and Pigott noted that while the means on the BRIEF and performance measures of executive functioning fell within the average range for the TBI sample, there was wide variability in the types of scores that were obtained. They also pointed out that 29 - 35% of the various BRIEF indices were within a clinical range with ratings greater than 1.5 standard deviations from the mean. Approximately 9 – 21% of the objective measures yielded scores that were greater than 1.5 standard deviations from the mean. Vriezen and Pigott suggested that while there was a lack of statistical significance with their study in terms of the correlational relationships between the BRIEF Indices and performance-based executive function measures, their study demonstrates that a subset of the TBI population has difficulties within the clinically significant range with regards to of executive functioning.

Rationale for the Current Study

Thus far, there are no studies of post-injury BRIEF ratings at an acute timepoint within the pediatric TBI population. Vriezen and Pigott (2002) examined a TBI sample that was two-and-a-half years post-injury. The TBI cohort studied by Gioia et al. (2002) and Mangeot et al. (2002) was five years from injury.

Second, while the BRIEF manual publishes preliminary results with regards to the performance of mild/moderate TBI cases in comparison to severe TBI years after injury, to my knowledge no peer-reviewed studies have reported on BRIEF ratings in a mild TBI sample for a timepoint closer to their actual injury. Furthermore, methodological information supplied for the raw data published in the BRIEF manual suggests that the mild/moderate group used may have been more severe than a typical mild TBI classification. Abnormal radiological (e.g., CT scan) or neurological findings or a loss of consciousness greater than fifteen minutes were allowed in the mild/moderate group, and this type of criteria is not typical for the mild TBI population.

Third, although some studies have begun to explore the relationship between the BRIEF scales and particular performance measures of executive dysfunction, such studies have focused primarily on the two Composite Index scores from the BRIEF and the Global Executive Composite score rather than the individual BRIEF clinical scales. Mangeot et al. (2002) and Vriezen and Pigott (2002) found few significant relationships between the BRIEF Index scores and performance measures of executive function for their pediatric TBI samples. The literature on the construct of executive function suggests that there are a wide range of specific behaviors and approaches to problem-solving that need to occur to successfully complete various tasks of executive function. Therefore, it may be more appropriate to compare particular scales of interest within the BRIEF Indices. Gioia et al. (2002) found impairments across several of the BRIEF individual clinical scales for their severe TBI sample. Using the clinical scales may also increase the specificity and help us comprehend more thoroughly the relationship between parental report of suboptimal executive functioning in the home and community environment and those performance behaviors seen within the confines of neuropsychological testing.

Finally, no literature on the BRIEF and TBI has attempted to look at parent reports of pre-injury functioning in comparison to current functioning in pediatric TBI or the rate of behavioral change that occurs acutely following TBI. This information is particularly relevant from a clinical standpoint, since clinical referral is often based on reported changes in behavior resulting from the injury. Yeates (2000) emphasized the need to control for premorbid status in studies of behavioral adjustment with the pediatric TBI population, particularly for children with mild TBI. Asarnow and colleagues (Asarnow et al., 1995; Light et al., 1998) showed that children with mild head injuries display higher rates of pre-injury behavior problems on the Child Behavior Checklist (Achenbach, 1991) than children with no injury. However, when compared to children with injuries that did not involve the head, the mild head injury children did not show differences in terms of pre-injury behavior. While head injuries increase the risk for behavioral problems, behavioral disturbances may also likely increase the risk of head injury. There are certain methodological issues with trying to obtain pre-injury ratings at a timepoint following injury, such as potential response bias and differences in report of pre-injury symptoms based on time since injury. Despite such limitations, it was believed that the clinical relevance of evaluating changes in behavioral ratings was important to explore within the TBI population.

Aims and Hypotheses

The current study was designed to examine several dimensions of executive functioning within mild and moderate/severe pediatric TBI samples as compared to an orthopedic control population. The first aim was to examine children's post-injury behavior in terms of everyday executive functioning. Post-injury BRIEF data as completed by the child's parent was used to gauge this level of functioning. Differences between the mild and moderate/severe TBI population and orthopedic controls were evaluated for five specific BRIEF scales (Inhibit, Shift, Initiate, Working Memory and Plan/Organize). Hypotheses regarding this first aim were that group differences would be present for the five BRIEF scales. Hypothesis 1 predicted that the moderate/severe TBI group would be rated as having more problems, i.e. higher ratings of frequency for problems, than either the mild TBI group or the orthopedic controls across all BRIEF scales. Hypothesis 2 predicted that the mild TBI group would be rated as exhibiting more problems than the orthopedic controls.

The second aim was to examine children's post-injury behavior in terms of performance measures of executive functioning. The Test of Everyday Attention for

Children (TEA-Ch; Manly et al., 1999), Trail Making Test A and B (Reitan, 1979), Stroop Color and Word Test (Golden, 1978), and the computerized Wisconsin Card Sort Test-64 (WCST; Heaton et al., 1993) were used to assess executive functioning performance. Differences between the mild and moderate/severe TBI population and orthopedic controls were evaluated for five specific measures from these instruments (TEA-Ch Creature Counting and Opposite Worlds subtests, Trails B, Stroop Interference, and WCST Perseverations). Hypotheses regarding this second aim were that group differences would be present for the five performance measures. Hypothesis 3 predicted that the moderate/severe TBI group would demonstrate greater executive dysfunction than either the mild TBI group or the orthopedic controls on all five measures. Hypothesis 4 predicted that the mild TBI group would exhibit more executive dysfunction than the orthopedic control sample for these measures.

The third aim for the current study was to examine the relationship between children's post-injury behavior as measured by the five BRIEF scales and performance measures of executive functioning. Inconsistent results have been found in the previous literature in regards to the relationship between performance measures of executive function and behavioral rating scales. Proctor et al. (2000) had found significant correlations between a working memory test and the Pro-Ex. In contrast, Mangeot et al. (2002) and Vriezen and Pigott (2002) found few correlations between performance measures and the BRIEF, finding that only the Consonant Trigrams test had a relationship with the BRIEF for this clinical population. However, both of the BRIEF studies used the Index scores provided by the BRIEF rather than the individual scales. Therefore, the current study set out to examine the relationship between select BRIEF scales and performance measures of executive function. Since higher T-scores for the performance measures indicate better performance and higher T-scores on the BRIEF suggest more impairment, Hypothesis 5 consisted of the following: 1) correlations between paired BRIEF scales should positive, 2) correlations between paired performance measures of executive function should be positive, and 3) correlations between a BRIEF scale paired with a performance measure should be negative.

The final aim for the current study was to examine changes in children's behavior in terms of everyday executive functioning from prior to the child's injury to the current timepoint. Retrospective "pre-injury" and current "post-injury" BRIEF ratings were completed by the child's parent in order to gauge the change in everyday executive functioning. Differences in ratings for pre- and post-injury behavior were examined for the mild and moderate/severe TBI population and orthopedic controls using the five specific BRIEF scales. Hypotheses regarding this last aim were that group differences would be present for the five BRIEF scales. Hypothesis 6 predicted that the moderate/severe TBI group would be rated as having greater changes in executive function than either the mild TBI group or the orthopedic controls. Hypothesis 7 predicted that the mild TBI group would be rated as exhibiting more changes in executive function than the orthopedic control group.

CHAPTER 2
METHODS

This study was approved by the University of Florida Institutional Review Board (IRB Project Number 649-2001). Informed consent was obtained from all participants' parents or legal guardians, and informed assent was obtained from all pediatric participants prior to inclusion in the study.

Subjects

Thirty-five participants were obtained via referral from the Pediatric Intensive Care Unit, the Emergency Department, and the Pediatric Orthopedics Clinic at Shands Hospital at the University of Florida and by self-referral from the community. Children between the ages of 6 to 17 years of age were invited to participate in the study. All participants were medically stable at the time of the evaluation.

TBI participants were classified by injury severity based on several criteria, including length of loss of consciousness immediately following the injury, post-traumatic amnesia duration, whether they had CT/MRI abnormalities resulting from their injuries, and Glasgow Coma Scale (GSC) scores from their hospital admission. The GCS (Teasdale & Jennett, 1974) is a measure frequently used in the TBI literature to classify injury severity. Individuals who have sustained a head injury are rated for the following: verbal responsiveness, motor responsiveness, and eye opening. Scores range from 3 to 15, with lower scores indicating more severe levels of injury. Table 1 outlines how participants in the current study were classified in terms of their head injury. Only 3 children assessed for this study were classified as having a TBI "moderate" in severity.

Given the small sample size of the group and the fact that the TBI literature often includes moderate TBI cases with severe TBI cases when examining deficits as compared to controls, the three moderate TBI cases from the general TBI sample were included with the Severe TBI group for the purposes of analyses. Based on the outlined injury criteria, 9 subjects were classified as Mild TBI, 18 as Moderate/Severe TBI, and 8 subjects were in the Orthopedic Control group.

Table 1. TBI classification

	Mild	**Moderate**	**Severe**
Glasgow Coma Scale (admission)	13 - 15	9 - 12	< 8
Loss of Consciousness	< 1 hour	1 - 24 hours	> 24 hours
Post Traumatic Amnesia	< 24 hours	1 - 7 days	> 7 days
CT/MRI scan abnormalities	No	Yes	Yes

Table 2 presents the demographic characteristics of the sample. Sixty-six percent of the total sample was male, and the gender breakdown was similar to that typically seen in the TBI literature. The Moderate/Severe TBI group had a higher proportion of female subjects than that seen in the other two subject groups. Approximately 77% of the participants were Caucasian, 17% were African American, 3% were Hispanic and 3% did not provide additional information in order to determine specific race information (e.g., "other"). Eighty percent of the children were right-handed, although this figure may be higher since handedness information was not provided for two subjects. Four of the participants had a history of Attention Deficit Hyperactivity Disorder (ADHD) prior to their injuries. One case of premorbid ADHD was in the Mild TBI group, two were in the moderate/Severe group, and one was in the Orthopedic Control group. Mechanism of injury included falls, motor vehicle accidents, sports injuries, and assault. The three groups did not differ significantly in terms of time since injury, regardless of whether they had a TBI or an orthopedic injury, $F(2, 32) = 2.32$, $p = .11$. The TBI groups and the Orthopedic Control group also did not differ in terms of age at assessment, $F(2, 32) = 0.64$, $p = .54$. The three groups did differ in terms of Full Scale IQ, $F(2, 26) = 3.69$, $p = .04$. Tukey's honestly significance difference (HSD) tests revealed that the Full Scale IQ for the Moderate/Severe TBI group was significantly lower than the Orthopedic Control group, $p = .03$. Yeates (2000) describes that intelligence scores reflecting nonverbal skills (e.g., Performance IQ scores) are particularly vulnerable following head injury, particularly because they often require speeded motor output and fluid problem-solving. In contrast, Verbal IQ assesses previously acquired knowledge and requires few speeded responses. Therefore, Verbal IQ was analyzed in order to assess whether there were any premorbid IQ differences between the three groups. The three groups did not differ in terms of Verbal IQ, $F(2, 26) = 2.40$, $p = .11$.

Table 2. Demographic information

	Mild TBI	**Mod/Severe TBI**	**Orthopedic Controls**
# Subjects	9	18	8
Sex (M:F)	8:1	9:9	6:2
Age at assessment (years)	11.94 (3.74)	13.60 (3.83)	13.64 (3.99)
Time since injury (weeks)	33.71 (23.17)	35.20 (19.84)	16.77 (19.95)
Full Scale IQ	101.50 (6.63)	94.87 (11.75)	108.50 (13.76)
Verbal IQ	101.50 (9.79)	96.00 (16.76)	111.38 (17.97)

Procedures

Parent-Reported Executive Function

Behavior Rating Inventory of Executive Function (BRIEF). Parent-reported executive function was measured using the Behavior Rating Inventory of Executive Function (BRIEF; Gioia et al., 2000). The BRIEF is an 86-item questionnaire completed by parents or teachers of school age children to assess executive functions in the home and school environments. The respondent rates each item's frequency of occurrence as either occurring "Never," "Sometimes," or "Often," and a number value from 1 to 3, respectively, is assigned to the frequency endorsed. Each of the 86 individual BRIEF items are assigned (via factor analysis) to one of eight empirically derived scales that measure the following aspects of executive functioning: Inhibit, Shift, Emotional Control, Initiate, Working Memory, Plan/Organize, Organization of Materials, and Monitor. Ratings within each scale are summed and the total raw score is transformed into an age- and gender-corrected T-score relative to the published normative data. Higher T-scores indicate more executive dysfunction, and a T-score ≥ 65 is considered clinically significant. The BRIEF also yields a Global Executive Composite score as well as two Composite Index scores (the Behavioral Regulation Index and the Metacognition Index). The Behavioral Regulation Index consists of the Inhibit, Shift and Emotional Control scales, and the Metacognitive Index consists of the Initiate, Working Memory, Plan/Organize, Organization of Materials, and Monitor scales. The internal consistency (i.e., the degree to which the items in a single construct are measuring the same construct) ranged from .82 to .98 for the parent form when used with a heterogeneous clinical sample and from .80 to .97 when used to evaluate the normative sample. Test-retest reliability for the parent form ranged from .72 to .84 for a clinical sample and from .76 to .88 for the normative sample.

For the current study, parents completed two BRIEFs at the time of the assessment. One BRIEF was completed to serve as an estimate of pre-injury functioning (i.e., retrospective rating) and one was completed to assess current behavior. The T-scores for five clinical scales (Inhibit, Shift, Initiate, Working Memory, and Plan/Organize) were used as the measures of parent-reported executive functioning for the current study.

Performance Measures of Executive Function

Several traditional performance-based measures of executive functioning were given to the children participating in this study. The measures are each described in more detail below and consist of the following: Creature Counting and Opposite Worlds from the Test of Everyday Attention for Children (TEA-Ch; Manly et al. 1999), Trail Making Test A and B (Reitan, 1979), Stroop Color and Word Test (Golden, 1978), and the computerized Wisconsin Card Sort Test-64 (WCST; Heaton et al., 1993). These tests have been widely used to assess executive dysfunction in a variety of patient populations, including TBI (e.g., Levin et al., 1997, Vriezen and Pigott, 2002).

TEA-Ch Creature Counting. The Creature Counting subtest assesses the ability to switch back and forth between strategies (Manly et al., 1999). For the Creature Counting task, children were asked to complete several trials during which they count creatures along a path. At various points within the path, arrows are present that prompt the child to change the direction in which they are counting (e.g., “1, 2, 3” versus “3, 2, 1”). Time to complete the counting of the creatures and counting accuracy are scored for this test. The average time for accurately completed trials provides a timing score for which an age- and gender-corrected scaled score was obtained using normative data from the TEA-Ch manual. The timing score was the measure of interest for the current study.

TEA-Ch Opposite Worlds. The Opposite Worlds subtest evaluates the ability to suppress an automatic or prepotent verbal response (Manly et al. 1999). During the precursor Same World trial of the test, children were to name along a path consisting of tiles numbered '1' and '2'. They were to say '1' when they saw the number '1' and '2' when they saw the number '2'. In contrast, during the Opposite World trials of the task, as children named along the path, they were to say '1' when they saw the number '2' and '2' when they saw the number '1'. Two trials of Same World and two trials of Opposite World were completed. The measure of interest for this study was the age- and gender-corrected scaled score obtained from the TEA-Ch manual for the total time that it took children to complete the Opposite World portion of the task.

Trail Making Test. The Trail Making Test evaluates attention, visual scanning, information processing, and switching/executive skills (Reitan, 1979). Trail A measures the speed with which individuals are able to draw a line connecting consecutive numbers. Trail B requires individuals to alternate between connecting consecutive numbers and letters. Children in the current study were given the non-adult version of the Trail Making Test. This version is similar to the adult version with the exception that there are fewer items to complete. While the time to complete each Trail and the number of errors committed as subjects completed the tasks were collected, only the time to complete Trails B was used for the current study. Data acquired was converted to standardized z-scores using normative data provided by several studies (Reitan, 1971; Klonoff and Low, 1974; Knights, 1966).

Stroop Color and Word Test. The Stroop measures the ability to inhibit a particular response set and the ability to maintain a particular response set while inhibiting another (Golden, 1978). The first trial of the task required the subject to read vertical columns of color words (e.g., "RED") typed in black ink as quickly as possible. The second trial required the subject to scan vertically columns of X's typed in a certain color of ink (e.g., "XXXXX" in red ink) and state in what color the X's were typed. For the third trial, subjects were asked to read vertical columns of color words, but instead of saying the typed word, subjects were to tell the examiner in what color of ink the word was typed. Words for this trial were typed in a color of ink incongruent to that of the actual word (e.g., the word "RED" typed in blue ink). Each of the trials was allotted 45 seconds for completion. If a subject made an error on any of the three trials, they were prompted to correct themselves before continuing to the next item. The three trials provided raw scores for word reading, color naming, and color-word reading, respectively. An interference score was calculated in order to compare the subject's actual rate during the color-word reading trial to a predicted rate of color-word reading that would be expected given the subject's performance during the word reading and color-naming trials. Raw scores for the trials were converted to T-scores using the normative data provided by Golden (1978). The interference T-score was the primary measure of interest for the current study.

Wisconsin Card Sorting Test (WCST). The WCST assesses the ability to apply, maintain and shift appropriate problem-solving strategies across changing conditions in order to reach a future goal (Heaton et al, 1993). The computerized version of the WCST-64 consists of four stimulus cards and 64 response cards that display figures of varying colors (red, green, yellow or blue), forms (triangles, stars, crosses or circles) and numbers (one, two, three or four figures). Subjects were asked to match each response card to one of the four stimulus cards in the way he or she thought that the response card should match. The subject was told whether the match was correct or incorrect but was not told the sorting principle. Once the subject performed ten consecutive correct matches, the sorting principle changed without warning. The subject was then supposed to use feedback from the examiner to develop a new sorting strategy. The WCST moves through a number of set shifts among the three sorting principles (Color, Form and Number) until all 64 response cards have been used or until six sorting categories (two for each of the above) have been completed. While several scoring dimensions are produced by the test (e.g., trials to complete first category, learning to learn, categories completed), the T-score for perseverative responses during the task was the primary measure used for the current project.

Analyses

All analyses were done using the Standard Version of SPSS 11.0.1 for Windows (SPSS, Inc. 2001). Since the normative data provided for all of the measures used in this study with the exception of the Stroop Color and Word test allows for both gender and age-correction, gender was not used a covariate for any of the statistical analyses. IQ was not used as a covariate given the previously stated rationale for evaluating Verbal IQ in lieu of Full Scale IQ. Analyses for this study were the following and are designated by the hypothesis for which they are being performed:

Hypotheses 1 and 2. In order to examine group differences at post-injury for the parent report measure of executive functions, one-way ANOVAs were done for the five BRIEF scales of interest. Group (Mild TBI, Moderate/Severe TBI, Orthopedic Control) was the independent variable and the post-injury ratings for the five BRIEF scales (Inhibit, Shift, Initiate, Working Memory, Plan/Organize) were the dependent variables for the one-way ANOVAs. All scores used were age- and gender-corrected T-scores based on the normative data provided by the BRIEF manual (Gioia et al, 2000), with higher T-scores on the five BRIEF scales suggestive of greater impairment. Planned post-hoc analyses for the ANOVAs that showed a significant effect for Group consisted of Tukey's (HSD) tests.

Hypotheses 3 and 4. One-way ANOVAs were done to examine group differences for the performance measures of executive function. Group remained the independent variable for the one-way ANOVAs and the five dependent variables for this set of analyses were the TEA-Ch Creature Counting (Timing scaled score), TEA-Ch Opposite Worlds (Time scaled score), Trails B (standard score for time to complete), Stroop Interference (T-score), and WCST Perseverations (T-score). Prior to data analysis, all performance measures' scores were converted to T-scores in order to examine the data in a common metric. In contrast to the BRIEF scales, higher T-scores on the five performance measures of executive function indicated better performance. Planned post-hoc analyses consisted of Tukey's HSD tests for the ANOVAs that showed a significant effect for Group.

Hypothesis 5. Evaluation of the relationship between the different types of executive function measures was done by performing one-tailed Pearson correlations on the BRIEF scales and the performance measures. One-tailed correlations were chosen since it was hypothesized a priori that the relationships between measures should go in a particular direction. It was hypothesized that correlations between two BRIEF scales should positive, correlations between two performance measures of executive function should be positive, and correlations between a BRIEF scale paired with a performance measures should be negative since while higher scores on the performance measures indicate better performance, higher scores on the BRIEF suggest more impairment. Two sets of the Pearson one-tailed correlations were performed. One set of correlations was performed in order to examine the relationships between tests for the two types of measures within the entire study sample. The second set of correlations was done exclusively with the TBI participants in order to determine if there were differences in how the test variables were related to one another as the result of being part of a clinical population with suspected neuropsychological deficits. Due to the number of variables examined in relation to the size of the study sample, a conservative level of significance ($p < .01$) was selected to determine significant correlations.

Hypotheses 6 and 7. In order to assess changes in BRIEF rating from before the injury to the current post-injury time point, repeated-measures ANOVAs were performed for each set of pre- and post- injury BRIEF scale (e.g., pre-Inhibit and post-Inhibit score) for all subjects who had pre-and post-injury ratings. Group served as the independent variable and Time (pre-injury versus post-injury ratings for the five BRIEF scales) was the dependent variable for this set of analyses. Difference scores were calculated for the five BRIEF scales by subtracting the pre-injury rating T- score from the post-injury rating T-score. One-way ANOVAs were then performed using the difference scores for the BRIEF scales that had shown a Group x Time Interaction. Group served as the independent variable and the BRIEF scales' difference scores served as the dependent variables. Planned post-hoc analyses consisted of Tukey's HSD tests for the ANOVAs that showed a significant effect for Group.

CHAPTER 3
RESULTS

Post-Injury BRIEF Measures (Hypotheses 1 and 2)

Tables 3 and 4 and Figure 2 display the one-way ANOVA results examining post-injury group differences for the five BRIEF scales of interest. The Working Memory BRIEF scale demonstrated significant group differences, $F(2, 26) = 3.49$, $p < .05$. Planned post-hoc Tukey tests did not reveal specific group differences (Mild vs. Moderate/Severe TBI ($p = .13$), Mild TBI vs. Orthopedic controls ($p = .94$), and Moderate/Severe vs. Orthopedic controls ($p = .07$). The other four BRIEF scales, Inhibit, Shift, Initiate, and Plan/Organize, did not show significant group differences: Inhibit $F(2, 26) = .53$, $p = .60$; Shift $F(2, 26) = .56$, $p = .58$; Initiate $F(2, 26) = .65$, $p = .53$; Plan/Organize $F(2, 26) = .40$, $p = .67$.

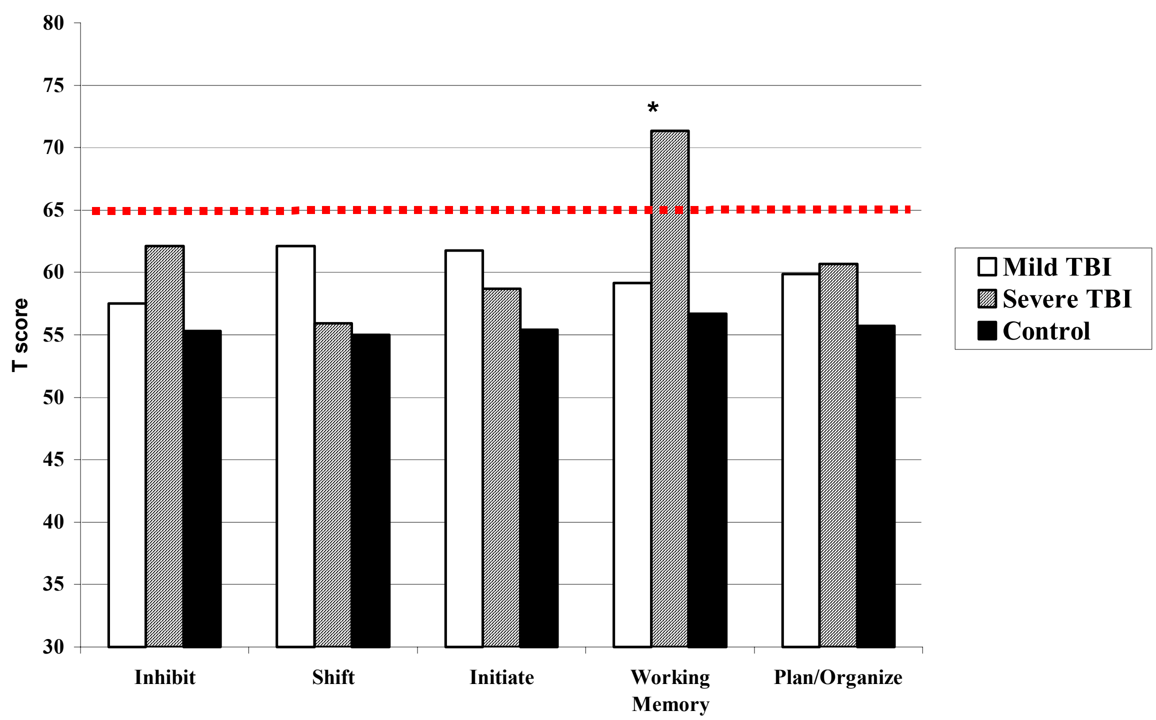
Table 3. Mean T scores for the 5 BRIEF scales

	Mild TBI	**Mod/Severe TBI**	**Orthopedic Control**	**Significance level**
Inhibit	57.50 (16.72)	62.14 (15.84)	55.29 (12.72)	.60
Shift	62.13 (16.85)	55.93 (13.29)	55.00 (15.74)	.58
Initiate	61.75 (11.55)	58.71 (9.58)	55.43 (11.97)	.53
Working Memory	59.13 (12.85)	71.36 (14.43)	56.71 (13.15)	.05*
Plan/Organize	59.88 (12.86)	60.71 (11.01)	55.71 (13.93)	.67

Note: Standard deviation data is provided in ( )
* = p <.05

Table 4. Effect sizes for BRIEF scales post-injury

	Mild vs. Mod/Severe TBI	**Mild TBI vs. Orthopedic Control**	**Mod/Severe TBI vs. Orthopedic Control**
Inhibit	.28	.15	.48
Shift	.41	.44	.06
Initiate	.29	.54	.31
Working Memory	1.05	.18	1.07
Plan/Organize	.07	.31	.40



Note: The dotted line displays mean group performance 1.5 SD above the mean.
* = p <.05

Figure 2. Mean T scores for the 5 BRIEF scales

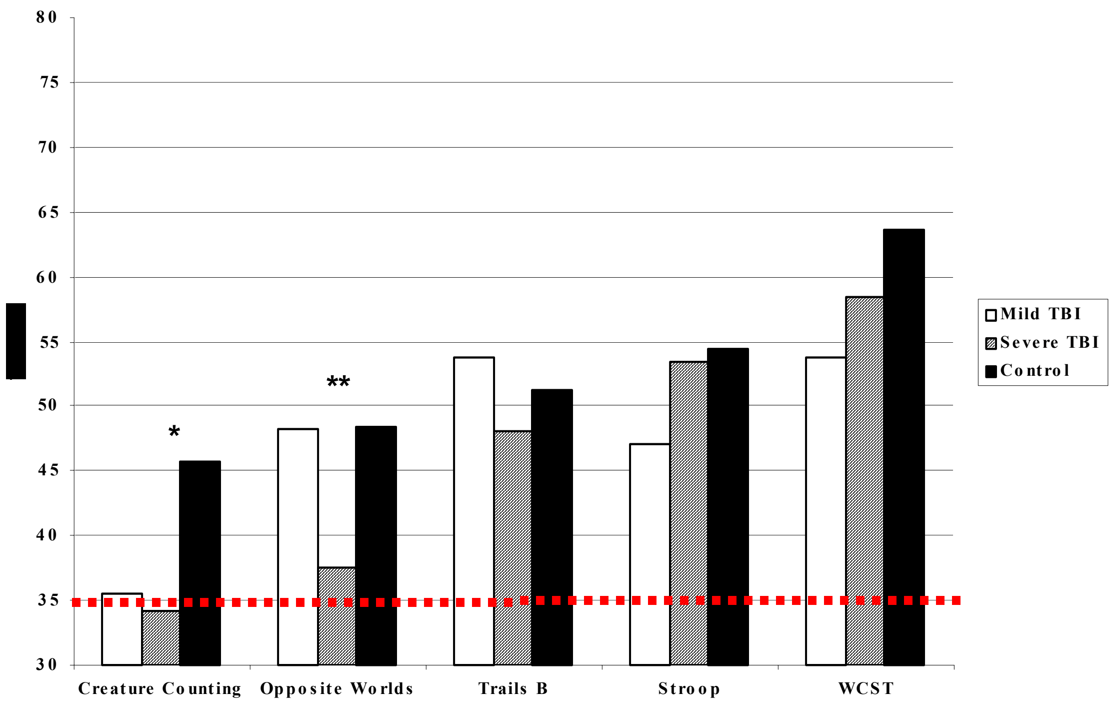
Performance Measures of Executive Function (Hypotheses 3 and 4)

Table 5 and Figure 3 display the one-way ANOVA results examining group difference on the five performance measures of executive function, and Table 6 shows effect sizes for each group and performance measure. In sum, the TEA-Ch Creature Counting test demonstrated a significant group difference, $F(2, 30) = 4.44$, $p = .02$. Planned post-hoc Tukey tests revealed that the group differences were significant between the Moderate/Severe TBI and Orthopedic Control groups, $p = .02$. The TEA-Ch Opposite Worlds test demonstrated a significant group difference, $F(2, 32) = 7.00$, $p < .01$. Group differences were significant between the Moderate/Severe TBI and Orthopedic Control groups, $p = .01$, as well as between the Moderate/Severe TBI and Mild TBI groups, $p = .01$. There were no significant group differences for Trails B, Stroop Interference and the WCST Perseveration scores.

Table 5. Mean T scores for the 5 performance measures of executive function

	Mild TBI	**Mod/Severe TBI**	**Orthopedic Control**	**Significance level**
Creature Counting	38.52 (9.15)	34.12 (9.47)	45.71 (5.35)	.02*
Opposite Worlds	48.15 (4.12)	37.59 (10.40)	48.33 (6.42)	.01**
Trails B	53.71 (6.59)	48.03 (6.84)	51.19 (9.17)	.22
Stroop Interference	47.00 (8.90)	53.43 (6.38)	54.38 (6.97)	.09
WCST Perseverations	53.75 (17.29)	58.50 (14.92)	63.63 (19.27)	.51

Note: Standard deviation data is provided in ( )
* $= p < .05$
** $= p < .01$



Note: The dotted line displays mean group performance 1.5 SD below the mean.
* $= p < .05$
** $= p < .01$

Figure 3. T scores for the 5 performance measures of executive function

Table 6. Effect sizes for performance measures of executive function

	Mild vs. Mod/Severe TBI	**Mild TBI vs. Orthopedic Control**	**Mod/Severe TBI vs. Orthopedic Control**
Creature Counting	.47	1.00	1.60
Opposite Worlds	1.45	.04	1.27
Trails B	.85	.32	.40
Stroop Interference	.83	.93	.15
WCST Perseverations	.29	.54	.30

Correlations between BRIEF Scales and Executive Function Performance Measures (Hypothesis 5)

Tables 7 and 8 provide the results of the correlational analyses between the various executive function measures.

BRIEF Scales—BRIEF Scales

All of the BRIEF scales were correlated with one another when all of the study participants were included in the correlation matrix, $p < .01$. Similarly, all of the BRIEF scales with the exception of Working Memory – Shift were correlated with one another, $p < .01$, when only the TBI study participants were included in the correlation matrix.

BRIEF Scales—Neuropsychological Measures

None of the BRIEF scales were correlated with the performance measures of executive function at the significance level set for the study. However, if a less conservative yet acceptable significance level was used ($p < .05$), the correlation between the TEA-Ch Opposite Worlds and BRIEF Inhibit scores would be considered significant when evaluating all study participants. However, the WCST Perseverations score would also be considered significantly correlated with the BRIEF Working Memory and BRIEF Plan/Organize scores when examining only the TBI study participants, with the direction of the relationships suggesting that higher (i.e., worse) BRIEF scores are actually positively correlated with better scores (i.e., less perseverations) on the WCST.

Neuropsychological Measures—Neuropsychological Measures

Only the TEA-Ch Creature Counting and the TEA-Ch Opposite Worlds tests were significantly correlated. This was the case when all subjects were used as well as when only the TBI subjects were examined ($p < .001$, $p < .01$, respectively). The TEA-Ch results were unsurprising given that the two tests comprise the Attentional

Control/Switching domain for the TEA-Ch. None of the other five performance measures were correlated with one another at the conservative significance level set for this study. However, it should be noted that Trails B and Creature Counting demonstrated a correlation when evaluating all study participants as well as just the TBI subjects using a less stringent significance criteria of $p < .05$. Similarly, the WCST Perseverations and the TEA-Ch Creature Counting scores were correlated when evaluating the TBI subjects alone.

Table 7. Correlations between BRIEF scale scores and performance measures of executive function for all study participants

	BRIEF Inhibit	BRIEF Shift	BRIEF Initiate	BRIEF Working Memory	BRIEF Plan/ Organize	TEA-Ch Creature Counting	TEA-Ch Opposite Worlds	Trails B Time	Stroop Interference
BRIEF Shift	.650** <.001								
BRIEF Initiate	.589** <.001	.716** <.001							
BRIEF Working Memory	.593** <.001	.484** <.01	.583** <.001						
BRIEF Plan/Organize	.602** <.001	.651** <.001	.833** <.001	.739** <.001					
TEA-Ch Creature Counting	-.062 .379	.047 .408	-.135 .205	.023 .454	-.012 .477				
TEA-Ch Opposite Worlds	-.373* .023	-.143 .229	-.256 .090	-.283 .069	-.266 .081	.600** .000			
Trails B Time	-.087 .327	.027 .445	-.044 .410	-.195 .155	-.158 .207	.415* .013	.227 .110		
Stroop Interference	.063 .375	.140 .239	.016 .468	.178 .183	.228 .121	.152 .215	.057 .382	.000 .499	
WCST Perseverations	.001 .498	-.065 .376	.102 .310	.211 .150	.257 .103	.311 .057	.098 .310	.003 .494	.283 .072

Note: * = $p < .05$ ** = $p < .01$

Table 8. Correlations between BRIEF scale scores and performance measures of executive function for TBI participants

	BRIEF Inhibit	BRIEF Shift	BRIEF Initiate	BRIEF Working Memory	BRIEF Plan/ Organize	TEA-Ch Creature Counting	TEA-Ch Opposite Worlds	Trails B Time	Stroop Interference
BRIEF Shift	.652** <.001								
BRIEF Initiate	.527** <.01	.640** <.01							
BRIEF Working Memory	.522** <.01	.417* <.05	.501** <.01						
BRIEF Plan/Organize	.525** <.01	.620** <.01	.821** <.001	.700** <.001					
TEA-Ch Creature Counting	.031 .447	.239 .148	.059 .400	.234 .153	.212 .178				
TEA-Ch Opposite Worlds	-.294 .092	-.045 .422	-.114 .307	-.161 .237	-.136 .273	.518** <.01			
Trails B Time	-.087 .349	.107 .317	.031 .446	-.198 .188	-.072 .376	.397* <.05	.332 .067		
Stroop Interference	.163 .239	.182 .215	.074 .375	.345 .063	.291 .100	.129 .284	-.085 .354	.169 .226	
WCST Perseverations	.078 .376	.009 .485	.199 .206	.461* .023	.384* .05	.407* <.05	.112 .319	-.006 .489	.215 .181

Note: * $= p < .05$ ** $= p < .01$

Differences in BRIEF Ratings for Pre- and Post-Injury (Hypothesis 6 and 7)

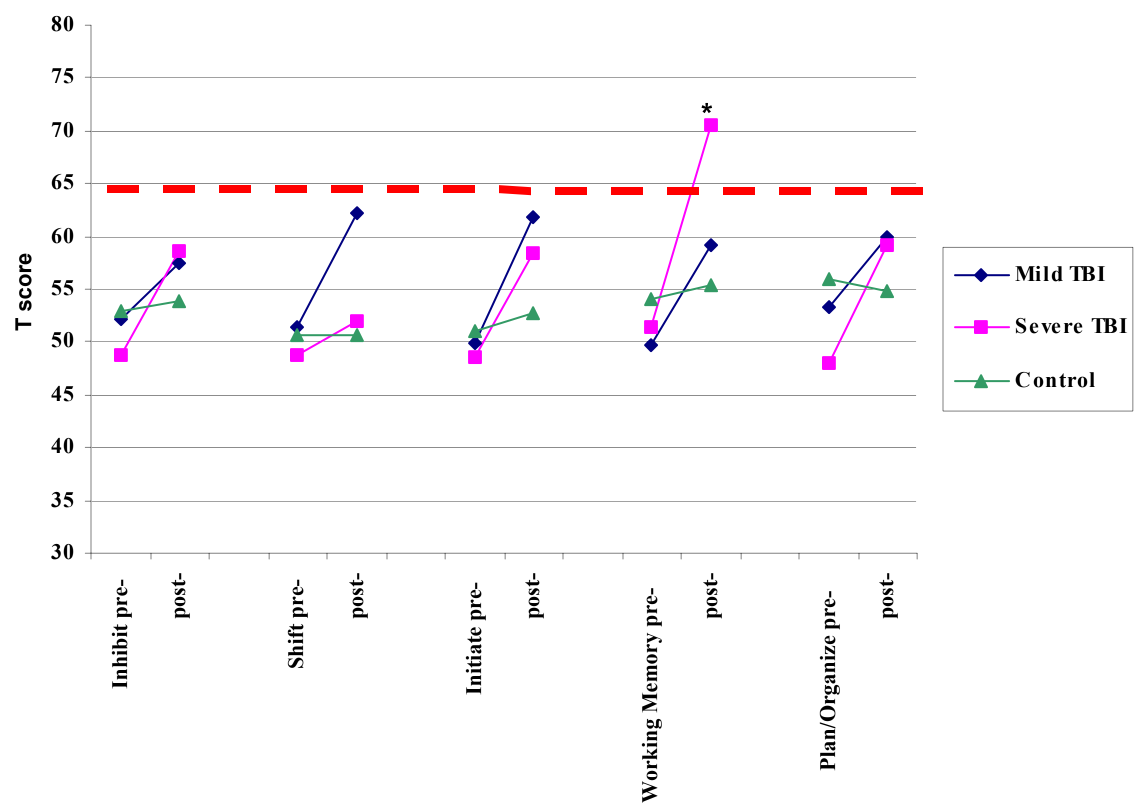
Table 9 and Figure 4 display data from the repeated-measures ANOVAs examining differences in BRIEF scale scores from the pre-injury and post-injury BRIEF ratings. For the Inhibit scale, there was a main effect for Time (i.e. pre- to post-BRIEF scores), $F(1, 22) = 6.07$, $p < .05$. There was no Group x Time interaction, $F(2, 22) = 1.47$, $p = .25$. The Shift scale also showed a main effect for Time, $F(1, 22) = 5.46$, $p < .05$, but there was no Group x Time interaction, $F(2, 22) = 2.42$, $p = .11$. The Initiate scale showed a main effect for Time, $F(1, 22) = 14.79$, $p < .01$, with no Group x Time interaction, $F(2, 22) = 2.02$, $p = .16$. The Working Memory scale showed a main effect for Time, $F(1, 22) = 13.25$, $p < .01$, and there was a Group x Time interaction for the Working Memory scale, $F(2, 22) = 3.66$, $p < .05$. Lastly, the Plan/Organize scale showed a main effect for Time, $F(1, 22) = 8.02$, $p = .01$, and the Group x Time interaction showed marginal significance, $F(2, 22) = 3.27$, $p = .057$.

Table 9. Group x time differences in pre- and post-injury T scores for the 5 BRIEF scales

	Mild TBI	Mod/Severe TBI	Orthopedic Control	Significance level
Inhibit				
Pre:	52.25 (12.01)	48.82 (12.35)	53.00 (13.51)	.25
Post:	57.50 (16.72)	58.55 (15.50)	53.83 (13.29)	
Shift				
Pre:	51.38 (11.11)	48.82 (10.38)	50.67 (10.67)	.11
Post:	62.13 (16.85)	52.00 (11.06)	50.67 (11.81)	
Initiate				
Pre:	49.88 (12.19)	48.64 (5.37)	51.00 (12.13)	.16
Post:	61.75 (11.55)	58.45 (10.53)	52.67 (10.39)	
Working Memory				
Pre:	49.63 (12.92)	51.36 (11.34)	54.00 (13.97)	.04*
Post:	59.13 (12.85)	70.55 (16.16)	55.33 (13.84)	
Plan/Organize				
Pre:	53.25 (16.25)	48.00 (8.76)	56.00 (18.04)	.06
Post:	59.88 (12.86)	59.09 (11.87)	54.83 (15.04)	

Note: Mean (SD) data from repeated-measures ANOVAs

* = $p < .05$



Note: The dotted line displays executive dysfunction reported 1.5 SD above the mean.
* = $p < .05$
** = $p < .01$

Figure 4. Group x time differences pre- to post-injury for the 5 BRIEF scales

Table 10 displays data regarding differences in BRIEF scale scores between the pre-injury and post-injury BRIEF ratings. In order to perform post-hoc analyses, difference scores for the BRIEF (post-injury BRIEF score minus pre-injury BRIEF score) had been calculated for the five BRIEF scales of interest. As mentioned before, the Working Memory scale from the BRIEF showed a significant difference in terms of pre-to post-injury ratings for the three injury groups, $F(2, 22) = 3.66$, $p < .05$. Planned post-hoc Tukey's HSD tests that the Working Memory scale differences were significant between the Moderate/Severe TBI and Orthopedic Control groups, $p < .05$, but not between the Mild TBI and either the Moderate/Severe TBI or Orthopedic Control groups. Group differences for the Plan/Organize BRIEF scale ratings from pre- to post-injury showed marginally significant differences, $F(2, 22) = 3.27$, $p = .057$. Planned post-hoc Tukey's HSD tests revealed that the Plan/Organize scale differences were significant between the Moderate/Severe TBI and Orthopedic Control groups, $p < .05$, but not between the Mild TBI and either the Moderate/Severe TBI or Orthopedic Control groups. Since there were no significant group differences for the BRIEF Inhibit, Shift and Initiate scales, no post-hoc analyses were done for these three scales.

Table 10. Pre- and post-injury T score differences for the 5 BRIEF scales

	Mild TBI	**Mod/Severe TBI**	**Orthopedic Control**	**Significance level**
Inhibit	5.25 (8.33)	9.73 (13.68)	0.83 (1.33)	.25
Shift	10.75 (13.02)	3.18 (7.12)	0.00 (8.37)	.11
Initiate	11.88 (11.46)	9.82 (9.51)	1.67 (7.74)	.16
Working Memory	9.50 (15.54)	19.18 (14.82)	1.33 (2.16)	.04*
Plan/Organize	6.63 (10.68)	11.09 (10.44)	-1.17 (3.92)	.06

Note: Mean (SD) data
* = p <.05

CHAPTER 4
DISCUSSION

The current study attempted to examine both everyday executive functioning and neuropsychological performance measures of executive functioning in an acute pediatric TBI population that ranged in severity. Findings from the study suggest that in terms of BRIEF post-injury ratings, Moderate/Severe TBI children are reported to have greater dysfunction than either Mild TBI or Orthopedic Control children in terms of Working Memory functioning in their day-to-day environment. The Moderate/Severe TBI group also had significantly greater differences in ratings of behavior from pre-injury to post-injury on the BRIEF Working Memory and Plan/Organize scales than either the Mild TBI or Orthopedic Control groups.

For the performance measures of executive function, the two TEA-Ch subtests were the only neuropsychological tests that displayed significant differences between the three subject groups. The Moderate/Severe TBI group performed significantly worse than the Orthopedic Control group for the TEA-Ch Creature Counting test, and the Moderate/Severe TBI group performed significantly worse than both the Mild TBI and Orthopedic Control groups on the TEA-Ch Opposite Worlds test.

Few findings resulted from the correlations between the BRIEF scales and performance measures of executive function. The various BRIEF scales were correlated with one another. For the comparisons between neuropsychological measures, Trails B and Creature Counting demonstrated a correlation when evaluating all study participants as well as just the TBI subjects using a less stringent significance criteria ($p < .05$), and the WCST Perseverations and TEA-Ch Creature Counting scores were correlated when evaluating the TBI subjects alone using this same significance criteria. When comparing BRIEF scales to the neuropsychological measures, the TEA-Ch Opposite Worlds and BRIEF Inhibit scores were significant when evaluating all study participants using $p < .05$. Unexpectedly, the WCST Perseverations score was also significantly correlated with the BRIEF Working Memory and BRIEF Plan/Organize scores when examining only the TBI study participants using $p < .05$. The direction of the relationships for the WCST and the BRIEF Working Memory and Plan/Organize scales suggests that worse BRIEF scores are positively correlated with better scores (i.e. less perseverations) on the WCST.

Overall, the lack of correlational findings for the BRIEF and performance measures of executive function is similar to what has been found by Vriezen and Pigott (2002) and Mangeot et al. (2002). Vriezen and Pigott (2002) had used the BRIEF's Composite Index scores in comparison with performance measures of executive function, including the WCST and Trails B, and found no relationship between the Composite Index scores and the performance measures. Mangeot et al. (2002) had also utilized BRIEF Composite Index scores and found only the Consonant Trigrams test to be correlated with the BRIEF Indices. The results from the correlational analyses suggest that either the two types of measures for executive function may be capturing different aspects of the same cognitive domain, labeled as executive function, or that the two kinds of measures are evaluating altogether separate constructs. Either way, the findings imply that the use of measures of everyday executive function in addition to neuropsychological measures may provide a more thorough examination of the executive function domain across a range of situations and provide insight as to how problems displayed in a testing situation translate into difficulties on tasks in the child's day-to-day environment that requires such skills.

Limitations

One of the limitations for this pilot study was the size of the sample. The 35-subject sample size was smaller than some of the previous studies of the BRIEF in a chronic pediatric TBI population. One of the other risks of having a small sample is that a lack of statistical findings is reported as being evidence for no group differences, when in fact the lack of findings may be more appropriately attributed to the lack of power resulting from an inadequate sample size. In order to address this issue, effect sizes were calculated for the statistical results in order to thoroughly assess the findings within the sample. Some of the effect sizes would suggest that the small sample size prevented the detection of significant group differences. For example, the effect size for Creature Counting in the comparison between the Mild TBI and Orthopedic Control groups is large (1.0), but the difference between the groups on this measure did not reach a significance level of $p < .05$. Sample size issues are also pertinent when numerous analyses are being performed. Because this study was a pilot study, Tukey's HSD post-hoc analyses were selected instead of a more conservative analysis, such as the Bonferroni test. However, in order to examine whether Bonferroni results would have changed the findings, additional post-hoc analyses using Bonferroni tests were performed. There were no differences in the results using the Bonferroni tests.

Another of the study limitations involved the heterogeneity of the sample. The children in the TBI samples had various means of injury. As such, hypothesizing that the TBI samples should exhibit executive function deficits, which are associated primarily with injuries to the frontal lobes, makes interpretation of the data somewhat complex.

Neuroradiological data was not available for all participants and was not evaluated for the current study. However, this heterogeneity issue in not specific to the current study. TBI research typically does not limit subject recruitment to exclusively acceleration-deceleration injuries, which are more likely to involve the frontal lobes.

Wide variability in ratings for the BRIEF existed was displayed across all of the groups as demonstrated by the standard deviations in this study. Another study of the BRIEF in pediatric TBI had shown this as well. Standard deviation data presented by Mangeot et al. (2002) ranged from T-scores of 8.7 to 18.4 across BRIEF clinical scales and the three groups. This is in contrast to the standard deviation data for the normative sample presented in the BRIEF manual (Gioia et al., 2000), which displays standard deviations ranging from 2.6 to 5.6 for the individual clinical scales. This finding supports the notions of study sample heterogeneity and sample size limitations.

Four of the subjects in this pilot study had a pre-injury history of ADHD. The inclusion of participants with premorbid ADHD could have affected some of the results since ADHD has been implicated in specific cognitive deficits, such as inhibition problems. However, given the small number of ADHD cases in this sample and that they were divided evenly across the three study groups, it was decided to include these children for this pilot study in order to increase sample size. Furthermore, including cases of premorbid ADHD lends a certain level of generalizability to the results of this study, since a subset of pediatric TBI cases have pre-existing ADHD in the general pediatric TBI population.

The potential for response bias on the BRIEF parent report was another limitation. There is no way to determine response bias for the BRIEF and whether response bias may have affected the study's results. While some scales of behavioral report have a measure to look at response bias, the BRIEF does not. There are several ways response bias may affect the data. One, it may be possible that following their child's injury, the parent was distressed by what had occurred and did not want to rate their child's behavior as poorly as it may have been. On the other hand, following an accident, a parent may have been hypervigilant and subsequently overreported behavior following the injury. This limitation is one for the measure rather than for the study but is an important one to consider.

Strengths

Despite these limitations, the current study has several strengths. First, it is the first study to examine executive functioning both in terms of observational ratings and behavioral performance in an acute pediatric TBI population. While other studies have looked at the BRIEF (Mangeot et al, 2002; Vriezen and Pigott, 2002), those studies' samples were several years post-injury. None of the published studies have looked at behavioral rating within the first year of TBI recovery. Second, this study broadened the range of the TBI population evaluated with the BRIEF by examining mild pediatric TBI cases in addition to the more severe TBI population. Third, this study attempted to parse apart aspects of executive function by studying individual BRIEF scale scores rather than Composite Indices from the BRIEF. Gioia et al. (2002) is the only study to date to have examined the individual clinical scales. Finally, this study expands the literature by looking at change in BRIEF ratings over time using pre-injury and post-injury BRIEF clinical scale ratings. No studies to date have been published regarding executive function behavioral change following TBI as measured by the BRIEF parent ratings.

Future Directions

One area within the development of the BRIEF that should be addressed is the construction of a response bias measure. While parents are able to report the frequency of certain behaviors, there is no measure on the BRIEF to assess the consistency or validity of responses. A response bias measure would be useful in the interpretation of the BRIEF both for clinical and research purposes for those reasons.

In terms of future directions for studying executive function and cognition constructs associated with it, the utilization of functional imaging techniques would be future direction for the study of executive function in pediatric TBI. In the TBI literature, it has been difficult to come up with consistent behavioral findings for executive function, especially for mild TBI. Some TBI patients display severe impairment on tasks involving executive function, while others do not. However, it may be the case that in those patients where performance output does not appear to be impaired, the underlying brain systems involved in executive function tasks may still be compromised to a certain degree. During two functional magnetic resonance imaging (FMRI) study of working memory in adult mild TBI, McAllister et al. (1999, 2001) found that the pattern of frontal activation in relation to memory load was altered in an adult mild TBI sample as compared to uninjured controls despite similar outward task performance for both groups. Both studies used an auditory n-back working memory task that had varying load, and in both studies, the mild TBI group performed similar to controls in regards to behavioral accuracy for the tasks. In the 1999 study, McAllister et al. reported that controls showed bifrontal and biparietal activation in a low-processing load task, with a small increase in activation associated with a medium-load (2-back) task. In contrast, mild TBI patients showed a greater increase in activation during the medium-load task, notably in the right parietal and dorsolateral frontal regions. McAllister et al. (2001) showed that in a high-low condition (3-back), controls continued to increase activation within regions of working memory circuitry. In contrast, the mild TBI group had a greater increase of activation during the moderate-load condition, with little additional activation for the highest processing load condition. FMRI studies of executive function concepts such as working memory have not been done to date using a pediatric TBI sample. However, studies in the adult TBI literature suggest that processing differences could exist between pediatric TBI patients and age-matched healthy counterparts.

Last, the study of age-based subgroups would be an additional research direction in order to examine the relationship between age and executive function in pediatric TBI. Welsh, Pennington and Grossier (1991) and Levin et al. (1991) suggested that various aspects of executive function become efficient at different points during development. The pediatric TBI studies of executive function performance by Slomine et al. (2002) and Levin and colleagues (1994, 1997) described greater impairment in the younger TBI samples than in the older groups of children. Similarly, there may be age differences within this current study sample. The children who were injured at a younger age may have received worse BRIEF ratings and may have performed worse on the performance measures. While this was not examined for the current study due to the small sample size, it would be an interesting direction of study. Similar to the idea of age-based subgroup analyses, the use of a longitudinal study design would provide information about the relationship between age and executive function as well as the trajectory of recovery over time.

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BIOGRAPHICAL SKETCH

Michelle Benjamin graduated from DePaul University with a bachelor's degree in psychology. She spent two years working in Madison, Wisconsin, at the Wisconsin Early Autism Project as a research assistant. There she studied the outcome effects of a behavioral modification treatment program for children diagnosed with autism and other pervasive developmental disorders. Ms. Benjamin then went on to work as a research assistant for the Department of Psychiatry at the University of Iowa. At the University of Iowa, she was involved in research evaluating decisional capacity in schizophrenia and prisoners, cognitive and psychiatric change in Huntington's disease, and the cognitive effects of atherosclerotic vascular disease. Ms. Benjamin is currently working towards a doctorate in clinical and health psychology with a specialization in clinical neuropsychology at the University of Florida.