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Mild Traumatic Brain Injury and Executive Functions in School-Aged Children

Anne Maillard-Wermelinger[1], **Keith Owen Yeates**[2,3], **H. Gerry Taylor**[4,5], **Jerome Rusin**[6], **Barbara Bangert**[7], **Ann Dietrich**[2,8], **Kathryn Nuss**[2,8], and **Martha Wright**[4,5]

[1]Department of Psychiatry, Children's Hospital, Boston, Massachusetts

[2]Department of Pediatrics, The Ohio State University

[3]Center for Biobehavioral Health, The Research Institute at Nationwide Children's Hospital, Columbus, Ohio

[4]Department of Pediatrics, Case Western Reserve University

[5]Rainbow Babies & Children's Hospital, University Hospitals Medical Center, Cleveland, Ohio

[6]Department of Radiology, Nationwide Children's Hospital, Columbus, Ohio

[7]Departments of Radiology and Neurosurgery, University Hospitals Health System, Cleveland, OH

[8]Department of Emergency Medicine, Nationwide Children's Hospital, Columbus, Ohio

Abstract

Objective—This study sought to examine the effects of mild traumatic brain injury (TBI) on executive functions in school-aged children.

Participants and Method—The prospective, longitudinal study involved 8–15 year old children, 186 with mild TBI and 99 with mild orthopedic injuries (OI). They were administered the Stockings of Cambridge and Spatial Working Memory subtests from the Cambridge Neuropsychological Testing Automated Battery (CANTAB) about 10 days, 3 months, and 12 months post-injury. Parents completed the Behavior Rating Inventory of Executive Functions (BRIEF) on each occasion, with ratings at the initial assessment intended to assess premorbid functioning retrospectively.

Results—On the CANTAB, the groups did not differ on the Stockings of Cambridge, and the mild TBI group unexpectedly performed better than the OI group on Spatial Working Memory. On the BRIEF, children with mild TBI showed a marginally significant trend toward more problems than the OI group on the Metacognition Index composite. The only BRIEF subscale on which they demonstrated significantly more problems was Organization of Materials. The presence of intracranial abnormalities on MRI was associated with more problems on the BRIEF Organization of Materials subscale at 3 months, but other findings were not consistent with hypothesized effects of TBI severity. The CANTAB subtests were significant predictors of later ratings on the BRIEF, but accounted for modest variance.

Discussion—Children with mild TBI show limited evidence of deficits in executive functions, either cognitively or behaviorally, irrespective of injury characteristics. Cognitive tests of

Correspondence to Keith Owen Yeates, Ph.D., Department of Psychology, Nationwide Children's Hospital, 700 Children's Dr., Columbus, OH 432205. keith.yeates@nationwidechildrens.org..

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executive functions are modest predictors of ratings of executive functions in everyday life, for children both with and without mild TBI.

INTRODUCTION

Traumatic brain injury (TBI) accounts for substantial morbidity in children and adolescents in the United States [1,2]. Approximately 1,000,000 children sustain TBI annually, with an overall incidence of 200–300 per 100,000 children. Incidence varies as a function of injury severity, with 80 to 90 % of TBI being classified as mild[3]. Despite its common occurrence in the pediatric population, controversy persists regarding the outcomes of mild TBI in children [4–6]. Reviews of the literature [4,7] find little evidence for long-term adverse cognitive outcomes. However, important conceptual and methodological shortcomings characterize much of the existing research on pediatric mild TBI [6].

Executive dysfunction is one of the hallmark outcomes of TBI [1,8,9]. Executive functions involve a complex, environmentally sensitive set of interrelated processes that are responsible for purposeful, goal-directed, problem-solving behavior [10]. They also refer to the ability to consciously control one's cognitive activities and to monitor and regulate one's affect and behavior. These functions are important for success in “real world” environments, including school. A deficit in the executive domain following TBI is likely to affect cognitive, social, and emotional functioning [8,11–13].

Although executive dysfunction has been well described following moderate to severe TBI in childhood [8,14,15], less is known about mild TBI. Although a number of studies of various aspects of executive functions (e.g. flexibility, inhibition, goal setting, planning, working memory) did not report significant deficits following mild TBI in children [16–20], others did find noticeable executive difficulties, particularly on measures of working memory [21,22]. Working memory is an aspect of executive function often considered sensitive to TBI [1,17,22,23]. It refers to the process of holding information in mind for the purpose of completing a related task and involves both the storage and manipulation of information [17]. Levin et al [22] documented reduced working memory in children with mild TBI and abnormal CT findings relative to children without abnormal CT findings during the first year post-injury. Thus, mild TBI in children may be associated with deficits in executive functions, at least for so-called “complicated” injuries.

All of the above studies have typically used performance-based tests to examine executive functioning [24]. The ecological validity of such tests may be limited, in that they may not be predictive of day-to-day functioning. Indeed, the nature of standardized testing (i.e., distraction free, highly structured) may mask executive dysfunction, thereby reducing the opportunities to observe critical processes associated with executive functions [25]. Thus, performance-based tasks may overestimate the child's competence in everyday tasks [1]. Despite the apparent absence of deficits on cognitive measures of executive functions following mild TBI, patients and parents often report post-concussive symptoms such as distractibility, inattention, and forgetfulness, suggestive of executive deficits [26–29].

Rating scales provide an alternative approach to assessing executive functions that may tap everyday behavior more readily [8]. The Behavior Rating Inventory of Executive Function (BRIEF;[30]) is a standardized rating scale that was developed with ecological validity in mind, because it was meant to assess children's everyday executive behaviors in natural settings (e.g., behavioral inhibition, emotional regulation, working memory and planning). The questionnaire enables parents to rate their children's executive behaviors at home and in the community. Studies have found the BRIEF to be valid and reliable both in typically developing and children with TBI [10]. Mangeot et al [8] found that children with moderate to severe TBI displayed more deficits in executive functions on the BRIEF relative to children with orthopedic injuries approximately 5 years after injury. The magnitude of group differences did not vary across the BRIEF subscales, suggesting a generalized pattern of executive deficits. In their study, standardized cognitive tests of executive function demonstrated modest but significant associations with parent ratings on the BRIEF.

Very little research using the BRIEF has been conducted with children with mild TBI. We could find only one previous study, by Sesma et al [1], which showed that children with mild, moderate and severe TBI were all rated by parents as having significantly more executive dysfunction on the BRIEF General Executive composite, Behavioral Regulation, and Metacognition summary scores 12 months after injury as compared to children with orthopedic injuries. The working memory subscale was the only domain that demonstrated significant differences between the control group and all three TBI severity groups at 3 and 12 months after injury. The proportion of children with mild TBI who were rated as having significant executive dysfunction doubled by 3 months after injury and remained at a similar level 12 months after injury. Although the results are noteworthy, they may not be representative of the broader population of children with mild TBI, because all of the participants were hospitalized.

The overall goal of the present study was to examine cognitive and behavioral aspects of executive functioning in children with mild TBI up to 1 year post-injury. We relied on data collected as part of a larger prospective, longitudinal study of children injured between the ages of 8 and 15. Participants included children with mild TBI and a comparison group of children with orthopedic injuries (OI) not involving the head who were recruited prospectively from admissions to emergency departments at two large children's hospitals. They were administered two subtests from the Cambridge Neuropsychological Testing Automated Battery (CANTAB [31]) to assess cognitive aspects of executive functions (i.e., working memory and planning) and the BRIEF to assess executive functions in everyday life.

Our primary aim in this study was to determine whether the mild TBI and OI groups differed on cognitive or behavioral aspects of executive function. Because the differentiation of complicated versus uncomplicated mild TBI has been related to outcomes in the adult and pediatric populations [32–34], we also wanted to determine whether indices of severity (i.e., loss of consciousness or MRI abnormalities) were related to executive dysfunction in our sample of children with mild TBI. Our second aim was to determine whether cognitive tests of executive function were predictive of behavior ratings of executive functions. Previous research has demonstrated a modest but significant relationship between standardized cognitive tests and behavior ratings, suggesting that the two types of measures tap related but distinct constructs [8].

METHODS

Study Design and Procedures

The study used a concurrent cohort, prospective, and longitudinal design. Participants were recruited from the Emergency Departments at Nationwide Children's Hospital in Columbus, Ohio and Rainbow Babies and Children's Hospital in Cleveland, Ohio. All children from 8 to 15 years of age who presented for evaluation of mild TBI or OI were screened to determine if they met criteria for participation. Children with OI were included as a comparison group to control for demographic factors and premorbid characteristics that may be related to the propensity to injury (e.g., lower socioeconomic status, attention problems), as well as for the actual experience of a traumatic injury. The appropriate institutional

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review boards approved the research. Informed parental consent and child assent were obtained in writing prior to participation.

Children who met all inclusion/exclusion criteria and whose parents consented to participate were scheduled for an initial assessment no later than 3 weeks following their injury (M = 11.35 days; SD = 3.42). At the initial assessment, caregivers completed the BRIEF[35] retrospectively, to assess premorbid status, and children completed neuropsychological testing, including two measures of executive functions. Follow-up assessments were conducted at 3 and 12 months post-injury, during which parents completed the BRIEF based on the children's current functioning and children repeated neuropsychological testing.

At the initial assessment, children with mild TBI also completed structural MRI of the brain. The pulse sequence for the MRI included sagittal T1-weighted spin echo images, axial T2-weighted and proton density fast spin echo images, coronal 2-dimensional gradient echo images, coronal fluid attenuated inversion recovery (FLAIR) images, and axial diffusion-weighted echo planar images. Board-certified radiologists specializing in pediatric neuroradiology who were blinded to the results of other assessments rated the scans for TBI-related intracranial abnormalities.

Participants

Children were eligible for the mild TBI group if they suffered a blunt head trauma resulting in an observed LOC, or a Glasgow Coma Scale (GCS) score of 13 or 14, or at least two acute symptoms of concussion as documented by Emergency Department medical personnel (i.e. persistent post-traumatic amnesia, transient neurological deficits, vomiting, nausea, headache, diplopia, or dizziness). Exclusion criteria for the mild TBI group included a LOC lasting more than 30 minutes, any GCS score of less than 13, any delayed neurological deterioration, or any medical contraindication to MRI. Children were not required to have undergone a CT scan to be eligible to participate. Children who had an acute CT scan were not excluded from the study if they demonstrated intracranial lesions or skull fractures, as long as they did not require surgical intervention.

Children were eligible for the OI group if they sustained upper or lower extremity fracture associated with an Abbreviated Injury Scale (AIS; American Association for Automotive Medicine, 1990) score of 3 or less. They were excluded if they displayed any evidence of head trauma or symptoms of concussion.

Exclusionary criteria for both groups were as follows: neurosurgical or surgical intervention following injury; any associated injury with an AIS score greater than 3; any associated injury that interfered with neuropsychological testing (e.g., fracture of preferred upper extremity); hypoxia, hypotension, or shock during or following the injury; ethanol or drug ingestion involved with the injury; previous head injury requiring medical treatment; premorbid neurological disorder or mental retardation; any injury determined to be a result of child abuse or assault; or a history of severe psychiatric disorder requiring inpatient hospitalization.

The final sample included 186 children with mild TBI and 99 children with OI. Table 1 summarizes group characteristics at the initial assessment. The groups did not differ in age at injury, gender, race, or socioeconomic status. Also, they did not differ in overall cognitive ability as measured by the Wechsler Abbreviated Scale of Intelligence (WASI [36]) full scale IQ or premorbid executive functioning as measured by the BRIEF. In the mild TBI group, 24 (16%) had GCS scores less than 15, 71 (39%) had a brief LOC (median = 1 minute, range = <1 to 15 minutes), and 32 (18% of 182 who completed MRI) had intracranial abnormalities related to their head trauma on MRI, with 18 (56%) of those involving pathology in the frontal regions. Four children in the mild TBI group were unable to complete MRI.

Of the 285 children who completed the initial assessment, 268 (94%) completed the assessment at 3 months post-injury and 253 (89%) completed the assessment at 12 months post-injury. Attrition occurred primarily because of family unwillingness to continue the study and multiple missed appointments. The groups did not differ significantly in the rate of attrition at either follow-up assessment. Four children from the mild TBI group were unable to complete the MRI at the initial assessment. The current analyses are based only on children with complete data. Children with and without complete data did not differ in age at injury, gender, socioeconomic status, overall injury severity, or premorbid executive functioning as measured by the BRIEF. However, children without complete data were more likely to be non-white and had lower WASI Full Scale IQs, as compared to children with complete data.

Measures

Neuropsychological tests—Overall cognitive ability was assessed at the initial assessment using the two-subtest version of the WASI. The WASI yields a Full Scale IQ score that is highly correlated with other measures of general intellectual functioning [36].

Children were administered two tests of executive functioning (i.e., Spatial Working Memory and Stockings of Cambridge) from the computerized Cambridge Neuropsychological Testing Automated Battery (CANTAB[31]) at the initial, 3 and 12 month post-injury assessments. Spatial Working Memory is a self-ordered pointing task that assesses the ability to retain spatial information in working memory. On each trial of this task, a number of colored boxes are shown on the screen. A black column appears at the right bottom corner of the screen. The child is told that the black column is a container and that a stack of blue tokens belongs in the container. The child is also told that the tokens are hidden inside the colored boxes on the screen. The goal is to find a blue token in each of the boxes and use them to fill the empty column on the right hand side of the screen. Each colored box will contain only one token in the course of a trial. The child must touch each box in turn until one opens with a blue token inside, while trying not to return to boxes where a blue token has already been found on previous searches. The order in which the child searches the colored boxes is self-determined. The 12 test trials include four with 4 boxes, four with 6 boxes, and four with 8 boxes. The color and position of the boxes vary from trial to trial to discourage the use of stereotyped search strategies. For this study, the measure of interest was the number of “between” errors, which reflect the number of times within a trial a box is revisited on a subsequent search when a token has already been found in it, totalled across all trials.

The Stockings of Cambridge is a spatial planning task based upon the Tower of London [37]. In this task, the computer screen is split into a top half and a bottom half. Each half contains three rows of “black holes”. Three holes are in the first row, two in the second row, and one in the third row. Three colored balls (blue, red, green) are placed in predetermined position in the displays. The balls in the lower display are in different locations than in the upper display. The child is told that upper display is the model and the goal is to make the lower display match the upper display by moving the balls to different locations in a minimum number of moves possible. The child must thus move the balls in the lower display to copy the pattern shown in the upper one. The balls may be moved one at a time by touching the required ball, then touching the position to which it should be moved. Only balls at the top of a stack can be moved. The starting position of the balls is varied on each trial so that the solution can be reached after a minimum of 2, 3, 4, and 5 moves. The problem is terminated if the participant makes more than double the number of moves that are necessary for the simplest solution. The test ends after the computer terminates three problems in a row. For this study, the number of problems solved in the minimum possible moves (maximum 12) was the variable of interest.

BRIEF—Parents rated children's executive functions in everyday life using the BRIEF, which is a standardized rating scale that was developed to capture children's everyday functioning at home and in the community [10]. As mentioned above, the BRIEF has demonstrated sensitivity to executive difficulties in children with a variety of developmental and acquired disorders, including TBI [8,10,38]. The scale contains 86 items that reflect eight theoretically and empirically derived subscales that measure different aspects of executive functions: Inhibit, Shift, Emotional Control, Initiate, Working Memory, Plan/ Organize, Organization of Materials, and Monitor. The subscales are correlated but non-overlapping and contain between 6 and 12 items each. The Inhibit, Shift, and Emotional Control subscales define a composite Behavioral Regulation Index. The other subscales define a composite Metacognition Index. Finally, a Global Executive Composite is derived from all subscales. For the current study, analyses were based on T-scores for the eight individual subscales and the three composites.

Data Analyses

Differences between the mild TBI and OI groups on the CANTAB were examined using repeated measures multivariate analyses of covariance (MANCOVA), with group and assessment occasion as independent variables. Age at injury and socioeconomic status were treated as covariates. Dependent variables were the total number of errors on the Spatial Working Memory subtest and the number of problems solved in the minimum possible moves on the Stockings of Cambridge, as assessed at the initial, 3 month, and 12 month assessments.

Group differences on the BRIEF also were examined using repeated measures MANCOVA. The BRIEF subscales and composite index T-scores from the 3 and 12 month post-injury assessments were treated as dependent variables, with group membership and assessment occasion as the independent variables. Covariates included socioeconomic status and the corresponding BRIEF rating from the initial assessment, representing children's premorbid functioning.

We subsequently examined whether the severity of mild TBI, as indexed by LOC or the presence of abnormal findings on MRI, accounted for differences on the BRIEF or CANTAB. To do so, the mild TBI group was divided into (1) those with and without LOC and (2) those with and without trauma-related abnormalities on MRI. Children in the subgroups were compared in separate analyses involving the BRIEF subscales and composite indexes, as well as each of the CANTAB tasks. The two indices of severity were not entirely independent, and 17 children (9%) of the children with mild TBI showed both a LOC and an MRI abnormality ($p < .06$, Fisher's Exact Test).

The final set of analyses examined the relationship between cognitive measures and behavioral ratings of executive functions using hierarchical linear regression analyses. The CANTAB measures obtained at the initial assessment were treated as predictors of the BRIEF at 3 and 12 months post-injury. In each linear regression analysis, age at injury, the corresponding baseline BRIEF score (representing premorbid functioning), socioeconomic status, and a dummy variable representing group membership were entered in an initial step. The CANTAB variables were entered in a second step. Finally, interaction terms involving group and the CANTAB variables were entered in a third step, to determine if the relationship between the CANTAB and the BRIEF differed for the two groups. Separate analyses were conducted for each BRIEF subscale and composite index.

RESULTS

Group Comparisons

CANTAB—Table 2 displays group means and standard deviations on the CANTAB tasks at the three assessment occasions. The mild TBI and OI groups did not differ on the Stockings of Cambridge; neither the group main effect nor the group × time interaction was significant. A significant main effect was found for assessment occasion, $F(2,245) = 5.22$, $p < .01$, $\eta^2 = .04$, as both groups demonstrated improved performance over time, likely reflecting maturation or a practice effect. Within the mild TBI group, no difference was found between children with and without LOC. However, children with abnormalities on MRI unexpectedly completed more problems in the minimum number of moves than those without intracranial abnormalities, $F(1,159) = 13.29$, $p < .001$, $\eta^2 = .08$. Both subgroups significantly improved their performance over time, as reflected in a significant main effect of assessment occasion, $F(2,158) = 6.85$, $p < .001$, $\eta^2 = .08$.

Surprisingly, the OI group made more errors on the Spatial Working Memory subtest than the mild TBI group, $F(1,246) = 6.68$, $p < .05$, $\eta^2 = .03$. The magnitude of the group difference declined with time, as reflected in a trend toward a significant group × time interaction, $F(2,245) = 3.01$, $p = .051$, $\eta^2 = .02$. Both groups showed significant improvements in performance over time, as reflected in a significant main effect of assessment occasion, $F(2,245) = 11.51$, $p < .001$, $\eta^2 = .09$. Within the mild TBI group, children with and without LOC did not differ on the Spatial Working Memory task. Unexpectedly, children with abnormalities on MRI made fewer errors than those without abnormalities, $F(1,159) = 4.91$, $p < .05$, $\eta^2 = .03$.

BRIEF—Table 3 presents the adjusted means and standard errors on the BRIEF subscales and composite indexes for each group at 3 and 12 months post injury. After controlling for premorbid functioning (i.e., BRIEF ratings at the initial assessment), the mild TBI and OI groups did not differ on the Behavioral Regulation Index or Global Executive Composite. However, they did show a trend toward a significant difference on the Metacognition Index, $F(1,246) = 3.03$, $p = .08$, $\eta^2 = .01$, with more metacognitive difficulties reported in the mild TBI group. Examination of specific subscales showed that the groups differed significantly only on the Organization of Materials subscale, $F(1,246) = 5.76$, $p < .05$, $\eta^2 = .02$, with the mild TBI group rated as showing more problems in this domain. Neither the group main effect nor the group × time interaction was significant for any other BRIEF subscales. Within the mild TBI group, LOC did not predict differences on any of the BRIEF subscales and composite indexes. The presence of MRI abnormalities was associated with a significant group × time interaction on the Organization of Materials subscale, $F(1,160) = 7.44$, $p < .01$, $\eta^2 = .04$; children with MRI abnormalities were reported to display more problems in that domain at 3 months post-injury, but not at 12 months post-injury, as compared to children without such abnormalities.

Prediction of BRIEF from CANTAB

The results of hierarchical linear regression analyses examining the contribution of the CANTAB subtests to the prediction of BRIEF scores at 3 and 12 months post-injury are summarized in Tables 4 and 5. At 3 months post-injury, socioeconomic status, group membership, age at injury, and initial ratings on the BRIEF collectively accounted for significant variance in all BRIEF scales and indexes. After controlling for those variables, the two CANTAB subtests together accounted for significant variance on the Inhibit, $F(2,259) = 3.39$, $p < .05$, and Shift, $F(2,259) = 3.65$, $p < .05$, scales but not on any other scales or indexes. The Stockings of Cambridge accounted for unique variance on the Shift scale, $t = -2.250$, $p < .05$. In all cases, better performance on the CANTAB predicted lower (i.e., better) scores on the BRIEF. The relationship between the Spatial Working Memory subtest and the BRIEF differed across the mild TBI and OI groups on the Shift, Emotional Control, and Organization of Materials scales and the Behavior Regulation Index, as reflected in significant group × Spatial Working Memory interaction terms. In all cases, the relationship was stronger among children with mild TBI than among those with OI, with better performance on the Spatial Working Memory subtest predicting better scores on the BRIEF.

At 12 months post-injury, socioeconomic status, group membership, age at injury, and premorbid ratings on the BRIEF collectively accounted for significant variance in all BRIEF scales and indexes. After controlling for those variables, the two CANTAB subtests together accounted for significant additional variance on most subscales, including Inhibit, $F(2,245) = 3.89$, $p < .05$, Shift, $F(2,245) = 3.10$, $p < .05$, Emotional Control, $F(2,245) = 3.24$, $p< .05$, Initiate, $F(2,245) = 5.097$, $p < .01$, Working Memory, $F(2,245) = 6.125$, $p < .01$, and Monitor, $F(2,245) = 4.299$, $p < .05$, and on the Behavior Regulation index, $F(2,245) = 3.88$, $p < .05$, Metacognition index, $F(2,245) = 3.861$, $p < .05$, and General Executive Composite, $F(2,245) = 4.532$, $p < .05$. Spatial Working Memory accounted for unique variance on Inhibit, $t = 2.14$, $p < .05$, Emotional Control, $t = 2.32$, $p < .05$, Working Memory, $t = 2.72$, $p < .05$, and the Monitor, $t = 2.890$, $p < .01$, scales, as well as the Metacognition, $t = 2.40$, $p < .05$, and Behavioral Regulation indexes, $t = 2.32$, $p < .05$, and Global Executive Composite, $t = 2.61$, $p < .05$. The Stockings of Cambridge subtest accounted for unique variance on the Initiate scale, $t = -2.32$, $p < .05$. In all cases, better performance on the CANTAB predicted better scores on the BRIEF. None of the interaction terms were significant, indicating that the relationships between the CANTAB and BRIEF were consistent for children with and without mild TBI.

DISCUSSION

Mild TBI occurs frequently in the pediatric population, but controversies persist regarding the neurobehavioral outcomes associated with mild TBI[6]. The goal of the present study was to determine whether mild TBI has an impact on executive functions. Executive functions are known to be sensitive to more severe TBI and contribute to many aspects of everyday functioning, but previous research has not clearly indicated whether mild TBI is associated with deficits in executive functions. The current findings do not indicate significant executive dysfunction, either cognitively or behaviorally, during the first year following mild TBI in school-aged children. This is consistent with previous research showing that mild TBI has less negative impact on neuropsychological functioning than moderate to severe TBI [20].

On two cognitive tests of executive function, children with mild TBI either did not differ from or actually performed better when compared to children with OI. Moreover, children with complicated mild TBI (i.e., those with intracranial abnormalities on MRI) actually performed better than children with uncomplicated injuries on both measures. We are not sure of the reason for these unexpected findings. One possibility is that the CANTAB is not valid for use with children. The measure was initially designed for adults, and has not been used extensively in pediatric research. However, a number of studies have found deficits in children with developmental disorders such as autism and medical problems such as low birth weight [39]. Thus, the unexpected findings are not likely to reflect limited test validity and are probably either spurious or reflect background differences between the groups that existed prior to injury. Indeed, the children with complicated mild TBI in our study display higher overall cognitive ability and are less likely to be of minority status than the children with uncomplicated mild TBI, and these differences may help account for the unexpected findings on the cognitive tests of executive function.

On the BRIEF, we found no group differences on most subscales after controlling for ratings of premorbid functioning. Children with mild TBI displayed significantly more difficulties only on the Organization of Materials scale, suggesting a tendency to be messier and more disorganized than controls, although the scores of both groups were well within the normal range compared to normative data. These findings differ from those of Sesma et al [1], who documented executive dysfunction using the BRIEF during the first year after mild TBI. Inclusion of younger children in that study might account, at least in part, for this discrepancy. Younger children have been shown to be more vulnerable to negative outcomes following TBI [9,40–42]. Also, in the study by Sesma et al [1], the participants demonstrated a higher rate of premorbid learning and behavior problems than the control population. This may also account for the observed increase in executive problems following injury. Finally, all of the children in the Sesma et al study were hospitalized, and so those with mild TBI likely represented the more severe end of the spectrum in terms of injury severity.

We were interested in determining if injury severity was related to executive functions in children with mild TBI. Among children with mild TBI, LOC did not predict differences on any of the outcome measures. However, the presence of intracranial abnormalities was associated with differences on the CANTAB and the BRIEF. On the CANTAB, the differences observed were not in the expected direction, as children with abnormal MRI findings performed better on both tasks. In contrast, on the BRIEF, children with MRI abnormalities were reported to display more problems on the Organization of Materials scale at 3 but not 12 months post-injury. In our sample, only 18% of the children with mild TBI had abnormal MRI findings. Thus, future studies with larger samples are needed to replicate these results. Also, LOC and MRI abnormalities are not the only indicators of injury severity that may predict outcomes following mild TBI. For instance, recent advances in neuroimaging, such as diffusion tensor imaging or susceptibility weighted sequences [43], may better differentiate children with mild TBI who are at risk for executive deficits and other negative outcomes.

Another goal of the study was to determine whether cognitive tests of executive function were predictive of behavior ratings of executive functions. Our analyses showed that, after controlling for group membership, age at injury, and initial ratings on the BRIEF, the two CANTAB tasks made significant collective contributions to several BRIEF scales for the mild TBI group at 3 months post-injury and to most scales for children in both groups at 12 months post-injury. We are not sure why the CANTAB was a stronger predictor of the BRIEF for the mild TBI group than for the OI group at 3 months, although it does not appear to be simply a function of greater variability in the mild TBI group. Notably, the CANTAB spatial working memory task predicted scores on the BRIEF Working Memory scale, suggesting some specificity in the relationship between cognitive and behavioral measures. Overall, our findings suggest that the CANTAB may have some ecological validity and is predictive of aspects of executive functioning in everyday life, both for children with mild TBI and those with OI. The relationship is modest in magnitude, but somewhat stronger than some previous studies relating standardized cognitive test performance to ratings on the BRIEF [39].

The current results should be interpreted in the context of several limitations. We used two CANTAB tests designed to assess specific aspects of executive functions (i.e. planning, working memory). However, executive functioning encompasses a much larger group of functions not targeted in this study that may be worth investigating in the future. Parents were asked to report premorbid executive functioning on the BRIEF retrospectively. Because rating scales relying on subjective impressions, the accuracy of those reports is difficult to determine. We tried to limit any potential biases in the ratings of premorbid functioning by asking the parents to complete the BRIEF shortly after the injury. Another limitation is that only children with complete data were included in the analyses. Children with incomplete data were less likely to be white and had lower WASI Full Scale IQs. Thus, our results may slightly overestimate the competence of the mild TBI population, and may not generalize to the larger population of children with mild TBI. Finally, as mentioned earlier, the inclusion of more children with complicated mild TBI would be desirable to assess differences related to injury severity.

Overall, the current study provides limited evidence of deficits in executive functions, either cognitively or behaviorally, during the first year following a mild TBI, irrespective of injury characteristics. Although further studies are needed to better understand the role of injury severity as a possible predictor of executive dysfunction, the findings may help clinicians reassure families about the long-term outcomes following mild TBI in school-aged children. Future research is needed to examine the effect of mild TBI in younger children, given evidence that their outcomes following TBI may be poorer than those of older children [40–42].

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Table 1

Sample characteristics at initial assessment

	Group	
	TBI	**OI**
N	186	99
Age at injury in years, *M* (*SD*)	11.96 (2.22)	11.76 (2.23)
Males, *n* (%)	132 (71)	64 (65)
White, non-Hispanic, *n* (%)	132 (71)	64 (65)
Socioeconomic status[a]	0.5 (0.91)	−0.09 (1.15)
WASI Full scale IQ	99.66 (13.83)	98.90 (15.01)
Retrospective BRIEF		
Behavioral Regulation Index	50.18 (9.45)	52.35 (11.27)
Metacognition Index	52.05 (10.55)	52.44 (11.11)
General Executive Composite	51.48 (10.24)	52.56 (11.42)

Note: TBI = traumatic brain injury; OI = orthopedic injury; WASI = Wechsler Abbreviated Scale of Intelligence; BRIEF = Behavior Rating Inventory of Executive Function. The two groups did not differ significantly on any of the variables listed.

[a]Socioeconomic status is a composite score that reflects the average of z-scores for maternal education, occupational status, and median census tract income.

Table 2

Adjusted means and standard errors on the CANTAB subtests for each group at 3 and 12 months post-injury

	Baseline		3 months		12 months	
	TBI	**OI**	**TBI**	**OI**	**TBI**	**OI**
	MSE	MSE	MSE	MSE	MSE	MSE
Stockings of Cambridge total solutions in minimum possible moves	7.31 .13	7.18 .18	8.35 .14	7.86 .20	8.53 .14	8.43 .19
Spatial Working Memory total between errors*	35.49 1.15	42.48 1.62	30.30 1.16	33.01 1.63	27.94 1.15	31.32 1.61

*Significant group X time interaction, $p < .05$

Table 3

Adjusted means and standard errors on the BRIEF subscales and composite indexes for each group at 3 and 12 months post-injury

	3 months		12 months	
BRIEF Scales	**Mild TBI**	**OI**	**Mild TBI**	**OI**
	MSE	MSE	MSE	MSE
Inhibit	50.71 0.56	50.86 0.80	51.01 0.64	50.65 0.91
Shift	48.61 0.67	50.53 0.95	48.91 0.63	50 05 0.90
Emotional control	49.25 0.64	49.32 0.91	49.25 0.62	49.34 0.89
Initiate	51.01 0.54	50.46 0.76	50.85 0.56	49.68 0.81
Working Memory	53.11 0.59	51.24 0.84	52.18 0.66	50.66 0.94
Plan/Organize	52.43 0.59	50.80 0.84	51.83 0.62	50.35 0.88
Organization of Materials***	53.25 0.57	49.81 0.81	53.07 0.59	50.21 0.84
Monitor	49.98 0.56	49.69 0.79	50.21 0.58	49.06 0.83
Behavioral Regulation Index	49.51 0.58	50.21 0.82	49.83 0.59	50.03 0.85
Metacognition Index	52.39 0.51	50.56 0.73	51.94 0.56	50.02 0.80
Global Executive Composite	51.43 0.51	50.52 0.73	51.25 0.55	49.97 0.78

Group main effect significant,

*p< .05

Table 4

Summary of hierarchical regression analyses with the CANTAB baseline predicting the BRIEF 3 months post-injury

Predictors	Dependent variables										
	Inhibit	Shift	Emotional Control	Initiate	Working Memory	Plan/organize	Organization of Materials	Monitor	BRI	MI	GEC
STEP 1 β											
Group membership	−.01	.03	−.04	−.07	−.06	−.01	−.11**	.00	−.02	−.06	−.04
zSES	.−14**	−.08	−.12**	−.06	−.10*	−.03	−.08*	−.07	−.11**	−.06	−.07
Age at injury	−.06	−.04	−.05	−.10*	.02	−.04	−.02	−.08	−.06	−.05	−.06
Individual premorbid BRIEF score	.68***	.65***	.70***	.71***	.74***	.816***	.75***	.76***	.71***	.82***	.79***
Total $R2$ for Step 1	.54***	.45***	.52***	.50***	.60***	.67***	.59***	.58**	.56***	.69***	.65***
STEP 2 β											
Group membership	−.02	.02	−.04	−.08	−.07	−.02	−.12**	−.01	−.02	−.06	−.05
zSES	−.12**	−.05	−.11*	−.04	−.09*	−.02	−.08	−.06	−.09*	−.05	−.06
Age at injury	.03	.04	−.03	−.04	.06	−.01	−.00	−.04	.01	−.03	−.02
Individual premorbid BRIEF score	.65***	.62***	.69***	.69***	.73***	.81***	.74***	.75***	.69***	.81***	.78***
CANTAB-SWM	.09	.07	.00	.09	.05	.04	.03	.06	.05	.04	.05
CANTAB-SOC	−.09	−.12*	−.06	−.03	−.02	−.02	.01	.00	−.09	−.01	−.03
Δ $R2$ for Step 2	.01*	.02*	.00	.01	.00	.00	.00	.00	.01	.00	.00
STEP 3 β											
Group membership	−.11	.36	.27	.03	−.08	−.04	.14	.13	.18	−.02	.06
zSES	−.12**	−.06	−.12*	−.04	−.09*	−.02	−.08*	−.06	−.10*	−.05	−.07
Age at injury	.03	.04	−.03	−.04	−.06	−.01	−.01	−.04	.01	−.03	−.02
Individual premorbid BRIEF score	.65***	.62***	.69***	.69***	.73***	.81***	.74***	.74***	.69***	.81***	.78***
CANTAB-SWM	.03	−.07	−.14	.04	.02	.05	−.11	−.02	−.07	−.01***	−.02
CANTAB-SOC	−.02	−.16	−.08	−.04	.01	−.02	.00	.01	−.09	.01	−.02
Group X SOC	−.19	.20	.10	.04	−.08	−.01	.04	.00	.02	−.04	−.00
Group X SWM	.10	.25*	.26*	.09	.06	−.02	.26*	.16	.22*	.09	.14
Δ $R2$ for Step 3	.00	.00	.01	.00	.00	.00	.01	.00	.01	.00	.00

Note. CANTAB-SOC = Stockings of Cambridge task; CANTAB-SWM = Spatial Working Memory task; BRI = Behavior Regulation Index; MI = Metacognition Index; GEC =General Executive Composite;

* $p < .05$

** $p < .01$

*** $p < .001$

Table 5

Summary of hierarchical regression analyses with the CANTAB baseline predicting the BRIEF 12 months post-injury

Predictors	Dependent variables										
	Inhibit	Shift	Emotional Control	Initiate	Working Memory	Plan/organize	Organization of Materials	Monitor	BRI	MI	GEC
STEP 1 α											
Group membership	−.03	.00	−.02	−.10	−.06	−.02	−.08	−.02	−.03	−.06	−.06
zSES	−.02	−.00	−.06	−.07	−.01	−.00	−.04	−.01	−.02	−.00	−.00
Age at injury	−.05	−.02	.00	−.07	.02	−.04	.00	−.06	−.03	−.04	−.04
Individual premorbid BRIEF score	.75***	.69***	.66***	.66***	.69***	.76***	.64***	.72***	.74***	.77***	.78***
Total $R2$ for Step 1	.56***	.48***	.45***	.44***	.49***	.58***	.43***	.50***	.56***	.59***	.60***
STEP 2 β											
Group membership	−.05	−.01	−.04	−.12*	−.08	−.03	−.10	−.05	−.05	−.08*	−.08
zSES	.01	.03	−.02	−.03	.03	.02	−.02	.03	.01	.03	.02
Age at injury	.05	.07	.10	.05	.16**	.03	.06	.04	.07	.06	.06
Individual premorbid BRIEF score	.72***	.67***	.64***	.65***	.65***	.74***	.64***	.70***	.72***	.75***	.75***
CANTAB-SWM	.12*	.09	.14*	.12	.16**	.10	.08	.17**	.13*	.13*	.14*
CANTAB-SOC	−.08	−.09	−.04	−.12*	−.10	−.04	−.01	−.01	−.06	−.05	−.06
Δ $R2$ for Step 2	.01*	.01*	.01*	.02**	.02	.01	.00	.02*	.01*	.01*	.01*
STEP 3 β											
Group membership	−.26	.12	−.05	−.45	−.25	.03	−.11	.19	−.10	−.13	−.12
zSES	.01	.03	−.03	−.03	.02	.02	−.03	.03	.00	.02	.02
Age at injury	.06	.07	.10	.05	.16**	.03	.06	.04	.07	.06	.06
Individual premorbid BRIEF score	.72***	.67***	.64***	.65***	.65***	.74***	.64***	.70***	.72***	.75***	.75***
CANTAB-SWM	.05	.58	.05	.12	.09	.05	−.04	.09	.06	.06	.06
CANTAB-SOC	.04	−.12	.02	.00	.01	−.02	.06	−.05	−.00	.01	.01
Group X SOC	−.34	.10	−.16	−.37	−.31	−.03	−.21	.14	−.17	−.17	−.17
Group X SWM	.12	.06	.16	−.00	.13	.10	.21	.14	.12	.13	.13
Δ $R2$ for Step 3	.01	.00	.00	.00	.01	.00	.01	.00	.01	.01	.01

Note. CANTAB-SOC = Stockings of Cambridge task; CANTAB-SWM = Spatial Working Memory task; BRI = Behavior Regulation Index; MI = Metacognition Index; GEC =General Executive Composite

* $p < .05$

** $p < .01$

*** $p < .001$