Pediatric Traumatic Brain Injury and Attention Deficit

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abstract

BACKGROUND: We investigated the impact of pediatric traumatic brain injury (TBI) on attention, a prerequisite for behavioral and neurocognitive functioning.

METHODS: Children aged 6 to 13 years who were diagnosed with TBI (n = 113; mean 1.7 years post-injury) were compared with children with a trauma control injury (not involving the head) (n = 53). TBI severity was defined as mild TBI with or without risk factors for complicated TBI (mildRF+, TBI, n = 52; mildRF− TBI, n = 24) or moderate/severe TBI (n = 37). Behavioral functioning was assessed by using parent and teacher questionnaires, and the Attention Network Test assessed alerting, orienting, and executive attention. Ex-Gaussian modeling determined the contribution of extremely slow responses (lapses of attention) to mean reaction time (MRT).

RESULTS: The TBI group showed higher parent and teacher ratings of attention and internalizing problems, higher parent ratings of externalizing problems, and lower intelligence than the control group (P < .05, d = 0.34). No effect of TBI on alerting, orienting, and executive attention was observed (P ≥ .55). MRT was slower in the TBI group (P = .008, d = 0.45), traced back to increased lapses of attention (P = .002, d = 0.52). The mildRF− TBI group was unaffected, whereas the mildRF+ TBI and moderate/severe TBI groups showed elevated parent ratings of behavior problems, lower intelligence, and increased lapses of attention (P ≤ .03, d ≥ 0.48). Lapses of attention fully explained the negative relation between intelligence and parent-rated attention problems in the TBI group (P = .02).

CONCLUSIONS: Lapses of attention represent a core attention deficit in children with mildRF+ TBI (even in the absence of intracranial pathology) or moderate/severe TBI, and relate to daily life problems after pediatric TBI.

WHAT’S KNOWN ON THIS SUBJECT: Attention is a prerequisite for neurocognitive and behavioral functioning, having a crucial role in academic and social child development. Children with traumatic brain injury have pronounced deficits in attention, but the nature and consequences of these deficits remain unclear.

WHAT THIS ADDS: Lapses of attention represent a core attention deficit after pediatric mild traumatic brain injury with risk factors for complicated traumatic brain injury, or moderate/severe traumatic brain injury. Importantly, lapses of attention explain the relation between intelligence and parent-rated attention problems.
Traumatic brain injury (TBI) is the leading cause of death and acquired disability in children and adolescents. Children with TBI suffer from neurocognitive impairments and are at risk for delayed academic and social development. Attention is a prerequisite for behavioral and neurocognitive functioning, by selecting environmental sensory information for perception and gating the information flow to and from memory. Therefore, attention deficits may play a key role in the consequences of pediatric TBI.

Interacting neural networks direct alerting, orienting, and executive attention, facilitating the abilities to (1) achieve and maintain an alert state, (2) spatially orient to environmental information, and (3) resolve conflict between competing responses, respectively. A review of studies investigating attention after pediatric TBI revealed that deficits in attention are prominent in the subacute phase of recovery and often persist into the chronic phase. Attention deficits have been observed ≤10 years postinjury, in particular after severe TBI. Aspects of attention related to executive attention are most consistently affected, but results heavily depend on the tests used to measure attention. The disparate findings in the literature may originate partly from the use of traditional paper-and-pencil tests, which often lack the ability to isolate aspects of attention from processing speed and visuomotor coordination, while these functions have consistently been found to be affected after TBI. The Attention Network Test (ANT) has been developed to measure the efficiency of alerting, orienting, and executive attention and overcomes drawbacks of traditional measures by correcting for processing speed and minimizing the load on visuomotor functions. One study used the ANT to investigate attention in adolescents with mild TBI, identifying a deficit in executive attention 1 month postinjury. Recent evidence from adults additionally suggests that TBI causes momentary lapses of attention (ie, short moments of attention loss) that cause extremely slow responses on timed tasks.

The current study uses the ANT to identify the nature of attention problems after pediatric TBI along the complete span of injury severity. We hypothesized that children with TBI have impaired executive attention and increased lapses of attention. In addition, the role of attention deficits in behavior problems and intelligence was explored.

**METHODS**

**Participants**

**Sample**

This study compared a TBI group of 113 children to a trauma control (TC) group of 53 children with traumatic injury not involving the central nervous system. Of all 375 children admitted from October 2009 to October 2013 who were enrolled in the Dutch language, (3) hospital admission with a clinical diagnosis of traumatic injury not involving the central nervous system, (1) age 6 to 13 years, (2) proficient in the Dutch language, (3) hospital admission with a clinical diagnosis of TBI for inclusion in the TBI group, (4) hospital admission for traumatic injuries below the clavicle for inclusion in the TC group, and (5) ≥2 months postinjury. Exclusion criteria were (1) previous TBI, (2) visual disorder interfering with neurocognitive testing, or (3) current condition, other than TBI, affecting the central nervous system. Of all 375 children admitted from October 2009 to October 2013 who were eligible for inclusion (TBI, n = 232; TC, n = 143), 54 were not reached (TBI, n = 39; TC, n = 15) and 137 declined participation (TBI, n = 68; TC, n = 69). Main reasons not to participate were as follows: not interested (TBI, 25%; TC, 32%), no time (TBI, 22%; TC, 22%), or load on child (TBI, 8%; TC, 16%). Eighteen children were excluded (TBI: n = 6 not proficient in Dutch, n = 5 age exceeding criterion, n = 1 motor retardation; TC: n = 3 not proficient in Dutch, n = 1 previous TBI, n = 1 brain tumor; n = 1 mental retardation). Participation rate was higher in the TBI group (n = 113, 49%) than the TC group (n = 53, 37%) (P = .03), but study samples did not differ from their respective cohorts in age or gender (P ≥ .14).

**Injury Severity**

Diagnosed injuries, the lowest score on the Glasgow Coma Scale (GCS) on the day of admission, and admission duration were extracted from medical files, as well as risk factors for complicated mild TBI according to the European Federation of Neurologic Societies guidelines on mild TBI: impaired consciousness (GCS ≤ 15), focal neurologic deficits, persistent vomiting (≥3 episodes), postinjury epileptic insults, progressive headache, and abnormal head computed tomography scan. Injury severity was categorized into mild TBI (GCS 15 to 13, loss of consciousness duration ≥30 minutes, posttraumatic amnesia duration ≥1 hour) without risk factors (mildRF-TBI, n = 24) or with ≥1 risk factor (mildRF-TBI, n = 52) and moderate/severe TBI (GCS 12 to 3, loss of consciousness duration ≥30 minutes, posttraumatic amnesia duration ≥1 hour; n = 37).

**Measures**

**Demographic Information**

Data on gender, age, socioeconomic status (SES), and diagnosed psychiatric or learning disorders were collected by using a parental questionnaire. SES was defined as the...
average level of parental education ranging from 1 (no education) to 8 (postdoctoral education).20

**Behavioral Functioning**

Parent and teacher ratings of attention problems, internalizing problems (eg, anxiety), and externalizing problems (eg, aggression) were obtained by using the widely used Child Behavior Checklist, Strength and Difficulties Questionnaire, and their teacher equivalents, which have adequate psychometric properties.21,22 Questionnaire scales measuring highly overlapping symptom domains ($0.88 \geq r \geq 0.72$) were collapsed for parents and teachers separately (sum of $z$-transformed raw scores) to yield aggregated parent and teacher ratings of attention and internalizing and externalizing problems.

**Intelligence**

Full-scale IQ (FSIQ) was estimated by using a short form of the Wechsler Intelligence Scale for Children III (including the subtests Vocabulary, Similarities, Block Design, and Picture Arrangement), with excellent validity ($r = 0.93$) and reliability ($r = 0.93$) in estimating FSIQ.23

**Attention Performance**

We used a child-friendly adaptation of the ANT (Fig 1).13 Children responded to a target presented on the left or right side of a computer screen by pressing the corresponding button. Targets appeared in 4 trial types containing no cue, a central cue, a valid location cue, or an invalid location cue. The main dependent measure was mean reaction time (MRT). Alerting, orienting, and executive attention were assessed by the difference in MRT between (1) no-cue trials and central-cue trials, (2) central-cue trials and valid-location-cue trials, and (3) valid-location-cue trials and invalid-location-cue trials. Speed of processing was assessed by MRT on no-cue trials to prevent attention networks from contaminating the analysis. As lapses of attention cause extremely slow responses that inflate MRT, we used so-called ex-Gaussian modeling of reaction time distributions to calculate the contribution of extremely slow responses to MRT ($\tau$), measuring lapses of attention.24 Likewise, we calculated MRT as corrected for extremely slow responses ($\mu$), measuring processing speed adjusted for lapses of attention. Background information on ex-Gaussian modeling and its clinical utility for psychiatric and neurologic disorders is provided elsewhere.24–26 Table 1 provides an overview of measures derived from the ANT.

**Procedure**

The families of eligible children were sent an information letter and contacted by telephone 2 weeks later. After written informed consent was provided by parents and children aged $>11$ years, trained examiners administered a fixed neurocognitive test battery while parents filled out questionnaires in a waiting room. Thereafter, teachers were contacted to fill out questionnaires. The ANT was administered using 15-inch laptops at 50-cm viewing distance with standardized instructions in a cover story, 30 practice trials, and 6 blocks of 60 experimental trials presented in fixed randomized order (duration 26 minutes). This study was part of a study registered at Clinicaltrials.gov (NCT01720979) and was approved by the VU University Medical Centre medical ethics committee (NL37226.029.11).

**Statistical Analyses**

Statistical analyses were performed by using SPSS 22.0. All dependent variables were screened for outliers ($P < .001$) that were rescaled according to Tabachnick and Fidell.27 Missing data (1% to 6%) were imputed by using multiple imputation.28 Differences in demographics, injury-related information, and clinical diagnoses were assessed between all groups using independent $t$ tests and $\chi^2$ tests.
Parent and teacher ratings of attention and internalizing and externalizing problems were subjected to multivariate analysis of variance (MANOVA) with group as between-subject factor (TBI, TC), and ANOVA assessed group differences in FSIQ. To assess alerting, orienting, and executive attention, MRT was subjected to 3 repeated-measures ANOVAs, with group as between-subject factor (TBI-TC), and spatial cue as withinsubject factor (no cue, central cue, central cue/valid spatial cue, central cue/invalid spatial cue). Differences between groups in (1) processing speed, (2) lapses of attention, and (3) processing speed adjusted for lapses of attention were assessed by comparing MRT, τ, and μ, respectively, using ANOVA. When a group difference for τ was found, we investigated whether this was driven by more frequent and/or longer lapses by comparing the number and MRT of extremely slow responses (reaction time > μ + 2SD) between groups. Variables for which a significant group difference was obtained were analyzed for their association with time since injury using Pearson correlation coefficients to analyze recovery effects. Likewise, analyses differentiating between TBI severity groups were performed on only those variables that showed differences between the TBI and TC group, to reduce the risk of type I errors while maintaining acceptable statistical power in comparing the relatively small groups. Statistical testing was 2-sided at α = 0.05, and effect sizes of group differences were calculated as Cohen d.29

RESULTS

**Demographics, Injury-Related Information, and Clinical Diagnoses**

The TBI group (n = 113) did not differ from the TC group (n = 53) in demographics, injury-related information, or clinical diagnoses (Table 2), except for lower SES in the TBI group and more extracranial fractures and orthopedic surgery in the TC group. Likewise, the TBI severity groups did not differ from the TC group in demographic variables, except for lower SES in the mildRF+ TBI and moderate/severe TBI groups. The moderate/severe TBI group had longer hospital admission, lower GCS scores, and more neurosurgery than all other groups (P ≤ .001), whereas progressively more cranial fractures and intracranial pathology were observed in the mildRF+, mildRF−, and moderate/severe TBI groups (P < .01). Differences in the prevalence of psychiatric conditions reached significance only between the mildRF+ TBI and TC groups (P = .05).

**Behavior Problems and Intelligence After TBI**

**TBI Versus TC Group**

Parent ratings of attention and internalizing and externalizing problems were higher for the TBI group than the TC group (Table 3). The TBI group also showed higher teacher ratings of attention and internalizing problems than the TC group, while no differences were observed on externalizing problems. The TBI group had lower FSIQ than the TC group. Time postinjury in the TBI group was not related to ratings of behavior problems or FSIQ (r ≤ 0.10, P ≤ .29).

**TBI Severity Groups**

The mildRF− TBI group did not differ from the TC group in parent and teacher ratings of attention or internalizing and externalizing problems (P ≥ .07, d = −0.07 to 0.57) or FSIQ (P = .44, d = −0.20), except for higher teacher ratings of internalizing problems (P = .04, d = −0.61). The mildRF+ TBI group showed higher parent ratings of attention and internalizing and externalizing problems (P ≤ .03, d = 0.48 to 0.63), higher teacher ratings of attention and internalizing problems (P = .002, d = 0.59, and P = .008, d = 0.56, respectively), and lower FSIQ (P = .01, d = −0.52) than the TC group. The moderate/severe TBI group had higher parent ratings of attention and internalizing and externalizing problems (P = .001, d = 0.75, and P = .005, d = 0.61, respectively), higher teacher ratings of internalizing problems (P = .003, d = 0.70), and lower FSIQ (P = .03, d = −0.50) than the TC group. Differences between the moderate/severe TBI and TC groups in parent and teacher ratings of attention problems did not reach significance (P > .12), although exploratory analyses revealed that children with severe TBI (n = 21) did

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alerting attention</td>
<td>The ability to achieve and maintain an alert state, measured by the decrease in MRT between ANT no-cue trials and central-cue trials.</td>
</tr>
<tr>
<td>Orienting attention</td>
<td>The ability to spatially orient to environmental information, measured by the decrease in MRT between ANT central-cue trials and valid-cue trials.</td>
</tr>
<tr>
<td>Executive attention</td>
<td>The ability to resolve conflict between competing responses, measured by the increase in MRT between ANT valid-cue trials and invalid-cue trials.</td>
</tr>
<tr>
<td>Processing speed</td>
<td>Information processing speed, measured by MRT on ANT no-cue trials.</td>
</tr>
<tr>
<td>τ</td>
<td>The contribution of extremely slow responses (ie, short moments of attention loss, lapses of attention) to information processing speed (MRT), calculated using so-called ex-Gaussian analysis.</td>
</tr>
<tr>
<td>μ</td>
<td>Information processing speed adjusted for the impact of extremely slow responses (lapses of attention), calculated using so-called ex-Gaussian analysis.</td>
</tr>
</tbody>
</table>
have higher parent ratings of attention problems than the TC group ($P = .04$, $d = 0.53$). There were no significant differences between the TBI severity groups on behavior ratings or FSIQ ($P > .05$), except for higher teacher ratings of attention problems in the mildRF+ TBI group compared with the moderate/severe TBI group ($P = .03$, $d = 0.47$).

### Attention Function After TBI

#### TBI versus TC Group

Although children with TBI showed slower performance in all trial types, no differences were observed in the efficiency of alerting attention ($P = .69$, $d = 0.04$), orienting attention ($P = .55$, $d = 0.18$), and executive attention ($P = .84$, $d = 0.07$), indicating that children with TBI have no specific deficits in these aspects of attention (Fig 2).

### Table 2: Analysis of Demographic and Injury-Related Characteristics in TBI and TC Groups

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>TBI</th>
<th>TC</th>
<th>Contrast</th>
<th>TBI Severity Groups</th>
<th>Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>113</td>
<td>53</td>
<td></td>
<td>24</td>
<td>52</td>
</tr>
<tr>
<td>Demographics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male gender</td>
<td>56</td>
<td>51</td>
<td>.56</td>
<td>46</td>
<td>60</td>
</tr>
<tr>
<td>Age at testing, y</td>
<td>8.8 (2.0)</td>
<td>9.3 (2.1)</td>
<td>.11</td>
<td>8.7 (2.1)</td>
<td>8.8 (2.0)</td>
</tr>
<tr>
<td>SES</td>
<td>5.3 (1.3)</td>
<td>5.9 (1.2)</td>
<td>.006a</td>
<td>5.3 (1.2)</td>
<td>5.3 (1.3)</td>
</tr>
<tr>
<td>Injury-related information</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age at injury, y</td>
<td>7.1 (2.3)</td>
<td>7.8 (2.2)</td>
<td>.07</td>
<td>7.0 (2.4)</td>
<td>7.1 (2.2)</td>
</tr>
<tr>
<td>Lowest GCS</td>
<td>12.6 (3.9)</td>
<td>15.0 (3.0)</td>
<td>14.6 (0.7)</td>
<td>8.3 (2.8)</td>
<td>1 and 2 &gt; 3</td>
</tr>
<tr>
<td>Hospital admission, d</td>
<td>8.8 (18.2)</td>
<td>1.4 (1.8)</td>
<td></td>
<td>0.9 (0.3)</td>
<td>2.5 (2.8)</td>
</tr>
<tr>
<td>Time since injury, y</td>
<td>1.7 (1.1)</td>
<td>1.6 (0.8)</td>
<td>.37</td>
<td>1.7 (1.0)</td>
<td>1.7 (1.0)</td>
</tr>
<tr>
<td>Range</td>
<td>0.5–5</td>
<td>0.4–4</td>
<td></td>
<td>0.5–4</td>
<td>0.3–4</td>
</tr>
<tr>
<td>Extracranial fracture</td>
<td>15</td>
<td>76</td>
<td>&lt;.001a</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>More than 1 extracranial fracture</td>
<td>6</td>
<td>8</td>
<td>.74</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Cranial fracture</td>
<td>36</td>
<td>0</td>
<td>35</td>
<td>62</td>
<td>3 &gt; 2 &gt; 1</td>
</tr>
<tr>
<td>Intracranial pathology</td>
<td>36</td>
<td>0</td>
<td>31</td>
<td>68</td>
<td>3 &gt; 2 &gt; 1</td>
</tr>
<tr>
<td>Orthopedic surgery</td>
<td>8</td>
<td>79</td>
<td>&lt;.001a</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>Neurosurgery</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>32</td>
<td>3 &gt; 1 and 2</td>
</tr>
<tr>
<td>Diagnosed conditions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psychiatric disorder</td>
<td>8</td>
<td>2</td>
<td>.13</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Premorbid ADHD</td>
<td>4</td>
<td>0</td>
<td>.17</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Learning disorder</td>
<td>8</td>
<td>6</td>
<td>.60</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

Values are expressed as % or mean (SD). ADHD, attention deficit/hyperactivity disorder; NS, not significant.
a Statistically significant at $P < .05$.

### Table 3: Analysis of Parent and Teacher Ratings of Behavior, FSIQ, and ANT Performance in TBI and TC Groups

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>TBI</th>
<th>TC</th>
<th>Contrast</th>
<th>TBI Severity Groups</th>
<th>Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>113</td>
<td>53</td>
<td></td>
<td>24</td>
<td>52</td>
</tr>
<tr>
<td>Parent ratingsa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attention problems</td>
<td>0.2 (1.9)</td>
<td>−0.5 (1.8)</td>
<td>.02b</td>
<td>0.1 (1.5)</td>
<td>0.4 (2.0)</td>
</tr>
<tr>
<td>Internalizing problems</td>
<td>0.3 (2.0)</td>
<td>−0.7 (1.4)</td>
<td>&lt;.001b</td>
<td>0.08 (1.8)</td>
<td>0.3 (2.0)</td>
</tr>
<tr>
<td>Externalizing problems</td>
<td>0.3 (2.0)</td>
<td>−0.6 (1.2)</td>
<td></td>
<td>0.04b</td>
<td>0.2 (1.6)</td>
</tr>
<tr>
<td>Teacher ratingsa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attention problems</td>
<td>0.2 (2.0)</td>
<td>−0.5 (1.8)</td>
<td>.03b</td>
<td>−0.1 (1.8)</td>
<td>0.7 (2.2)</td>
</tr>
<tr>
<td>Internalizing problems</td>
<td>0.3 (2.0)</td>
<td>−0.7 (1.3)</td>
<td>.001b</td>
<td>0.2 (1.8)</td>
<td>0.3 (2.0)</td>
</tr>
<tr>
<td>Externalizing problems</td>
<td>0.0 (1.9)</td>
<td>−0.1 (1.8)</td>
<td>.61</td>
<td>.09</td>
<td></td>
</tr>
<tr>
<td>FSIQ</td>
<td>98.4 (15.6)</td>
<td>105.0 (14.4)</td>
<td>.01b</td>
<td>102.0 (16.3)</td>
<td>97.3 (15.4)</td>
</tr>
<tr>
<td>ANT performancec</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MRT in ms</td>
<td>619 (122)</td>
<td>563 (130)</td>
<td>.008b</td>
<td>600 (136)</td>
<td>615 (124)</td>
</tr>
<tr>
<td>Ex-Gaussian parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t, ms</td>
<td>168 (69)</td>
<td>131 (51)</td>
<td>.002b</td>
<td>158 (79)</td>
<td>160 (70)</td>
</tr>
<tr>
<td>Lapses, sum</td>
<td>58.0 (15.5)</td>
<td>54.1 (16.7)</td>
<td>.14</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Lapse duration, ms</td>
<td>744 (153)</td>
<td>676 (159)</td>
<td>.008b</td>
<td>713 (156)</td>
<td>746 (153)</td>
</tr>
<tr>
<td>µ, ms</td>
<td>454 (69)</td>
<td>432 (98)</td>
<td>.09</td>
<td>.28</td>
<td></td>
</tr>
</tbody>
</table>

Values are expressed as mean (SD).
a Aggregated ratings (sum of z-transformed raw scores).
b Statistically significant at $P < .05$.
c Based on ANT no-cue trials.
Analyses on MRT, $\tau$, and $\mu$ in no-cue trials are displayed in Table 3. The TBI group showed higher MRT than the TC group, suggesting that children with TBI had slower processing speed. However, the TBI group also had higher $\tau$ than the TC group, whereas no group difference was obtained for $\mu$. These findings indicate that children with TBI demonstrate increased lapses of attention relative to the TC group, while having unaffected processing speed when accounting for lapses of attention. The number of lapses of attention did not differ between the TBI and TC groups, but lapses of attention were found to be longer in the TBI group (Table 3). $\tau$ was not related to time postinjury in the TBI group ($r = 0.00, P = .97$).

**TBI Severity Groups**

The mildRF+ TBI group did not significantly differ from the TC group on $\tau$ ($P = .08, d = 0.46$). Relative to the TC group, $\tau$ was higher in the mildRF+ TBI group ($P = .02, d = 0.49$) and moderate/severe TBI group ($P = .002, d = 0.77$), driven by longer lapses of attention in the moderate/severe TBI group ($P = .02, d = 0.52$). There were no significant differences between the TBI severity groups on $\tau$ ($P \geq .35$).

**Exploring the Role of Lapses of Attention**

The literature indicates that intelligence is predictive of behavior problems in children with TBI, a relationship hypothesized to reflect the importance of neurocognitive functioning for behavioral regulation. In line with this hypothesis, lower FSIQ was related to higher parent and teacher ratings of attention and internalizing problems and parent ratings of externalizing problems in the TBI group ($P < .02$). We explored whether lapses of attention may account for the negative relationship between FSIQ and behavioral ratings in children with TBI, using bootstrapping mediation models (as FSIQ is age-corrected, we likewise age-adjusted behavior ratings and $\tau$ using linear regression). Lower FSIQ was related to higher $\tau$ (Fig 3, Path A), and higher $\tau$ was in turn related to higher parent ratings of attention (Path B). Importantly, $\tau$ mediated the relation between FSIQ and parent ratings of attention ($P = .02$), fully accounting for the observed relation between intelligence and attention problems (Path C’). $\tau$ was not related to parent ratings of internalizing and externalizing problems or teacher ratings of attention and internalizing problems ($P > .15$), indicating that lapses of attention did not mediate internalizing and externalizing problems or teacher ratings of attention.

**Influence of Confounders**

To investigate the potential influence of SES on the observed differences between the mildRF+ and moderate/severe TBI groups relative to the TC group, the latter was matched on SES 1:2 (+2) to a collapsed mildRF+ moderate/severe TBI group. Demographic variables did not differ between the matched TC group ($n = 44$) and the original TC group ($P = .95$ to .13) or the collapsed mildRF+ moderate/severe TBI group ($n = 88; P = .46$ to .16). All reported group differences were replicated while (1) comparing the matched TC group and collapsed mildRF+ and moderate/severe TBI group, indicating that SES did not confound the reported results; (2) using data without missing value imputation; and (3) excluding all children with intracranial pathology ($n = 16$) or premorbid attention deficit/hyperactivity disorder ($n = 3$) from the mildRF+ TBI group, indicating that intracranial pathology or premorbid attention deficit/hyperactivity disorder did not account for the reported deficits in children with mildRF+ TBI.

**DISCUSSION**

This study indicates that children with TBI do not have persisting deficits in alerting, orienting, or executive attention, but rather exhibit impaired consistency as reflected by lapses of attention (ie, short moments of attention loss), representing a core attention deficit after pediatric TBI. Lapses of attention were found to explain the negative relation between intelligence and parent ratings of...
attention problems, suggesting an important role for lapses of attention in daily life functioning after pediatric TBI.

The results contrast with previous findings indicating impaired executive attention in pediatric TBI, as established in a recent review of the literature. Most studies covered in that review used traditional paper-and-pencil tests of attention, often not correcting for confounding effects of deficits in processing speed or visuomotor functions that may co-occur after TBI. The ANT, which controls for these confounders, revealed no evidence for impaired alerting, orienting, or executive attention, possibly reflecting the importance of correcting for processing speed and visuomotor functions in tests of attention. The results further revealed no evidence for attention deficits after mild TBI, while indicating that children with mild TBI or moderate/severe TBI have increased lapses of attention. As expected, we found that lapses of attention (1) account for decreased processing speed; (2) are driven by prolonged lapses of attention, not by more lapses; (3) relate to intelligence and parent-observed attention problems; and (4) fully explain the negative relation between intelligence and parent ratings of attention problems. These results suggest that lapses of attention play an important role in daily life functioning after pediatric TBI, although the observed relationships do not necessarily imply causal mechanisms. Lapses of attention were not related to teacher observations of attention problems, possibly because behavior associated with lapses of attention goes unnoticed in crowded classrooms.

This study has some weaknesses. The participation rate was higher in the TBI group than the TC group, potentially accounting for the group difference on SES that was observed despite the recruitment of a trauma control group to control for preexisting trauma risk factors and psychological effects of hospitalization and medical interventions. Confounding analysis showed that SES did not account for the reported results. The mild TBI group had a small sample size, limiting the statistical power of group comparisons. Furthermore, this was a multicenter study, potentially introducing heterogeneity in the treatment of TBI within our sample; however, this also increases the generalizability of our results.

**CONCLUSIONS**

This study proposes an important role of lapses of attention in attention performance, intelligence, and behavioral functioning of children with TBI. Clinicians should be aware that slower processing speed after pediatric TBI may actually reflect an attention deficit, characterized by momentary lapses of attention that likely play a role in daily life problems. Importantly, the long-term negative effects of mild TBI on lapses of attention were even observed in the absence of intracranial pathology, suggesting that clinicians should consider routine screening of children with mild TBI for neurocognitive and behavioral symptomatology. Interventions aimed at improving attention and processing speed should consider lapses of attention among primary outcomes. Pharmacologic stimulant treatment has proven to effectively decrease lapses of attention in children with ADHD and pediatric cancer survivors, possibly providing a promising treatment of children with TBI as well.

**ABBREVIATIONS**

ANT: Attention Network Test  
FSIQ: full-scale IQ  
GCS: Glasgow Coma Scale  
MRT: mean reaction time  
SES: socioeconomic status  
TBI: traumatic brain injury

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### Pediatric Traumatic Brain Injury and Attention Deficit


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