Attention and Memory Functioning Among Pediatric Patients with Medulloblastoma

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Objective  To test the hypotheses that memory and attention deficits are prevalent in survivors of childhood medulloblastoma (MB) and that these deficits are associated with problems with academic achievement.  Methods  The medical charts of 38 child survivors of MB, who were administered the California Verbal Learning Test, Child Version (CVLT-C), Conners’ Continuous Performance Test (CPT), and the Wechsler Individual Achievement Test (WIAT) as part of a comprehensive neurocognitive test battery, were retrospectively reviewed.  Results  Although no significant verbal memory deficits were found, 8 of 11 CPT variables were significantly below the standardization mean (p ≤ .01). Additionally, stepwise regression analyses found that increased omission errors were significantly associated with lower reading and math performance (p ≤ .01).  Conclusions  These findings confirm previous reports of attention deficits among survivors of MB and provide a better understanding of how the dysfunction of particular attentional substrates (e.g., perceptual sensitivity, response bias) may result in learning problems in this population.

Key words  academic achievement; attention; memory; pediatric brain tumors.

Brain tumors are the second most common form of childhood cancer, comprising 20% of new diagnoses (Heideman & Havens, 2000). Although there are different types of brain tumors that vary in their histology and location, the second most common malignant brain tumor found in children is medulloblastoma (MB). MB is an embryonal primary brain tumor that arises from the cerebellum located in the posterior fossa region of the brain. It is a fast growing tumor that often infiltrates the cerebral spinal fluid (CSF) and ventricular spaces, frequently resulting in central nervous system (CNS) and spinal cord metastasis. Because of this tendency to metastasize, treatment regimens include postoperative craniospinal irradiation (CSI) and chemotherapy. Though successful in reducing CNS dissemination, this treatment has many deleterious effects. In particular, intellectual (IQ) and academic declines have consistently been documented among MB survivors, with younger age at treatment, time since treatment, and CSI dose identified as significant risk factors (Copeland, deMoor, Moore, & Ater, 1999; Palmer et al., 2001, 2003; Reddick et al., 2003; Silber et al., 1992; Spiegel, Bouffet, Greenberg, Rutka, & Mabbott, 2004). Some evidence has been provided that these deficits are a result of the inability to acquire new information at an age-appropriate rate, rather than a sudden loss of previously learned information (Palmer et al., 2001). At this time, the role of basic cognitive processes, such as attention and memory, that
may underlie the slower rate of knowledge acquisition and associated IQ and academic declines are not fully understood.

Attention is the process by which stimuli are brought into conscious awareness (Dennis, Hetherington, & Spiegler, 1998). It involves a state of mental arousal, the selection of a target stimulus among competing stimuli, and the focused awareness of a stimulus over time. Memory is a multifaceted construct that involves the processes by which information is encoded, manipulated, stored, and retrieved. Although the exact nature of the relationship is unclear, it is generally accepted that attention and memory processes interact in the acquisition of new knowledge. Whereas attention promotes a selective awareness of presented information, memory provides a means of encoding, manipulating, and storing information for later use. Moreover, the disruption of attention or memory processes is likely to impede learning and ultimately impact academic achievement. Thus, it is logical to attempt to explain achievement deficits among pediatric brain tumor survivors as secondary to deficits involving attention and memory.

For most part, studies of attention in pediatric brain tumor survivors have used tests measuring focused and/or sustained attention (e.g., Conners’ Continuous Performance Test [CPT], Gordon Diagnostic System). Significant deficits in focused attention have been found in children treated for tumors of the third and fourth ventricles, with children treated with CSI showing more impairment than those without CSI (Dennis et al., 1998). Similarly, sustained attention was found to be significantly impaired in a heterogeneous group of pediatric brain tumor survivors treated with CSI, as well as MB survivors (Mulhern et al., 2001; Reddick et al., 2003). However, these studies used only a composite measure of attention rather than examining a wider range of attentional variables. In an attempt to provide a more detailed profile of attention deficits, Mulhern et al. (2004) assessed different attentional variables among a mixed sample of pediatric brain tumor survivors treated with CSI. They concluded that pediatric brain tumor survivors were less likely to respond to the target variable, were slow and variable when they did respond, had poor signal detection (perceptual sensitivity), and showed a conservative response style (biased toward minimizing false positive responding). In a study of the acute impact of local radiation therapy on attentional functioning, Merchant et al. (2002) examined the CPT scores of pediatric brain tumor patients who were assessed weekly during the radiation treatment. Although no significant deficits were found, there was a trend toward slower processing speed and decreased focused attention over time.

Studies of memory functioning among pediatric brain tumor survivors typically have used tests assessing explicit short-term and long-term memory via recall and recognition tasks (e.g., California Verbal Learning Test, Child Version [CVLT-C], Children’s Auditory Learning Test). Significant deficits in auditory verbal memory have been found among children diagnosed with tumors of the third and fourth ventricles treated with CSI (Dennis et al., 1998; Packer et al., 1989). Similarly, Mulhern et al. (2001) found MB survivors performed approximately one standard deviation below the mean on an auditory verbal memory task. More recently, Reddick et al. (2003) reported the overall verbal memory performance of 40 long-term survivors of pediatric brain tumors to be significantly lower than age-corrected test norms. To measure change in neurocognitive functioning over time, Spiegler et al. (2004) longitudinally assessed verbal and visual memory functioning among children treated for posterior fossa tumors. Although significant declines in visual memory were found over time, no decline was observed in verbal memory. However, the estimated intercepts of all verbal memory indices at baseline (i.e., immediate, delayed, short-term, and level of learning) fell below the standardization sample, and that immediate recall was approximately two thirds of a standard deviation below the mean.

Although the results of these studies provide documentation of attention and verbal memory deficits among pediatric brain tumor survivors, questions still remain about the specific nature of these deficits and how they may impact academic achievement. In an effort to more clearly understand the neurocognitive and physiological substrates underlying these deficits, Reddick et al. (2003) have proposed a developmental model explaining the relationships between normal-appearing white matter volume (NAWM) from Magnetic Resource Imaging (MRI) of the brain, attention, memory, IQ, and academic achievement. According to this model, more intact attention was associated with greater NAWM, higher IQ, and better academic achievement. Although providing a theoretical connection between attention, IQ, and academic achievement, questions still remain about the specific attentional processes involved and the role of memory functioning. More specifically, the composite attention score used in Reddick et al. (2003) model (overall index from the CPT) did not allow for the analysis of separate attentional processes such as selective attention, processing speed, and efficiency of signal detection. The use of the composite verbal memory score in
Reddick et al. (2003) model (list A, trials 1–5 from the CVLT-C) had similar limitations in understanding specific memory processes. Thus, the purpose of this study was to dismantle the global indices of attention and memory used previously and to then test the hypotheses: (a) that specific memory and attention deficits are prevalent in survivors of childhood MB and (b) that these deficits are associated with problems with academic achievement.

**Method**

**Patient Selection and Medical Therapy**

Data for this study were collected via retrospective medical chart review of children consecutively treated on the Treatment of Newly Diagnosed Medulloblastoma and Supratentorial PNTT in Patients >3 Years with a Phase II Topotecan Window (high-risk patients only), Risk Adapted Radiation Therapy and Dose-Intensive Chemotherapy with Peripheral Blood Stem Cell Support (SJMB96; Strother et al., 2001) protocol at St. Jude Children’s Research Hospital. Children and adolescents with histologically proven MB and treated on the SJMB96 protocol between October, 1996, and February, 2000 were considered for this study. Eligibility criteria required all patients to be 6 years of age or older at the time of testing, English-speaking, and that their neurological status permitted them to participate in the testing (i.e., sufficient vision, hearing; n = 56). Seventeen patients who either did not complete the CVLT-C or had received the adult version of the CVLT were not included in this study. Additionally, one child who did not receive achievement testing was also excluded, thus the final sample size was n = 38. If multiple testing sessions were available for a particular patient, the most recent session was chosen for analysis. The patients were a mean of 8.34 years of age (SD = 2.78, range = 4.01–13.92) at the start of CSI and, at the time of assessment, were an average of 1.97 years (SD = 1.54, range = −0.04–4.74) since the start of CSI. Two patients were tested before CSI, while the remaining 36 patients had begun CSI at the time of testing. There were 23 males (60.5%) and 15 females (39.5%). Twenty-nine patients were Caucasian (76.3%), 7 were African American (18.4%), and 2 were of Hispanic decent (5.3%). Eighteen patients received special education services and 8 patients repeated at least one grade in school. The patients had an average IQ score of 94.06 at the time of testing (SD = 18.20, range = 46–126) and were an average of 10.31 years of age (SD = 2.68, range = 6.34–16.10) at the time of testing. To provide an estimate of socioeconomic status (SES), we collected parental education. The parents of the MB survivors had an average of 14.51 years of education (SD = 2.5, range = 8–20).

Patients were treated with surgical resection, risk-adapted CSI, and primary site conformal irradiation and chemotherapy. Average risk patients (those with residual tumor measuring less than 1.5 cm² and no evidence of dissemination) received 23.4 Gy CSI (n = 26), posterior fossa irradiation to 36 Gy, and primary site irradiation to 55.8 Gy by using conformal treatment techniques. High-risk patients (those with residual tumor measuring greater than or equal to 1.5 cm² or metastatic disease) received preirradiation Topotecan followed by 36–39.6 Gy CSI (n = 13) and primary site irradiation to 55.8–59.4 Gy. Six weeks after the completion of CSI, all patients started adjuvant chemotherapy comprising of 4 cycles of high-dose cyclophosphamide, cisplatin, and vincristine.

**Neurocognitive Assessment**

CVLT-C (Delis, Kramer, Kaplan, & Ober, 1994) Patients received a protocol-driven assessment of verbal memory and learning as measured by the CVLT-C. This test requires patients to learn a list of 15 words across five trials and to retain this information across short and long-time delays. Eight subscores were selected to be included in the analysis. List A total recall was used to provide an estimate of immediate recall across five presentations of the word list. Short delay free recall was used to measure cumulative immediate recall across five presentations of the word list. Short delay free recall was used to provide an estimate of immediate auditory recall. Long delay free recall was used to measure auditory recall after a 20-minute interval. Short delay cued recall and long delay cued recall were used to distinguish encoding from retrieval problems, and correct recognition hits was used to measure response discrimination. The semantic cluster ratio score was used as an indicator of the extent to which the child used an active learning strategy and the learning slope was used as an indicator of acquisition rate. All subscores are reported as z-scores, with the exception of list A total recall which is reported as a t score. For comparability purposes, list A total recall was converted to z-score format in this study. The CVLT-C standardization sample consisted of 70% Caucasians, 14% African Americans, 12% Hispanics, and 4% of other ethnicities. The modal value of parent education was 12 years, and there was an equal representation of males and females (459 and 461, respectively). The age range was from 5 to 16 years of age, with an average of 10.84 (SD = 2.68) years of age. Test–retest reliabilities of the selected subtests are reported in the manual to range from .38 to .75. Factor analyses provide evidence of construct validity in that the CVLT-C scores loaded onto theoretically meaningful factor structures.
CPT (Conners, 1992/1995)
Each patient received also a protocol-driven assessment of attention and processing speed, as measured by the CPT. Patients’ CVLT-C and CPT assessments were matched based upon their dates of administration. The CPT is a computerized measure of attention and concentration that assesses ability to sustain attention and provides an estimation of processing speed. This version of the CPT is a 14-minute computerized test that requires the child to discriminate targets (i.e., X’s) from nontargets (i.e., letters of alphabet). Eleven age- and gender-corrected indices of the CPT were examined, each representing different attentional attributes: errors of omission (higher scores reflect problems with selective attention), hit reaction time interstimulus interval change and hit reaction time standard error interstimulus interval change (higher scores reflect problems in adapting response tempo to stimuli), hit reaction time standard error and hit reaction time variability standard error (higher scores represent inconsistency of responding), risk taking or β (higher scores reflect a conservative response style intended to minimize commissions), hit reaction time (reverse scored so that higher scores reflect slower processing speed), attentiveness or d’ (higher scores represent poor perceptual sensitivity), errors of commission (higher scores reflect impulsivity, disinhibition), hit reaction time block change and hit reaction time standard error block change (higher scores reflect problems with sustained attention). All variables are reported T-scores, with the exception of errors of omission which is reported as a percentile ranking. For comparability purposes, errors of omission were converted to T-scores format in this study. When multiple test administrations were given after CSI, the most recent was selected for inclusion. The CPT standardization sample had an equal representation of males and females (51.2 and 48.8%, respectively). The age range was from 4 to 30 years, with a modal age of 12–13 years old. No information was available for the SES or race of the sample. CPT test–retest reliability for a 3-month interval is reported to range from .55 to .84 (Conners, 2000). Support for validity comes from documented performance differences between Attention Deficit Hyperactivity Disorder (ADHD) and non-ADHD samples (Seidel & Joschko, 1990).

WIAT (The Psychological Corporation, 1992)
The WIAT was administered to assess academic achievement. Patients’ WIAT assessments were matched to the administration dates of the CVLT-C and CPT. For the purposes of this study, three subtests were examined to assess broad achievement: basic reading, spelling, and mathematical reasoning. The WIAT standardization sample consisted of 75.6% Caucasians, 12.4% African Americans, 9.9% Hispanics, and 2.0% of other ethnicities. The modal value of parent education was 12 years, and there was an equal representation of males and females (51 and 49%, respectively). The age range was from 5 to 19 years of age, with a modal age of 11 years old. The test–retest reliabilities as reported by the manual ranged from .89 to .94 for the three subtests. Multitrait-multimethod studies provide evidence of construct validity by correlating subtest scores from the WIAT with composite scores from three standardized measures of achievement. Convergent correlations ranged from .67 to .78 for basic reading, mathematical reasoning, and spelling.

Data Analyses
Data were analyzed by using the SPSS statistical software. One sample t tests were conducted to test the hypotheses that there would be deficits in CVLT-C, CPT, and WIAT performance. T-Scores from the CVLT-C were compared with a population mean of zero, whereas T scores from the CPT were compared with a population mean of 50. Standard scores from the WIAT were compared with a population mean of 100. In these analyses, the population means were derived from the CVLT-C, CPT, and WIAT standardization samples as reported in the test manuals. To determine how the MB sample in this study compared with the CLVT-C, CPT, and WIAT standardization samples on other dimensions (e.g., age, SES, ethnicity, gender) that may be relevant to task performance, we conducted statistical group mean comparisons via chi-square and t-test analyses. Because of the large number of CVLT-C, CPT, and WIAT indices compared in this study, a conservative statistical criterion was set (p ≤ .01; two-tailed). This allowed for the detection of an effect size (ES) of medium or greater magnitude (ES ≥ .50; Cohen, 1992).

Stepwise multiple regression analyses were conducted to test the hypotheses that the variables age at time of CSI, time since CSI, and CSI dose would predict deficit CVLT-C, CPT, and WIAT scores with the criterion for significance set at p ≤ .01. Lastly, to test whether deficit CVLT-C and CPT indices were associated with academic achievement after controlling for time since CSI, we conducted stepwise multiple regressions with basic reading, spelling, and mathematical reasoning subtests as the dependent variables.

Results
Patient and Standardization Sample Comparisons
Parental education levels were examined as a proxy for SES. No statistically significant differences were found
between the MB survivors and the CVLT-C standardization sample on gender, $\chi^2 = 2.02, p \leq .20$; age, $t = -1.211, p \leq .23$; and race, $\chi^2 = 3.6, p \leq .20$. Although significant differences were found for parental education, parents of MB patients had significantly higher levels of education than the CVLT-C standardization sample, making it unlikely that MB survivors would perform worse on the CVLT-C as a product of their SES. No significant differences were found between the MB survivors and the CVLT-C standardization sample on gender, $\chi^2 = 1.45, p \leq 1.0$. Because the CVLT-C manual reported only the modal age, mean comparisons could not be conducted. However, the modal age of the CPT standardization sample (mode = 11 years) was within one standard deviation of the mean age of the MB survivors at the time of testing ($M = 10.31, SD = 2.68$). No information was provided in the CPT test manual regarding parent education level or ethnicity. Finally, no statistically significant differences were found between the MB survivors and the WIAT standardization sample on gender, $\chi^2 = 1.64, p \leq 1.0$, and race, $\chi^2 = 4.62, p \leq 1.0$. Significant differences were found for parental education such that parents of MB patients had significantly higher levels of education than the WIAT standardization sample. But similar to the CVLT-C results, it is unlikely that MB survivors would perform worse on the WIAT as a product of their SES. Because the WIAT manual reported only the modal age, mean comparisons could not be conducted. However, the modal age of the WIAT standardization sample (mode = 11 years) was within one standard deviation of the mean age of the MB survivors at the time of testing ($M = 10.31, SD = 2.68$). Based on these findings, it was concluded that current MB sample is sufficiently similar to the CVLT-C, CPT, and WIAT standardization samples to allow mean group comparisons.

**CVLT-C Analyses**

Comparisons of the mean patient group performance to the standardization sample means for the eight CVLT-C subtests demonstrated no significant performance differences meeting the a priori criterion of $p \leq .01$ (Table I).

However, all mean subtest scores for the patient group fell below the normative mean of zero demonstrating a trend toward below average memory functioning. One possible explanation is that serial administrations of the CVLT-C masked the extent of memory deficits because of practice effects. However, the number of CVLT-C administrations ($M = 2.86$, range = 1–6) was not significantly associated with overall performance as measured by list A total recall ($r = .001, p = .995$).

### Table I. Mean z-scores and Effect Sizes (ES) for CVLT-C Scores

<table>
<thead>
<tr>
<th>Subtest</th>
<th>Mean z-score</th>
<th>SD</th>
<th>t value</th>
<th>p value</th>
<th>ES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short delay cued recall</td>
<td>-0.41</td>
<td>1.07</td>
<td>-2.35</td>
<td>.024</td>
<td>.38</td>
</tr>
<tr>
<td>Long delay cued recall</td>
<td>-0.30</td>
<td>0.84</td>
<td>-2.21</td>
<td>.033</td>
<td>.36</td>
</tr>
<tr>
<td>List A total recall $^a$</td>
<td>-0.41</td>
<td>1.13</td>
<td>-2.21</td>
<td>.034</td>
<td>.36</td>
</tr>
<tr>
<td>Learning slope</td>
<td>-0.37</td>
<td>1.16</td>
<td>-1.96</td>
<td>.054</td>
<td>.32</td>
</tr>
<tr>
<td>Short delay free recall</td>
<td>-0.32</td>
<td>1.25</td>
<td>-1.56</td>
<td>.128</td>
<td>.26</td>
</tr>
<tr>
<td>Long delay free recall</td>
<td>-0.29</td>
<td>1.15</td>
<td>-1.55</td>
<td>.129</td>
<td>.25</td>
</tr>
<tr>
<td>Semantic cluster ratio</td>
<td>-0.18</td>
<td>1.24</td>
<td>-0.91</td>
<td>.367</td>
<td>.15</td>
</tr>
<tr>
<td>Correct recognition hits</td>
<td>-0.13</td>
<td>0.98</td>
<td>-0.82</td>
<td>.415</td>
<td>.13</td>
</tr>
</tbody>
</table>

$^a$Mean standardization sample performance minus MB score.

### CPT Analyses

Comparisons of the means for CPT indices to the standardization sample demonstrated statistically significant deficits on 8 of 11 individual CPT variables ($p \leq 0.01$) as well as the composite overall index ($t = 9.24, p = .000$): errors of omission, hit reaction time, hit reaction time standard error, variability of standard errors, attentiveness, risk taking, hit reaction time interstimulus interval change, and hit standard error interstimulus interval change (Table II).

In contrast to the other scores, the mean for errors of commission scores is significantly lower than the standardization mean, reflecting better performance than the normal population. Therefore, it is not a deficit and was not included in subsequent analyses. Because the overall index is based upon several of the individual indices, we did not include it in further analyses.

Eight multiple regressions were conducted to test for association between age at CSI, CSI dose, and time since CSI and the identified CPT deficit indices. Age at CSI and CSI dose were not significant in any of the analyses. However, time since CSI significantly predicted three indices from the CPT: errors of omission, attentiveness, and risk taking. Time since CSI accounted for 34.7% of the variance in errors of omission, 25.6% of the variance in attentiveness, and 19.4% in risk taking. In each case, increasing time from CSI was associated with worse CPT performance.

Because errors of omission, attentiveness, and risk taking all worsened with increasing time from CSI, exploratory analyses were conducted to assess their interrelationships. Bivariate correlations revealed significant associations among all three, with errors of omission and risk taking sharing 63.2% of the variance ($r = .795, p = .000$), errors of omission and attentiveness
sharing 38.8% of the variance ($r = .623, p = .000$), and attentiveness and risk taking sharing 35.8% of the variance ($r = .598, p = .000$).

**WIAT Analyses**

Three multiple regressions were conducted to test for association between age at CSI, CSI dose, and time since CSI and the WIAT subtests. Age at CSI and CSI dose were not significant in any of the analyses. However, time since CSI significantly predicted the basic reading subtest of the WIAT, accounting for 20.2% of the variance. Although the associations between time since CSI and the math and spelling subtests did not reach statistical significance, the relationships with all three WIAT subtests were such that increasing time since CSI was associated with worse subtest performance.

Stepwise multiple regressions models were used to test the strength of association between the eight CPT deficit indices and academic achievement, as measured by the basic reading, spelling, and mathematical reasoning subtests of the WIAT, after controlling for time since CSI (Table III). The means for all three WIAT subtests were significantly below the standardization sample ($p \leq .01$). The results indicated that errors of omission, but no other CPT index, were significantly associated with basic reading and mathematical performance, accounting for 23% of the variance in basic reading ($p = .002$) and 19.4% of the variance in mathematical reasoning ($p = .006$). The association with spelling failed to meet our criterion for statistical significance. For each outcome score, greater errors of omission were associated with poorer academic performance.

**Discussion**

The purpose of this study was to examine aspects of attention and memory that are impaired among MB survivors and to assess their relationship with academic achievement deficits. In summary, we found that specific aspects of attentional functioning were impaired but that verbal memory abilities remained relatively intact. More specifically, three attentional functions that were deficient worsened with increasing time since the start of therapy and one was predictive of academic achievement problems.

The absence of significant verbal memory impairments in MB survivors is inconsistent with some previous reports of verbal memory deficits among pediatric brain tumor survivors (Dennis et al., 1998; Packer et al., 1989; Reddick et al., 2003). However, trends were

Table II. Mean Difference Scores, Effect Sizes (ES), and Results of Regression Analyses of Clinical Variables on CPT Deficit Scores

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean $T$ score</th>
<th>$SD$</th>
<th>$t$ value</th>
<th>$p$ value</th>
<th>ES</th>
<th>Clinical predictor</th>
<th>$p$ value</th>
<th>Model $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Errors of omission</td>
<td>64.17</td>
<td>6.72</td>
<td>13.00</td>
<td>.000</td>
<td>2.11</td>
<td>Time since CSI</td>
<td>.000</td>
<td>.350</td>
</tr>
<tr>
<td>Hit RT ISI change</td>
<td>73.14</td>
<td>18.56</td>
<td>7.66</td>
<td>.000</td>
<td>1.25</td>
<td>None</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Hit reaction time SE</td>
<td>67.71</td>
<td>14.58</td>
<td>7.49</td>
<td>.000</td>
<td>1.21</td>
<td>None</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Risk taking ($B$)</td>
<td>68.60</td>
<td>17.98</td>
<td>6.38</td>
<td>.000</td>
<td>1.03</td>
<td>Time since CSI</td>
<td>.007</td>
<td>.183</td>
</tr>
<tr>
<td>Hit reaction time variability of SE</td>
<td>60.81</td>
<td>10.27</td>
<td>6.49</td>
<td>.000</td>
<td>1.05</td>
<td>None</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Hit reaction time$^c$</td>
<td>62.89</td>
<td>14.05</td>
<td>5.70</td>
<td>.000</td>
<td>0.92</td>
<td>None</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Attentiveness ($d'$)</td>
<td>54.64</td>
<td>7.24</td>
<td>3.95</td>
<td>.000</td>
<td>0.64</td>
<td>Time since CSI</td>
<td>.000</td>
<td>.296</td>
</tr>
<tr>
<td>Hit SE ISI change</td>
<td>56.66</td>
<td>11.74</td>
<td>3.50</td>
<td>.001</td>
<td>0.57</td>
<td>None</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Errors of commission</td>
<td>45.17</td>
<td>9.20</td>
<td>−3.24</td>
<td>.003</td>
<td>0.53</td>
<td>None</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Hit SE block change</td>
<td>53.40</td>
<td>11.23</td>
<td>1.87</td>
<td>.070</td>
<td>0.30</td>
<td>None</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Reaction time block change</td>
<td>53.19</td>
<td>18.80</td>
<td>1.05</td>
<td>.302</td>
<td>0.17</td>
<td>None</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Isi, interstimulus interval; SE, standard error; RT, reaction time.

$^a$Mean standardization sample performance minus medulloblastoma (MB) score.

$^b$Converted to $T$-score format for comparability purposes.

$^c$Reverse scored for comparability purposes. Subtests are given in descending order by effect size. Only deficit scores with $p$ values $<.01$ were explored with regression analyses.

Table III. Results of Regression Analyses of Clinical Variables and CPT Deficit Scores on Academic Achievement

<table>
<thead>
<tr>
<th>Variable</th>
<th>$M$</th>
<th>$SD$</th>
<th>Clinical predictor</th>
<th>$p$ value</th>
<th>Model $R^2$</th>
<th>CPT predictor</th>
<th>$p$ value</th>
<th>Model $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic reading</td>
<td>92.50$^a$</td>
<td>15.28</td>
<td>Time since CSI</td>
<td>.005</td>
<td>.202</td>
<td>Errors of omission</td>
<td>.002</td>
<td>.228</td>
</tr>
<tr>
<td>Mathematical reasoning</td>
<td>89.18$^a$</td>
<td>11.60</td>
<td>None</td>
<td>—</td>
<td>—</td>
<td>Errors of omission</td>
<td>.006</td>
<td>.195</td>
</tr>
<tr>
<td>Spelling</td>
<td>91.24$^a$</td>
<td>14.56</td>
<td>None</td>
<td>—</td>
<td>—</td>
<td>None</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

$^a$Significantly below the standardization sample ($M = 100, SD = 15; p < .01$).
observed for the mean scores of all CVLT-C indices to fall below the standardization sample. One explanation for this finding is that there is an immediate, mild, and stable insult to verbal memory functioning. This finding is consistent with reports of below average verbal memory functioning among children treated with posterior fossa tumors at baseline testing (i.e., approximately 6 months after diagnosis), with no further change over time (Spiegler et al., 2004). Alternatively, practice effects caused by repeated CVLT-C testing may have masked the extent of verbal memory impairment, although the number of CVLT-C administrations was not associated with test performance. For the purposes of this study, the CVLT-C results are interpreted as showing no statistical evidence of verbal memory impairment. However, questions still remain regarding the clinical significance of the “below average memory functioning” of the MB survivors given that small to medium effect sizes were found. Additionally, the finding of no practice effects given serial administrations of the CVLT-C may also be clinically relevant, particularly if this were to be expected in the normal population. Unfortunately, the answers to these questions are beyond the scope of the current study and more research utilizing closely matched control subjects is needed to provide appropriate explanations.

Although there was no compelling evidence of verbal memory impairment, attention was found to be significantly impaired among long-term survivors of MB. The CPT results suggest that, as a group, the MB survivors had problems with selective attention (errors of omission), attempted to minimize errors of commission at the expense of correct hits (risk taking), were slow and inconsistent when they did respond (hit reaction time, hit reaction time standard error, hit reaction time variability of standard errors), had difficulty discriminating target from nontarget stimuli (attentiveness), demonstrated poor mental flexibility (hit reaction time interstimulus interval change and hit reaction time standard error interstimulus interval change), and exhibited fewer errors of commission than the standardization sample. This pattern is consistent with previous reports of attention deficits among pediatric brain tumor survivors (Dennis et al., 1998; Mulhern et al., 2001; Mulhern et al., 2004; Reddick et al., 2003) and uniquely articulates the pattern of observed attention deficits on the CPT as consisting largely of deficits in processing speed and selective attention rather than impulsivity and disinhibition.

Increased time since CSI was associated with worse performance on errors of omission, risk taking, attentiveness, and basic reading, consistent with numerous studies that demonstrate increasing neurocognitive problems with increasing time since therapy (Palmer et al., 2001, 2003; Spiegler et al., 2004). One explanation for the gradual decline in functioning is that CNS-directed therapy prevents the normal development of white matter, resulting in the inability to develop age-appropriate attentional functioning (Reddick et al., 2003). Additionally, with time since CSI controlled, errors of omission was the best predictor of reading and math achievement. However, the absence of other attention variables from the prediction equations does not reflect a lack of association between these variables and academic achievement. Post-hoc analyses reveal that both reading and math performance significantly correlated with errors of omission and attentiveness (p ≤ .01), and that reading performance also correlated with risk taking (p ≤ .01). It is possible that attentiveness and risk taking were excluded from the prediction models due to their strong correlations with errors of omission (i.e., multicollinearity of predictors). Based on these findings and consistent with previous reports (Reddick et al., 2003), the current study demonstrates that survivors of MB exhibit deficits on errors of omission, attentiveness, and risk taking in that their performance on these variables decreases over time and is highly associated with academic achievement.

The nature of the relationships between errors of omission, attentiveness, and risk taking can be understood in signal detection theory which has been useful in dissecting the CPT performance of otherwise healthy children with ADHD (Losier, McGrath, & Klein, 1996). Within this conceptualization, errors of omission are dependent upon attentiveness and risk taking. The non-target response (i.e., letters of alphabet) distribution and target response (i.e., X’s) distribution overlap in proportion to the difficulty of discriminating between non-targets and targets (attentiveness). This overlap represents a range of uncertainty in responding. Within this range of uncertainty, individuals may adopt a response style which emphasizes reduction of errors of commission, reduction of errors of omission, or one which balances the two sources of error (risk taking).

Among unmedicated children with ADHD, attentiveness is worse compared with normal children whereas risk taking is similar to normal children (Losier et al., 1996). In medicated children with ADHD, attentiveness is improved and risk taking is unchanged. In our sample, patients exhibited problems with attentiveness, consistent with the ADHD sample. However, unlike the ADHD sample, our patient sample also exhibited problems with risk taking. This
implies that the cognitive phenotypes may be qualitatively different, although Epstein et al. (2003) found that both attentiveness and risk taking were strongly associated with ADHD symptoms. Nevertheless, signal detection theory may provide a novel method of understanding the fundamental cognitive processing problems underlying attention deficits and academic failure among survivors of pediatric brain tumors. Whether attentiveness and risk taking change in response to stimulant therapy among survivors of pediatric brain tumors is not yet known; however, reductions in errors of omission with methylphenidate have been observed in a laboratory setting (Thompson et al., 2001).

Several limitations of this study should be considered when interpreting and generalizing the results. First, the relatively small sample size substantially decreased our power, reducing our ability to detect an effect size of less than 0.50 (Cohen, 1988). Although this may help explain why verbal memory deficits were not observed in this sample and why age at CSI and CSI dose were not significant risk factors, it also emphasizes the significance of the observed attention deficits. Second, the cross-sectional design of the current study does not address the developmental trends in attentional functioning that are expected to be significant given the association between attention deficits and time since CSI. Future studies including longitudinal designs will allow a more clear understanding of the onset of attentional impairment and its course over time, as well as a more thorough understanding of how attentional impairment effects long-term academic achievement. Third, this study was restricted to only one visual attention task and one auditory verbal memory task, which did not allow for a comprehensive evaluation of attention and memory processes (Baddeley, 1990; Mirsky, Anthony, Duncan, Ahearn, & Kellam, 1991). Finally, this study did not include a healthy comparison group.

This study provides a preliminary view of attention among MB survivors. Future studies should work toward the inclusion of larger samples, longitudinal designs, multidimensional assessment, and a control or comparison group. Additionally, the inclusion of more sensitive and specific measures of attention and memory will be more likely to provide a rationale for the design of intervention and remediation programs.

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