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Subtle Motor Signs and Executive Functioning in Chronic Paediatric Traumatic Brain Injury: Brief Report

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Abstract

Background: Children with traumatic brain injury (TBI) are reported to have persistent deficits in executive functioning and subtle motor functions.

Aim: This study examined the relationship between subtle motor signs and executive functioning in children with TBI.

Methods: Eighteen children aged 13–18 years with mild to severe TBI at least one year before study participation and 16 age-matched typically-developing controls were examined using the Revised Physical and Neurological Examination of Subtle Signs (PANESS), a simplified Go/No-go task, portions of the Delis-Kaplan Executive Function System Verbal Fluency and Trail Making tests, and a Wechsler Coding test.

Results: There were significant associations between PANESS scores and executive functioning measures in children with TBI but not in controls.

Conclusion: Results suggest that assessment of subtle motor signs may provide broader information regarding functioning after paediatric TBI.

Keywords

traumatic brain injury; subtle motor function; PANESS; paediatric; executive function

Paediatric traumatic brain injury (TBI) often results in chronic deficits in executive functions – a set of higher-order cognitive abilities such as inhibition and working memory, which mediates the neurobehavioural sequelae associated with TBI.¹ The importance of executive dysfunction in children with TBI is highlighted given the association between chronic impairments in executive functions (assessed approximately 5 years post-injury) and children's adaptive functioning and behavioural adjustment, as well as parent psychological

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Declaration of interest

The authors report no conflicts of interest.

distress and family burden.² More recently, subtle motor signs have been shown in children with TBI of varying levels of severity.³ Subtle motor signs were noted to be sensitive to differences between children with TBI and uninjured controls as well as to changes in children with TBI over time.⁴ However, the relationship between subtle motor signs and executive functioning after paediatric TBI has not been explored.

Subtle motor signs have been shown to be related to executive functioning in other neurodevelopmental disorders such as attention-deficit hyperactivity disorder (ADHD). In children with ADHD, subtle motor signs such as motor overflow (co-movement of body parts not specifically needed to efficiently perform a task) were found to be predictive of impaired inhibitory control on a behavioural task requiring conscious inhibition of effortful motor responses.⁵ Impairment in response inhibition, a core executive function deficit, is a major overlapping characteristic between children with TBI and children with ADHD.⁶ In addition, given the high rate of comorbid ADHD in TBI, subtle motor signs and executive function may be similarly related in TBI. However, due to differences in the pathophysiology of these two conditions, this relationship must be explicitly evaluated. Thébault and colleagues showed that manual dexterity was related to cognitive functioning, irrespective of sex, lesion side, and presence of cerebral palsy in children who experienced a focal brain insult during the neonatal period and typically-developing children.⁷ Moreover, in children with malignant posterior fossa tumours with injuries to the cerebellum, impaired fine motor dexterity was associated with low IQ scores.⁸ Similarly, a meta-analysis showed a relationship between motor and cognitive skills in children with developmental coordination disorder.⁹ These studies suggest a relationship between motor abilities and cognitive functioning.

The current study expanded on previous research examining subtle motor signs in paediatric TBI by examining the relationship between subtle motor signs and executive functioning across the range of TBI severity. Greater subtle motor signs were hypothesized to be associated with greater executive dysfunction across different measures of executive functioning.

Methods

Eighteen children ages 13 – 18 years [$M(SD) = 16.09(1.57)$; 11 males] who had sustained mild ($n=6$), moderate ($n=6$), or severe ($n=6$) TBI at least 1 year prior to study participation were included. Participants with TBI were recruited from outpatient paediatric brain injury rehabilitation clinics into a parent study designed to evaluate inhibitory control and processing speed which included the performance-based Common Data Elements for evaluating EF after pediatric TBI.¹⁰ Exclusion criteria were penetrating TBI and inability to complete paper-pencil tasks or push buttons due to cognitive or motor impairment. Severity of TBI was defined using the American Congress of Rehabilitation Medicine criteria.¹¹ Sixteen age-matched neurotypical uninjured controls were included [$M(SD) = 16.2(1.45)$ years; 12 males]. Controls were recruited using flyers, word-of-mouth, and radio advertisements. None of the controls met criteria for educational or behavioural diagnosis on a structured interview, Diagnostic Interview for Children and Adolescents (DICA-IV)¹²; the same was true for the children with TBI with regard to their pre-injury history. All

participants had IQ scores of 88 or above as measured by the two-scale Weschler Abbreviated Scale of Intelligence (WASI).¹³ The local university's Institutional Research Board approved this study. Written informed consent and assent were obtained from a parent or legal guardian and child participants, respectively.

Measures

Revised Physical and Neurological Examination of Subtle Signs (PANESS).—

The Revised PANESS is a standardized assessment that examines subtle motor abnormalities during gait, balance, and timed basic motor functions in children.¹⁴ The PANESS has two primary sub-scores - Gaits and Stations and Total Timed. Gaits and Stations included gait and balance tasks such as heel-walking and maintaining stance with eyes closed. The Total Timed score includes the time to complete 20 movements of 6 timed repetitive tasks, namely foot tapping, heel-toe tapping, hand patting, hand pronation/supination, finger tapping, and finger apposition (tapping the thumb to each of the four other fingers in a fixed sequence). Higher scores indicate poorer performance. The PANESS has been normed on 168 typically-developing children¹⁵ and has been shown to be sensitive to gender and age-related changes¹⁶ and has good test-retest reliability in older children.³

Simplified Go/No-go Task.—Cognitive demands were minimized using green and red colours, which are well-established cues for 'go' and 'stop'.¹⁷ Participants were instructed to press a button with their right index finger when a 'go' target (Green spaceship) is present and inhibit that response when a 'no-go' target (Red spaceship) is present. Go targets were presented 4 times as often as No-go targets to create the prepotent motor response that must be inhibited; there were a total of 207 trials. Response times were considered a measure of executive functioning due to the cognitive processes involved in the task. Raw scores of commission rate (percentage of failed inhibition trials), mean response times (in milliseconds), and intra-subject variability (ISV) in response times (calculated as [(SD of Go reaction time)/ (mean Go reaction time)]) were the primary outcome measures.

Delis-Kaplan Executive Function System (D-KEFS).—The D-KEFS Verbal Fluency and Trail Making subtests evaluate processing speed in verbal and visual-motor domains respectively and are normed for ages 8 - 89 years.¹⁸ For this study, only the standard scores from the switch condition of both subtests were analysed since they assess the executive components of the skill. The Verbal Fluency Switch condition assesses phonemic fluency wherein the child is asked to verbalize examples of specific categories. The Trail Making Switch is a timed connect-the-circle visuomotor task involving switching between numeric and alphabetic sequences.

Coding.—Coding subtests of the Wechsler Intelligence Scale for Children (WISC-IV)¹⁹ and Wechsler Adult Intelligence Scales (Digit symbol - WAIS-IV)²⁰ are measures of processing speed that require transcription of a digit-symbol code as quickly as possible for 2 minutes. The coding subtests are normed for children aged 6-16 years (WISC-IV) and ages 17 and up (WAIS-IV). Scaled scores were used to combine data across the 2 tests. Eleven children completed the WAIS-IV (5 TBI; 6 controls), and 23 completed the WISC-IV (13 TBI; 10 controls).

Statistical analyses

For the control group, data from PANESS Total Timed, Go/No-go response time, and D-KEFS Trail Making switch were not normally distributed. All other data were normally distributed. Independent samples *t*-tests or Mann-Whitney *U*-tests (for non-normal data) were conducted to examine group differences. For each group, Pearson's or Spearman's (for non-normal data) correlations were used to examine the relationship between the PANESS and executive functioning measures. If age and/or sex correlated with the study variables, they were used as covariates in the correlations. Alpha was set at .05. All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS), version 25.0.

Results and Discussion

Mean time since injury for the TBI group was 5.54 years, $SD = 5.44$ (Range 1 - 14.5 years). There was no group difference on age, $t_{(32)} = -.22$, $p = .83$ or IQ scores, $t_{(32)} = -1.41$, $p = .17$. Within the TBI group, there was no age difference between those with mild versus moderate injury, $t_{(10)} = .16$, $p = .88$, moderate versus severe injury, $t_{(10)} = -.02$, $p = .98$, or mild versus severe injury, $t_{(10)} = -.16$, $p = .87$.

Performance on study measures by severity of TBI is summarized in Appendix 1. As expected, mean scores suggest worst performance among the children with severe TBI, and the performance of the group children with moderate TBI, relative to those with mild or severe TBI, varied by task. Table 1 shows the differences between controls and the entire group of children with TBI on study measures. The TBI group had significantly greater subtle motor deficits as measured by the PANESS Total Timed. Significant group differences were observed on Go/No-go commission errors and D-KEFS Verbal Fluency switch number correct scores, and accuracy scores, with the TBI group showing poorer performance across these measures.

Within the TBI group, age was not associated with the study measures except commission errors on the Go/No-go task, $r = -.5$, $p = .034$, with fewer errors as age increased. Sex correlated with commission errors, $r_{pb} = -.47$, $p = .049$, response times, $r_{pb} = .66$, $p = .003$, and ISV, $r_{pb} = .66$, $p = .003$, on the Go/No-go task. Females with TBI had fewer errors, slower reaction times, and greater ISV than males. In the control group, age was only associated with the PANESS Gaits and Stations, $r = -.51$, $p = .043$, with better performance as age increased. Sex correlated with PANESS Total Timed, $r_{pb} = .77$, $p < .0005$ and Verbal Fluency switch number correct, $r_{pb} = .55$, $p = .027$, with female controls having poorer performance on the PANESS Timed Total but better performance on Verbal Fluency than males. In this limited group we were unable to explore the interaction between sex and injury severity which may have also contributed to these findings.

Correlations between PANESS and measures of executive functioning within the TBI group are listed in Table 2. Within the TBI group, higher (worse) PANESS scores on both subtests were associated with more variable Go/No-go response times, and higher PANESS Timed Total scores were associated with slower response times. Higher PANESS Total Timed scores were also associated with poorer performance on D-KEFS Trail Making and Coding in the TBI group. Higher (worse) PANESS Gaits and Stations scores were associated with

poorer performance on Verbal Fluency switch accuracy in the TBI group. In the control group, no significant relationships were observed between PANESS and the executive functioning measures.

As hypothesized, in children with TBI, greater subtle motor deficits were associated with greater executive function deficits across most of the performance-based measures, though this was not found in the control group. These results further expand on a growing body of literature regarding subtle motor signs in children with TBI by highlighting the relationship between subtle motor function and executive functioning in children across the spectrum of TBI severity.

Specifically, we found significant relationships between the PANESS Timed Total score and measures of executive functioning that required speeded motor output during a cognitive task - the Go/No-go, D-KEFS Trail Making, and Coding tasks. The PANESS Gaits and Stations score was associated with fewer executive functioning measures – inter-subject variability on the Go/No-go and D-KEFS Verbal Fluency. Together, this suggests that in the children with TBI, while both gross and fine subtle motor function is associated with executive functioning, performance on speeded fine motor tasks on the PANESS have particular relevance for speeded executive functioning tasks with cognitive and motor demands.

These findings focusing on speeded subtle motor and executive functioning tasks differ from the previous findings in children with ADHD which have specifically focused on the relationship among measures of inhibition.⁵ Although the executive dysfunction following TBI shares some similarity to the features of ADHD, the slowing of processing speed, especially during complex tasks, has been highlighted as different in children with TBI compared to children with ADHD without TBI.¹ Furthermore, the particular relevance of the speeded tasks of the PANESS in this cohort which includes children with a history of mild TBI is consistent with previous findings that children who have clinically recovered from mild TBI perform worse than never-injured controls on the PANESS Timed Total tasks.⁴

The absence of a relationship between subtle motor signs and executive functions in typically developing controls suggests that this relationship in children with TBI is driven by injury-related pathology. This lack of association within controls is consistent with previous research where no relationship was found between subtle motor signs such as overflow and inhibition in 30 typically-developing controls⁵; however, the small sample size in our study may also contribute to the lack of association within controls.

We identified differences in the relationship between age and performance in our TBI and control cohorts. In children with TBI, commission errors on the Go/No-go task reduced as age increased; however, age did not correlate with commission errors in controls. The children with TBI also showed significantly more commission errors than controls, suggesting that the underlying weakness in inhibitory control in children with TBI⁶ contributes to continued maturation over this age range whereas controls achieve a stable level of good performance at an earlier age. This finding is similar to the results of Mostofsky et al. where age correlated with commission errors in a younger ADHD group (8

– 12 years) but not controls.⁵ While in the control group, PANESS Gaits and Stations scores improved with age, there was no relationship between age and Gaits and Stations in the TBI group. This suggests that the effect of TBI outweighs the effect of age with regards to gross motor skills in children with TBI.

Given the small sample size of the current study, the relationship between subtle motor signs and executive functions must be re-examined in a larger cohort. Future studies must also examine differences between types of TBI severity and gender effects as well as a broader range of EF tasks. Additionally, due to the high rate of comorbid ADHD, both developmental (pre-injury) and secondary (post-injury), in children with TBI, it may be important to understand the profiles of subtle motor deficits and executive dysfunction in these subgroups. Identifying the patterns of subtle motor deficits and their relationship to executive functioning may provide valuable insight into assessment and interventions for these groups. Our results suggest that clinical examination of subtle motor signs using the PANESS, a simple bedside assessment, can be valuable as part of preliminary assessment of executive functioning in children with TBI. Specifically, children who demonstrate subtle motor difficulties using the PANESS appear to be at risk for executive dysfunction and therefore warrant careful evaluation of their executive functioning skills. Given the relationship between motor and executive skills, consideration should be given to designing rehabilitation interventions for children with TBI which target optimization of both motor and executive functioning skills, rather than one or the other in isolation.

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Appendix 1.: Means and standard deviations for study measures by TBI severity

	TBI		
	Mild <i>M</i> (<i>SD</i>)	Moderate <i>M</i> (<i>SD</i>)	Severe <i>M</i> (<i>SD</i>)
<u>PANESS</u>			
Gaits and Stations	3.3 (2.25)	5.33 (2.88)	4.67 (2.42)
Total Timed	8.83 (5.85)	20.33 (4.5)	20.17 (9.75)
<u>Go/No-go[#]</u>			
Response times (ms)	291.02 (24.7)	319.5 (47.03)	334.66 (55.46)
Commission errors (%)	10.6 (12)	9.5 (7)	19.7 (9)
Intra-subject Variability	.168 (.035)	.188 (.027)	.196 (.05)
<u>D-KEFS Trail Making[*]</u>			
Switch	11.33 (2.94)	11.6 (1.82)	8.17 (2.32)
<u>D-KEFS Verbal Fluency[*]</u>			
Switch number correct	8.67 (1.75)	10.0 (2.39)	7.67 (3.08)

	TBI		
	Mild <i>M</i> (<i>SD</i>)	Moderate <i>M</i> (<i>SD</i>)	Severe <i>M</i> (<i>SD</i>)
Switch accuracy	8.67 (2.58)	10.0 (3.32)	8.67 (2.8)
Coding [*]	13.17 (4.36)	11.67 (3.88)	6.0 (2.45)
# Raw Scores			
* Standard scores			

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Table 1.

Group difference on study measures

	Controls	TBI	<i>t/U</i>	<i>p</i>
<u>PANESS</u>	<i>M (SD)</i>	<i>M (SD)</i>		
Gaits and Stations	3.5 (2.9)	4.44 (2.5)	1.02	.31
Total Timed	11.31 (6.9)	16.44 (8.6)	83	.04
<u>Go/No-go</u> [#]				
Response times (ms)	337.11 (66.2)	315.06 (45.6)	115	.32
Commission errors (%)	6.8 (6)	13.2 (10)	2.25	.03
Intra-subject Variability	.164 (.05)	.184 (.04)	1.39	.17
<u>D-KEFS Trail Making</u> [*]				
Switch	11.27 (1.8)	10.29 (2.8)	99	.29
<u>D-KEFS Verbal Fluency</u> [*]				
Switch number correct	11.13 (2.9)	8.94 (2.7)	2.28	.03
Switch accuracy	11.13 (3.0)	9.06 (2.8)	2.07	.047
<u>Coding</u> [*]	10.88 (2.3)	10.28 (4.7)	.46	.65

[#] Raw Scores^{*} Standard scores

Table 2.

Correlations between PANESS and executive functioning measures in the TBI group

PANESS	Gaits & Stations		Timed total	
	<i>r</i>	<i>p</i>	<i>r</i>	<i>p</i>
<u>Go/No-go</u>				
Response times	.03 *	.90	.73	.001
Commission errors	.38 **	.14	.14	.60
Intra-subject Variability	.58 *	.015	.52	.034
<u>D-KEFS Trail Making</u>				
Switch	-.33	.20	-.58	.015
<u>D-KEFS Verbal Fluency</u>				
Switch number correct	-.30	.25	-.22	.40
Switch accuracy	-.53	.029	-.29	.26
<u>Coding</u>	-.44	.07	-.49	.038

* partial correlations controlling for sex;

** partial correlations controlling for age and sex