Postural sway changes during static standing with concurrent task in children with traumatic brain injury

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ABSTRACT

الأهداف: دراسة تأثير المهام المتزامنة (الحركية والمعرفيه) على أداء التحكم في الوضعية لدى الأطفال المصابين بإصابات دماغية (TBI) مقارنة بنموذج مجموعة الشاهد (TD).

الطريقة: شارك في دراسة الحالات والشواهد 16 طفلاً مصاباً بـ TBI (عمر 11.63±1.89 سنة) و 22 مجموعة الشاعد TD (أعمارهم 11.41±2.24 سنة). أجريت هذه الدراسة في الفترة ما بين مايو 2016 ومارس 2017. وقد قام كل طفل بأداء ثابت تحت ثلاث حالات مختلفة: حركه فرديه، والمتزامنه، والمهمة المعرفية المتزامنة. يتضمن قياس أداء الرقابة الوضعية منطقة التأثير، وسرعة التأرجح الأماميه الخلفيه (AP)، وسرعة التأرجح (ML)، ومسافة نفوذ AP ومسافة تمايل ML كما تم قياسه باستخدام APDM® Mobility Lab (أوريغون، بورتلاند). تم استخدام تحليل الاختلاف المتكرر لتحليل البيانات.

النتائج: وجدنا أن الأطفال الذين يعانون من TBI أظهروا تدهورًا أكبر بكثير في أداء التحكم في الوضعية مقارنة بأطفال مجموعة الشاهد(p<0.05). أدت كل من المهام المتزامنة (الحركيه والمعرفيه) إلى خفض كبير في أداء التحكم الوضعي في كل من المجموعتين مع تغييرات أكثر وضوحا في الأطفال المصابين بمرض TBI مقارنة مع ضوابط TD.

الخاتمة: أظهرت النتائج أن أداء المهام المتزامنة (الحركية والمعرفية) أثناء الوقوف المستقيم أدى إلى تدهور أداء الرقابة الوضعية. إن وجود ضعف إدراكي وتوازن في الأطفال المصابين بمرض TBI قد يتسبب في تعقيد المهام المتزامنة ويتطلب قدراً أكبر من الاهتمام مقارنة بالمهمة الفردية.

Objectives: To investigate the effects of concurrent tasks (motor and cognitive) on postural control performance in children with traumatic brain injury (TBI) compared to typically developing (TD) control subjects.

Methods: Sixteen children with TBI (aged 11.63±1.89 years) and 22 TD controls (aged 11.41±2.24 years) participated in this case-control study. This study was conducted between May 2016 and March 2017. Each child performed static standing under 3 different conditions: single, concurrent motor, and concurrent cognitive task. Postural control performance measure includes sway area, anterior-posterior (AP) sway velocity, medio-lateral (ML) sway velocity, AP sway distance and ML sway distance as measured using the APDM® Mobility Lab (Oregon, Portland). A repeated-measure analysis of variance was used to analyse the data.

Results: We found that children with TBI showed significantly more deterioration in postural control performance than TD children ($p<0.05$). Both concurrent tasks (motor and cognitive) significantly decreased postural control performance in both groups with more pronounced changes in children with TBI than that of the TD controls.

Conclusion: The results demonstrated that, performing concurrent tasks (motor and cognitive) during upright standing resulted in deterioration of postural control performance. The existence of cognitive and balance impairment in children with TBI will possibly cause concurrent tasks to be more complex and demands greater attention compared to single task.

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Traumatic brain injury is frequently referred to as a 'silent epidemic', with the majority of society being unaware on the magnitude a TBI can cause on an individual's function.[1] It remains a leading cause of death and long-term disability in children worldwide with approximately 3 million children experiencing TBI annually.[2] Consequently, TBI may lead to neurological impairment which contributes to long-term disability among this group of children.

With the cognitive and behavioral deficit, individuals with TBI are faced with a long-term functional disability including postural control instability.[3,4] Postural control refers to the act of maintaining, achieving or restoring the line of gravity or centre of mass (COM) within the base of support (BOS).[5] It is a complex collaboration of sensory, motor, and central nervous system. Disruption of any components such as visual, vestibular sensory inputs, muscle weakness and loss of proprioception will result in postural control instability. This impairment could seriously interfere with the child's level of independence and lead to increased risk of falls.[5]

The maintenance and control of posture and balance, whether in static or dynamic conditions, are essential requirements for daily activity. Postural control requires a lot of cognitive resources.[6] The more challenging postural task required more cognitive processing in order to sustain the position. Children with TBI have both cognitive and information processing deficits that impact attention and functional abilities.[7,8] In daily life, children encounter situations in which they must perform cognitive and motor tasks simultaneously, such as responding to verbal instructions or manipulating objects while sitting or standing. These situations may be complex and challenging for children with TBI as they present with both attention and information processing deficit. Using dual-task methodology, it can examine the effect of adding a concurrent task during a motor task. Trials using dual-task paradigm are commonly used in a clinical setting to measure automatic control of movement indirectly. It is crucial to understand the effects of a concurrent task on postural control performance while designing a dual-task paradigm intervention program in this population. The dual-task intervention during postural control could be more challenging and may improve the postural stability better as compared to single task intervention.

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Since attention is a limited resource, it may become overloaded by competing for attention demands and subsequently might lead to reduced performance in one or all tasks.[9] Children with TBI may need more attention during postural control and as a result might be more vulnerable to falls while doing concurrent task. A recent study among healthy children and youth 5-18 years old showed concurrent cognitive task resulted in decreased postural stability.[10] Comparing the effects of different surface (firm vs. foam surface) on postural stability during concurrent cognitive task reveals that the foam surface caused greater interference in postural stability.[10] A normative database was created as a result of this study, which may benefit future investigations of post-concussion performances with potential to assess post-concussion severity. In addition, it also focuses on assessing both motor and cognitive domains simultaneously. This study also reports information regarding the effect of cognitive task on postural stability in healthy children & youth. The examined effect of concurrent cognitive and motor task conditions on postural control in children with TBI is limited. Therefore, the objective of the present study was to investigate the postural control performance under concurrent tasks in children with TBI and TD controls. We hypothesized that both concurrent motor and cognitive tasks would cause significant postural control deterioration compared to single task condition.

Methods. Sixteen children with TBI (13 boys and 3 girls) were recruited from a government-funded hospital in the district of Sungai Buloh, Selangor, Malaysia. Recruitment by the use of purposive sampling was engaged in this case-control study. Children with TBI GCS score at admission ≤12, at least 6 months post-TBI, age range 8-14 years old, able to walk independently without walking aid, (foot orthoses permitted), able to follow one-step commands, able to hold a tray, GCS score must be full at time of recruitment and consented to participate were included. Excluded were those who had received botulinum toxin or had undergone orthopaedic surgery in the previous 6 months, had visual field defects and those who had disruptive behaviour disorder assessed with Conners clinical index assessment with T-score >75.

Twenty-two (18 boys and 4 girls) TD children matched to the study group for age, gender, body weight, and height were recruited from the local schools served as controls. The institutional ethics committee approved the study and written informed consent was obtained from each participant and their guardian (or legal attorney).

We recorded each participant's demographic data and measured their cognitive function with the

Children's color trail test (CCTT). Children's color trail test is an outcome measure used for neuropsychological assessment providing information on visual attention, scanning, the speed of processing, mental flexibility and performance.[11,12] The study among children with Attention Deficit Hyperactivity Disorder (ADHD) revealed CCTT has moderate test-retest reliability coefficient range (rtt=0.46-0.68) and moderate to high interference reliability coefficient range (rtt=0.75-0.78).[13] The test consists of 2 parts; CCTT-1 and CCTT-2. The direct score of each part is represented by the time of completion of the tasks.[11] In CCTT-1, the participant must connect numbered circles with alternate colour (yellow and pink) consecutively, while in CCTT-2, the participant must connect numbered in circles consecutively with alternate colour as the same number exist with a different colour.[14] We also assessed functional balance performance using the paediatric balance scale (PBS). The PBS consists of 14 items that evaluate balance in different activities. Each item in the PBS is scored on a 5-point scale (0-4) with a maximum total score of 56 (higher scores indicates better balance).[15] The study showed good test-retest and inter-rater reliability when implemented for school age children with mild to moderate motor impairments [intraclass correlation coefficient (ICC) model 3, 1=0.997].[15]

The APDM® Mobility Lab (Oregon, Portland) is a system that provides information on gait and balance. This system utilises the inertial sensors attached to the specific parts of the body to compute postural sway, postural transitions, trunk, and upper and lower limb movements.[16] In this study, 3-movement sensors called Opals® consisting of 3-axis accelerometer, gyroscope and magnetometer (Mobility Lab, APDM Inc., Oregon, Portland) were used to record postural sway parameters. Inertial sensor data was collected and wirelessly streamed to a laptop for automatic generation of information. This system was chosen as it is portable and user-friendly, therefore, could be set up quickly, in a more natural environment, compared to that of a laboratory.

Three Opal sensors were positioned by using Velcro straps on each ankle and lower back (level L5) of the participants. The APDM® has an analytical software assessment called the instrumented postural sway (Isway), which measures sway during static standing for 30 seconds. This test is useful in examining key aspects of postural sway such as sway area, sway velocity and sway distance during static standing. For each task, the children were asked to perform static standing for 30 seconds. 'Start' signs were positioned on the floor providing visual feedback to participants. The testing procedure was conducted in a gymnasium or school hall with standard-hard and even-surfaced floor.

Before the test was performed, a trained assessor gave standardized verbal instructions regarding the test procedure, along with a visual demonstration of the procedure. The participants from both groups performed 3 practice trials for each task to familiarise themselves with the test. The sequence of the tasks was randomly determined. Order and specific of each task are not shared with the participants prior to testing. Only at the beginning each of the trials, the subject will be given the specific task instructions for the trial. Each task was executed by 3-recorded trials with 3 minutes rest given in between each task. The participants wore their regular footwear or orthotics during testing.

The test consisted of 3 different conditions for each participant: single task, concurrent motor, and concurrent cognitive task. For the single task, participants performed static standing for 30 seconds without any secondary tasks. The procedure for concurrent motor and concurrent cognitive task were adopted from a previous study by Cherng et al.[17] This study was chosen because its protocol has been duplicated in the study among children with developmental coordination disorder with similar research design and method and similar group of researchers in 2009.[18] Thus, it showed that the tasks in this study are suitable to be used among children with disability and gave us a good benchmark to duplicate the protocol. Under the concurrent motor task, participants performed the test while holding a tray with 7 marbles on it (tray 17-cm in diameter and 1.2-cm in depth and marble 2-cm diameter each). In the concurrent cognitive task, participants performed the test while verbally counting backwards. The task was adapted from the digit span task of Wechsler intelligence scale for children (WISC). The series of numbers to be repeated was set at each child's ability, which was determined individually before the experiment by following the procedure of administering that section of the WISC.

All the primary outcomes, which were sway area, AP sway velocity, ML sway velocity, AP sway distance, and ML sway distance to complete postural sway task were calculated by the software of the APDM® Mobility Lab from 3 trials. All statistical analyses were performed using the SPSS statistical software version 23.0 (IBM Corp., Armonk, NY, USA). The participants' baseline characteristics were summarized using means and standard deviations (SD) or frequencies and percentages, as appropriate. Descriptive statistics and the normality in the distribution of variables were conducted with skewness and kurtosis tests for all outcome variables. The independent t-test was used to compare the demographic data between the cases and control group. Repeated measures analysis of variance (ANOVA) was used to analyse postural sway parameters under 3 different conditions (single, concurrent motor, and concurrent cognitive task conditions) and 2 groups (TBI and TD children). Post-hoc analyses for pairwise comparisons were conducted by using Bonferroni correction with p-value<0.05 for statistical significance.

Results. **Table 1** summarises the characteristics of participating children. The average time since injury for children with TBI was 2.43±1.48 years (range: 0.67-5.5 years), and glasgow coma scale (GCS) score was 9±2 (range: 5-12). There were no significant differences between the groups of children in age, body weight, body height, BMI, and time of CCTT-1 (p>0.05). In contrast, pediatric balance scale (PBS) score (p=0.034) and time of CCTT-2 (p=0.039) showed significant different between both groups. The children with TBI scored lower mean value for PBS (TBI: 52.13±5.76 vs. TD: 55.5±0.67) and higher for the time of CCTT-2 (TBI: 99.5±68.96 vs. TD: 59.64±20.36) when compared to TD children.

The result shows children with TBI had larger sway area compared with the TD children (group effect, p=0.048) in all categories of tasks (single, concurrent motor and concurrent cognitive). However, concurrent tasks condition revealed that there was no significant effect in sway area (condition effect, p=0.107), and the trend also failed to reach statistical significance (condition by group interaction, p=0.831)

Children with TBI had a significantly higher AP sway velocity compared with the TD children (group effect, p=0.005). Concurrent task conditions significantly increased the AP sway velocity (condition effect, p<0.001), and the influence was similar for both groups (condition by group interaction, p=0.648). Post-hoc analysis showed that both concurrent tasks (motor and cognitive) led to a significant increase in AP sway velocity compared with single task (p<0.001 for both comparisons) for both groups. Although concurrent cognitive task increased AP sway velocity slightly compared to a concurrent motor task, the difference failed to reach statistical significance (p=0.215).

As presented in **Table 2**, children with TBI had increased ML sway velocity compared with TD controls (group effect, p=0.003). Medio-lateral sway velocity was also affected by the concurrent task conditions, which was confirmed by a significant condition effect (p=0.002), but the trend for both group failed to reach statistical significance (condition by group interaction, p=0.433). Post-hoc comparison detects a significant

Table 1 - Demographic information of children with TBI and TD children.

Participants	TBI children (n=16)	TD children (n=22)	P-value
	Mean±SD		
Duration of injury (years)	2.43±1.48		
GCS Score	9±2		
Age (years)	11.63±1.89	11.41±2.24	0.756
Body Weight (kg)	40.64±12.35	41.83±16.93	0.802
Body Height	1.415±0.16	1.421±0.15	0.909
BMI (kg/m^2)	20.2±5.26	19.9±5.43	0.847
PBS Score (max 56)	52.13±5.76	55.5±0.67	0.034*
CCTT-1 (seconds)	54.94±48.85	33.36±15.27	0.106
CCTT-2 (seconds)	99.5±68.96	59.64±0.36	0.039*

*p-value<0.05, TBI - traumatic brain injury, TD - typically developing, GCS - Glasgow coma scale, BMI - body mass index, PBS - pediatric balance scale, CCTT-1 - children's color trail test-1, CCTT-2 - children's color trail test-2, SD - standard deviation

difference in ML sway velocity during concurrent tasks (single vs. concurrent motor, p<0.001; single vs. concurrent cognitive, p=0.001) for both groups. The concurrent cognitive task increased ML sway velocity slightly compared to a concurrent motor task, but the difference failed to reach statistical significance level (p=0.278).

The result shows children with TBI had increased AP sway distance compared to TD children (group effect, p=0.046). Concurrent task conditions significantly increased the AP sway distance (condition effect, p=0.001), and the influence was similar for both group (condition by group interaction, p=0.732). In addition, post-hoc comparison indicates that both concurrent motor (p<0.001) and concurrent cognitive (p=0.001) tasks led to a larger AP sway distance compared to the single task condition. Although concurrent cognitive task increased AP sway distance slightly compared to a concurrent motor task, the difference failed to reach statistical significance (p=0.059).

Medio-lateral sway distance during static standing was significantly higher in children with TBI compared with TD children (group effect, p=0.018). Medio-lateral sway velocity also affected by the concurrent task conditions, which was confirmed by a significant condition effect (p=0.003), and the trend was similar for both groups as evidenced by a non-significant interaction (condition by group interaction, p=0.61). Post-hoc analysis revealed both concurrent tasks (motor and cognitive) resulted in increased ML sway distance compared with a single task (p=0.001 for both comparisons). The concurrent cognitive task increased ML sway distance slightly compared to a concurrent

Table 2 - Postural sway performance under different attentional loading conditions in TBI and TD Children.

Postural sway	Single task		Concurrent motor task		Concurrent cognitive task		Within group factor	Between group factor	Interaction
	TBI children	TD children	TBI children	TD children	TBI children	TD children			
	Mean±SD						*P*-value		
Sway area (m^2/s^5)	0.026±0.059	0.007±0.005	0.026±0.005	0.011±0.007	0.037±0.029	0.02±0.015	0.107	0.048*	0.831
AP Sway velocity (m/s)	0.222±0.165	0.103±0.057	0.341±0.313	0.18±0.098	0.381±0.262	0.225±0.107	<0.001*	0.005*	0.648
ML Sway velocity (m/s)	0.125±0.104	0.06±0.037	0.166±0.102	0.095±0.049	0.198±0.161	0.1±0.056	0.002*	0.003*	0.433
AP Sway Distance (m/s^2)	0.086±0.077	0.054±0.024	0.115±0.09	0.074±0.034	0.128±0.071	0.099±0.053	0.001*	0.046*	0.732
ML Sway Distance (m/s^2)	0.059±0.049	0.031±0.017	0.064±0.043	0.044±0.027	0.077±0.042	0.054±0.022	0.003*	0.018*	0.61

**p*-value<0.05, TBI - traumatic brain injury, TD - typically developing, AP - anterior-posterior, ML - medio-lateral, SD - standard deviation.

motor task, but the difference failed to reach significance level (p=0.055).

Discussion. The preservation of postural control and balance in both static and dynamic conditions are essential components in our daily life activity. Thus, the present study aimed to examine the effects of concurrent tasks on postural control performance in children with TBI in comparison to TD controls. We discovered a few important findings. First, there was a negative effect on postural control performance when the children did the concurrent tasks (motor and cognitive) in both groups. Second, children with TBI have larger sway area, higher sway velocity in both AP and ML direction, and longer sway distance in both AP and ML direction when combined with concurrent tasks as compared with the performance of TD children. Lastly, types of concurrent task (motor or cognitive) did not lead to differential effects on postural control performance.

Our findings showed that all the children in both groups showed decrements in postural control performance when 2 tasks are executed simultaneously. The findings of this study have demonstrated that both groups of children experienced concurrent task-related changes in postural control performance. However, the deterioration was more marked in the TBI group, especially under concurrent cognitive tasks. This greater deterioration in children with TBI is possibly due to the existence of attention, executive function, and information processing speed impairment combined with postural instability.[7,8,19] In fact, difficulties in executing concurrent tasks simultaneously have been explained in a few theories, which are the bottleneck theory, the capacity-sharing theory, or the multiple resource model theory. The present finding reflects the capacity-sharing theory which explains the deterioration of at least one of the task performance because of the restricted capacity of attentional resources.[9,20] In this study, the children were asked to focus on the performance of the secondary task (holding the tray with marbles and counting backwards). As a result, both groups showed deterioration in postural control performance when concurrent tasks were executed simultaneously.

In addition, we found postural control deterioration was significantly observed during both concurrent motor and cognitive task compared with single task in both groups. This could be due to greater attentional resource required when compared to the single task. Both concurrent motor and cognitive tasks condition resulted in larger sway area, higher sway velocity in both AP and ML direction, and longer sway distance in both AP and ML direction compared with single task condition in both groups but to a greater degree in children with TBI. This result suggests that concurrent task conditions were challenging for children with TBI as they have balance and cognitive impairments (PBS= TBI: 52.13±5.76, TD: 55.5±0.67; CCTT-2= TBI: 99.5±68.96, TD: 59.64±0.36 sec).

The current findings are in line with recent research among healthy children and youth 5-18 years old which have consistently shown concurrent cognitive task resulted in increased postural control instability.[10] They found postural stability during concurrent cognitive task on the foam surface caused greater interference as compared with the firm surface.[10] Another study also showed concurrent cognitive task adversely affect postural sway in healthy children.[21] Increased postural sway under concurrent task in the present study can be explained by divided attention when one needs to maintain the balance of upright stance while performing a concurrent task, attention is divided between postural and motor or cognitive tasks. In addition, previous studies among healthy adult showed increase difficulty of concurrent cognitive task caused greater interference on postural control performance.[22,23] In contrast to this finding, a recent study among young adults found increasing the cognitive demand resulted in reducing postural sway.[24] Considerable disagreement exists on the difficulty level of cognitive demand towards influence on postural control; future research is necessary to determine the effect of the difficulty level of concurrent cognitive task on postural control performance.

This study has several limitations. First, we only included one type of task for motor and cognition in the study. Future research may include different types of concurrent tasks for motor and cognition when studying children's postural control performance under dual-task conditions. Second, we only examined postural control on the firm surface during upright standing as previous research also showed interference effects on postural control performance on foam surface among healthy children. Upcoming studies should investigate postural control performance on uneven or foam surface, as our daily activities need us to be confronted with variable surfaces such as inclining or declining surfaces and soft or hard surfaces.

In conclusion, the present results have clinical implications because the control of concurrent tasking effects is a crucial issue in TBI rehabilitation and might be essential for optimal functional recovery. The results of our study suggest that children with TBI are more vulnerable to dual-task interference during static standing compared to TD controls. Additionally, the current study revealed that both concurrent motor and cognitive task caused greater interference on postural control performance compared with the single task. Thus, we suggest the clinicians incorporate single task in early stages of motor training followed by the concurrent tasks in later stages in order to improve their postural control performance. In accordance with a previous study by Pellecchia,[25] concurrent task training resulted in decreased postural sway. Hence, it is crucial for clinicians to understand the effect of concurrent tasks on postural control performance in this population. This will assist clinicians in designing intervention by using a dual-task paradigm in evaluating and improving postural control performances.

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