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Research Article

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Abstract

Background

Acquired brain injury (ABI) is classified into traumatic brain injury (TBI) and ABI-PF. In ABI-PF, almost half of pediatric brain tumors arise in the posterior fossa (PF). Assessment of motor proficiency is commonly conducted with the Bruininks-Oseretsky Test of Motor Proficiency-2 (BOT2). This study assessed: 1) gross motor performance deficits in children with TBI and ABI on account of tumor in the PF (ABI-PF) using two different assessment methods (two-standard deviation and age equivalent methods); 2) BOT2 ability to discriminate between children with TBI and ABI-PF; and 3) factors associated with motor ability.

Methods

Participated in this study were children with TBI (n = 50) and ABI-PF (n = 30) (mean age = 11.34 ± 3.55 years). Participants were tested on BOT2 Upper-Limb Coordination, Balance, Strength, Running Speed and Agility, and Bilateral-Coordination subtests. Motor performance deficits were established using BOT2 two-standard deviation and age-equivalent methods. Differences in the prevalence of children with/without motor performance deficits were evaluated using a chi-square test. Between-group differences (TBI vs. ABI-PF) in BOT2 were assessed via independent t-tests. The ability of the BOT2 to distinguish between the two study groups was established using receiver operating characteristic curves.

Results

Motor deficits in the ABI-PF group were higher than in the TBI group. More specifically, according to the two-standard deviation method, motor deficits in the ABI-PF group ranged from 20% (bilateral coordination) to 66.66% (balance), whereas in the TBI group 8% (strength) to 16% (balance). The age-equivalent method revealed higher rates of motor deficits. In the TBI group, 40% (Upper Limb Coordination) to 66.0 (Bilateral Coordination) of the children presented motor function that is ≥ 36 months below their chronological age. In the ABI-PF group, 46.66% (Bilateral Coordination) to 76.66% (Balance) of the children presented such motor deficits. BOT2 discriminated between the two etiology groups. Several significant associations were observed between age and motor function.

Conclusions

Motor deficits post-pediatric ABI are prevalent. In comparison to the TBI group, deficits are greater in the ABI-PF group. Moreover, compared to the two-standard deviation method, the extent of motor deficiency is greater in the age-equivalent method. Finally, age is associated with several motor function deficits.

Introduction

Acquired brain injury (ABI) is a prevalent diagnosis in pediatric rehabilitation (1, 2) with an incidence of 661–1035 per 100,000 (3, 4). ABI can be classified into traumatic and non-traumatic (1, 2). Traumatic brain injury (TBI) occurs when a sudden trauma results in damage to the brain (e.g., car accidents, falls) (5). ABI-PF cases include, for example, stroke, hypoxic/ischemic brain damage, infectious diseases or toxicity, and brain tumors. Brain tumors are the most common disease group of solid tumors in childhood (6). Moreover, tumors are the second most common form of cancer in childhood and almost half of all pediatric brain tumors arise in the posterior fossa (PF) (7).

In ABI, motor disabilities are often considered a less pervasive problem than psychosocial and cognitive deficits (8). Accordingly, it has been reported that 56 to 72% of children with ABI were able to ambulate independently at the time of discharge from the hospital (9, 10). However, advanced gross motor skills (e.g., balance, static and dynamic postural control, speed and agility, coordination, and strength) which are important for high-level gross motor activities such as hopping, running and jumping are often affected by ABI. These problems remain long-lasting deficits that affect the higher motor performance of children for years after ABI (11, 12) and limit their ability to participate in various physical activities (5). However, as the ABI injury location is diverse, children with localized ABI, such as ABI in the PF (ABI-PF) may present unique and different motor disabilities than children with TBI. More specifically, damage because of PF tumors is usually localized to the cerebellar area, and the cerebellum is connected to many cerebral areas and its input regulates the excitability of cerebral motor control areas. Therefore, lesions to the cerebellum will affect the execution of various movements, specifically rapid, timed, and spatial dependent (13). Damage to the cerebellum may also result in balance and associative motor learning difficulties (14). In contrast, in TBI, this type of specific cerebellar damage is much less common, and the pathology commonly involves white matter tract damage because of diffuse axonal injury (15) as well as localized damage to specific cortical areas, most commonly to the frontal lobes. Accordingly, in comparison to ABI-PF, in TBI, it is a common finding that children will have a higher level of motor function. Differences in motor function between the two groups may be enhanced by high-grade malignant tumor-related chemotherapy in children with tumor-related ABI (16).

Despite the increased survival of children with brain tumors, studies investigating objective motor functioning in this population are scarce(17). For example, Piscione et al.(18) study revealed significant differences between children with brain tumors and normative population data for body coordination and strength and agility. Varedi et al.(19) observed balance impairments in 48% of adult survivors of pediatric central nervous system tumors. Specifically, within the pediatric PF tumor survivors, Piscione et al.(18) reported vermis infiltration of the tumor as a risk factor for lower body coordination scores and chemo- and radiotherapy for lower strength and agility scores. In a more recent study by Decock et al., among children with posterior fossa tumors (N = 56), motor
performance deficits at the beginning of rehabilitation ranged from 5.35% (upper limb mobility) to 26.78% (balance). At the end of the rehabilitation, the prevalence of motor performance deficits ranged from zero percent (upper limb mobility) to 8.92% (balance) (20).

Several outcome measures are used to assess advanced motor skills performance in children post-ABI (1). One of the most used outcome measures is the Bruininks-Oseretsky Test of Motor Proficiency 2 (BOT2) (21). The BOT2 is an evaluative eight-subtest standardized measure tool that assesses gross and fine motor proficiency (i.e., Fine Motor Precision, Fine Motor Integration, Manual Dexterity, Bilateral Coordination, Balance, Running Speed and Agility, Upper-Limb Coordination, and Strength) in children aged four to 21 years old. The test was acknowledged as a supplementary measure to the core outcome measures for the evaluation of children who sustained ABI (22). BOT2 can be used in two different ways to detect motor deficits. The first method utilizes the various subtests’ individual point scores. A cutoff point of two standard deviations below the mean is commonly used to establish the presence of motor performance deficits (23). The second method utilizes the different subtests’ age equivalents calculations. According to this method, children can be grouped according to the gap between their chronological age and their motor performance age equivalent. The two different evaluation methods may provide different results concerning the motor proficiency level of children with ABI. However, to date, a comparison of the prevalence of children with ABI presenting motor deficiencies using the two different assessment models was not investigated.

A better understanding of the motor proficiency of children with ABI is important. Clinicians and researchers can use the BOT2 to screen for motor impairment, determine the need for further assessment/intervention, develop and evaluate motor training programs and make placement decisions regarding physical education programs (5). This study was therefore undertaken to assess: 1) the gross motor performance of children with ABI using two different assessment methods; 2) the gross motor performance deficits in children with TBI vs. children with PF brain tumors (ABI-PF) using the two different assessment methods; 3) the BOT2 ability to discriminate between children with TBI and ABI-PF; and 4) to assess some factors associated with motor ability.

Materials and methods

Participants

Included in this cross-sectional study were: 1) children (males and females) diagnosed with moderate-to-severe ABI (e.g., Glasgow Coma Scale upon admission to the emergency room 3–9) on account of TBI and ABI-PF; 2) age range: 5–18 years old; 3) children with; 3) children in the chronic phase of recovery (i.e., at least six months post-injury); and 5) children who are able to follow simple three-step directions and commands (specifically: raising the arms, getting up from a chair and stopping an activity).

Excluded from the study were children: 1) unable to independently walk with or without orthotics for at least 10 meters, 2) who had any associated pre-trauma conditions affecting motor performance, and 3) who suffered fractures preventing appropriate administration of the BOT2.

Instrumented measure

BOT2 is a reliable and valid instrument of motor-skills performance, used in individuals ages four through 21 (21). The complete battery of BOT2 consists of 53 items classified into eight subtests: Fine Motor Precision, Fine Motor Integration, Manual Dexterity, Bilateral Coordination, Balance, Running Speed and Agility and Strength (21, 24). This study focused on gross motor function, therefore, only the following BOT2 subtests were examined: Upper Limb Coordination, Bilateral Coordination, Balance, Running Speed and Agility and Strength.

Information regarding ABI etiology (TBI or ABI-PF), GCS, demographic characteristics, and time from injury were established via examination of participants’ medical records.

Procedure

The BOT2 is administered routinely in the pediatric department by the department's physical and occupational therapists as part of a motor performance battery to every child having sustained an ABI. The therapists had at least five years of seniority in pediatric rehabilitation and a minimum of two years of experience in administrating the BOT2. All the administering therapists partook in BOT2 administration training, and inter-rater agreement was examined. The test was conducted according to the BOT2 manual using the long form (21). Testing was conducted in one session lasting approximately 60 minutes. Per the BOT2 protocol, item raw scores were calculated for each item (e.g., the number of correct responses or the duration of an activity sustained). Following this, the total point score is calculated for each subtest. Subsequently, using tables provided in the manual, each total point score is converted to a scale score (mean = 15; standard deviation = 5). Finally, age-equivalent scores were also calculated (21).

Ethical Approval and Consent to Participate

All the methods and procedures carried out in this study were in accordance with relevant guidelines and regulations. This study and a waiver from the requirement of signing an informed consent was approved by the ethics committee of Chaim Sheba Medical Center (6504-19-SMC).

Statistical analysis

To evaluate for demographic and clinical characteristics bias, differences between the TBI and the ABI-PF groups in age, time post-injury, and gender were evaluated using independent t-tests and chi-square tests.
Gross motor performance deficits in children with TBI and ABI-PF

The presence of motor performance deficits was established using individual point scores on each subtest. A cutoff point of two standard deviations below the mean was used to establish the presence of apparent motor performance deficits (23). In addition, age equivalents were obtained from the manual for each subject’s performance on each subtest evaluated. For this study, three groups of performance deficits below chronological age were obtained: 1) up to 24 months (25), 2) 25–35 months, and 3) ≥ 36 months. First, the prevalence of motor performance deficits in the two assessment methods in the entire group (TBI + ABI-PF) was calculated. Next, deficits prevalence in each etiology group was calculated separately and compared using a chi-square test.

**BOT2’s ability to discriminate between children with TBI and ABI-PF**

Receiver operating characteristics (ROC) curves were constructed. In ROC curves, the rate of true positive sensitivity was plotted on the y-axes, and the rate of false positives (1-specificity) was plotted on the x-axes (26). The area under the ROC curve (AUC) indicates the discriminative power of the instrument as it denotes the probability of the assessment to rank the child into the correct group. AUCs of 0.5–0.7, 0.7–0.9, and 0.9-1.0, represent low, medium, and high accuracy, respectively (27).

**Factors associated with motor ability.**

Associations between BOT2 and age and time post-injury were examined using Pearson correlations for the entire group and each study group (TBI and ABI-PF groups).

All data analyses were done using Statistical Package for Social Science (SPSS), version 29. ROC analysis was conducted using MedCalc statistical software, version 14.10.2.

**Results**

A total of N = 80 children with ABI participated in the study (mean age = 11.34 ± 3.55 years; age range: 5.6–19; 60% boys). Most participants had TBI (n = 50). The mean GCS upon admission to the emergency room of children with TBI was six and ranged from 3–9 (moderate-to-severe injury). For information regarding group differences and additional information, refer to Table 1.

Table 1

<table>
<thead>
<tr>
<th>Variables</th>
<th>Entire group (n = 80)</th>
<th>ABI-PF group (n = 30)</th>
<th>TBI group (n = 50)</th>
<th>Between groups differences:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chi square test</td>
<td>OR</td>
<td>t statistic</td>
<td>(p value)</td>
</tr>
<tr>
<td>Age, years: mean (SD)</td>
<td>11.34 (3.55)</td>
<td>10.17 (3.33)</td>
<td>11.78 (3.56)</td>
<td>1.708 (0.009)</td>
</tr>
<tr>
<td>Sex</td>
<td>Girls: n (%)</td>
<td>28 (34.14)</td>
<td>8 (26.66)</td>
<td>15 (30.00)</td>
</tr>
<tr>
<td>Time post injury, years: mean (SD)</td>
<td>3.03 (2.71)</td>
<td>3.33 (2.51)</td>
<td>2.91 (2.78)</td>
<td>0.653 (0.49)</td>
</tr>
<tr>
<td>Injury cause</td>
<td>TBI</td>
<td>Car accident, n</td>
<td>35 (70.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fall, n</td>
<td>5 (10.00)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other, n</td>
<td>10 (20.00)</td>
<td></td>
</tr>
</tbody>
</table>
| Notes: ABI-PF, acquired brain injury-posterior fossa; SD, standard deviation; TBI, traumatic brain injury

*Table 1 about here*

Gross motor performance deficits in children with TBI in comparison to ABI-PF

The prevalence of motor performance deficits in the two standard deviation method in the entire group (TBI + ABI-PF) ranged from 16.25% (Bilateral coordination) to 35.00% (Balance). Motor performance deficits were greater when using the age equivalent method and ranged from 75.00% (Balance) to 92.50% (bilateral coordination).

When looking separately at the TBI group, according to the two-standard deviation method, motor deficits ranged from 8.0% (Strength) to 16.0% (Balance and Running Speed and Agility). Motor deficit prevalence in the ABI-PF was higher and ranged from 20.0% (Bilateral Coordination) to 66.66% (Balance). In contrast, the age-equivalent method revealed higher rates of motor deficits. In the TBI group, 40% (Upper Limb Coordination) to 66.0 (Bilateral Coordination) of the children presented motor function that is ≥ 36 months below their chronological age. In the ABI-PF group, 46.66% (Bilateral Coordination) to 76.66% (Balance) of the children presented such motor deficits (see Table 2).
Table 2
Prevalence of motor performance deficits according to the age equivalent and two standard deviation methods

<table>
<thead>
<tr>
<th>Age equivalent</th>
<th>Upper-Limb Coordination</th>
<th>Bilateral Coordination</th>
<th>Balance</th>
<th>Running Speed and Agility</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 24 m of chronological age (%)</td>
<td>3 (10.00)</td>
<td>13 (43.33)</td>
<td>0</td>
<td>3 (10.00)</td>
<td>69 (86.25)</td>
</tr>
<tr>
<td>24–36 m below chronological age (%)</td>
<td>8 (26.66)</td>
<td>0</td>
<td>5 (16.66)</td>
<td>5 (16.66)</td>
<td>3 (10.00)</td>
</tr>
<tr>
<td>≥ 36 m below chronological age (%)</td>
<td>16 (53.33)</td>
<td>14 (46.66)</td>
<td>23 (76.66)</td>
<td>20 (66.66)</td>
<td>21 (70.00)</td>
</tr>
<tr>
<td>Total deficits: n (%)</td>
<td>27 (90.00)</td>
<td>10 (20.00)</td>
<td>28 (93.32)</td>
<td>28 (93.32)</td>
<td>27 (90.00)</td>
</tr>
<tr>
<td>Acquired brain injury – posterior fossa (N = 30)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>≤ 24 m of chronological age (%)</td>
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<tr>
<td>24–36 m below chronological age (%)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>≥ 36 m below chronological age (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total deficits: n (%)</td>
<td>14 (28.00)</td>
<td>4 (8.00)</td>
<td>4 (8.00)</td>
<td>9 (18.00)</td>
<td>12 (24.00)</td>
</tr>
<tr>
<td>Traumatic brain injury (N = 50)</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>≤ 24 m of chronological age (%)</td>
<td></td>
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<tr>
<td>24–36 m below chronological age (%)</td>
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<td></td>
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<tr>
<td>≥ 36 m below chronological age (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total deficits: n (%)</td>
<td>9 (18.00)</td>
<td>4 (8.00)</td>
<td>4 (8.00)</td>
<td>8 (16.00)</td>
<td>22 (44.00)</td>
</tr>
</tbody>
</table>

**BOT2’s ability to discriminate between children with TBI and ABI-PF**

ROC analysis was conducted to examine the BOT2 ability to separate the group into those with and without TBI. In the ROC curve, the true positive rate (sensitivity) is plotted as a function of the false positive rate (100-specificity). A test with perfect discrimination (no overlap in the two distributions) has a ROC curve that passes through the upper left corner (i.e., 100% sensitivity, 100% specificity). Therefore the closer the ROC curve is to the upper left corner, the higher the test’s overall accuracy (Zweig & Campbell, 1993). More specifically, An AUC of one represents a perfect test (100% accuracy in separating the group); 0.9–1.0, high accuracy; 0.7–0.9, medium accuracy; and 0.5–0.7 low accuracy (i.e., the test is not capable to accurately distinguish between the two groups). ROC showed that all BOT2 sub-scales, except for Bilateral Coordination, demonstrated medium accuracy in differentiating between children with PF and non-PF injuries (AUC = 0.7–0.9). Bilateral Coordination accuracy is considered low (AUC < 0.7) (Figs. 1a-1b and 2a-2c).

**Factors associated with motor ability**

In the entire group, no significant associations were found between time post-injury and BOT2. However, all BOT2 scores were significantly associated (positive moderate associations) with age. Similarly, in both the ABI-PF and TBI groups, no significant associations were observed between time post-injury and motor function. However, in the ABI-PF group positive moderate significant associations were found between age and Upper Limb Coordination ($r = 0.560$) and strength ($r = 0.558$). Similarly, in the TBI group positive moderate significant associations were found between age and Bilateral Coordination ($r = 0.383$) and Running Speed and Agility ($r = 0.372$) (Table 3).
Interventions for improving motor ability

Similarly, other motor activities which require speed. Slowness in the TBI group can be explained by the diffuse axonal injury, damage to the frontal cortex

Slowness – slowness as evaluated in the Running Speed and Agility is another domain in which children with ABI-PF and TBI exhibited significant difficulties.

persists years post-TBI (33). Such white matter changes may disrupt important cortical-subcortical connections that assist in motor control and balance (32).

Gross motor performance deficits after ABI

The data showed that deficits in motor performance are present in the chronic phase in children with moderate-to-severe ABI. According to the two-standard deviation method, the prevalence of deficits in the different BOT2 sub-domains ranged between 20.0%-66.66% in the ABI-PF group and 8.0%-16.0% in the TBI group. The prevalence of motor deficits in both study groups were considerably higher in the age equivalent method (>90% and >64% of children in the ABI-PF and TBI groups, respectively). The differences between the two methods regarding the prevalence of motor deficits post-ABI is important as according to Deitz et al. (24) the two-standard deviations method might be one of the criteria for receiving therapy services in certain programs. Therefore, using the two-standard deviations method to identify motor prevalence would not be accurate enough as a child with a score that falls between 1 and 2 standard deviations below the mean, will not be qualified for therapeutic services while he/she might still present significant motor deficits in comparison to his/her peers – preventing him/her from participating in common or mutual activities.

Sub-domains with most significant deficits

Balance - The sub-domain with the highest prevalence of deficits in both study groups is balance. More specifically, in the ABI-PF group 66.66% (two standard deviations method) to 93.32% (age equivalent method) of the group had deficits in balance. In the TBI group, the prevalence ranged from 16–64% (two standard deviation and age equivalent method, respectively). Other authors also reported balance deficits post-ABI (25). Long-lasting balance problems post-ABI is not surprising. In the ABI-PF group, damage to the cerebellum can cause balance deficits. More specifically, evidence indicates that certain areas of cerebellar cortex and nuclei (e.g., cerebellar vermis and fastigial nucleus) appear to be engaged in numerous functions, including, balance/vestibular behaviors (30). In the TBI group, balance problems may be explained by white matter lesions. More specifically, in a study of N = 507 children and adolescents with TBI, widespread disruption in white matter organization was observed following complicated mild to severe TBI. These alterations appear to persist and encompass a larger number of white matter regions with time post-injury. The corpus callosum appears to be particularly vulnerable to injury, an effect that persists years post-TBI (31). Such white matter changes may disrupt important cortical-subcortical connections that assist in motor control and balance (32).

Slowness – slowness as evaluated in the Running Speed and Agility is another domain in which children with ABI-PF and TBI exhibited significant difficulties. Accordingly, cognitive response speed deficits and cognitive motor speeded performance deficits (i.e. such as speeded hand function tests and finger tapping) (23) had previously been reported as a problem and a prominent characteristic post-ABI (33–35). Slowness also commonly manifests in gait. For instance, Schaaf et al (1997)(9) reported that in repeated gait analysis, ambulatory children with ABI demonstrate significant reductions in velocity and cadence. Similarly, other motor activities which require speed. Slowness in the TBI group can be explained by the diffuse axonal injury, damage to the frontal cortex (e.g., premotor cortex, supplementary motor area), and basal ganglia. In the ABI-PF group, slowness may be caused by damage to cerebellar controlling rhythmic movements areas (36). As with the deficits seen in balance, slowness may hinder children's post-ABI ability to reengage in school and community activity (5), specifically, the ability to engage in physical activities in the same pace with their peers.
Considering the impact of motor performance deficits in real life, it is also important to explore the extent to which interventions improve motor function. For example, based on a systematic review of the impact of physical therapy intervention on balance post-TBI (N = 259), the evidence about the effects of the physical therapy interventions in improving the balance ability post-TBI was limited (37). In another systematic review on the effectiveness of interventions on gross motor outcomes of children with an ABI, the authors concluded that although the included studies demonstrated preliminary evidence for a positive effect on gross motor outcomes following the interventions, low study methodological quality indicates that care is needed when interpreting and generalizing results to children with an ABI (38). In a more recent longitudinal cohort study that monitored the functional recovery of 600 pediatric patients with ABI receiving standardized rehabilitation, over a time span of 7 years, four distinctive patterns of recovery were observed: high-start fast responders (15%), low-start fast responders (28%), slow responders (22%), and non-responders (35%). Each of the four patterns showed an association with varied demographic and clinical characteristics. For example, longer comas corresponded to lower chances of a favorable trajectory of recovery (39). Considering the importance of balance in daily life and the limited ability to improve it post-ABI, knowledge of strategies for inclusion in sports of children post-ABI with balance deficits are important for physical education teachers, adapted physical education experts, and physical therapists.

Motor ability implications on adapted physical activity

The results of this study show that both groups of children, and especially the ABI-PF group, have low level of motor ability. In addition, according to the literature the ability to improve motor function is limited. Hence it is important to adapt activities in therapy and community-based activities to enable the child to partake in it (40). There are four main aspects that can be changed to adapt the activity: 1) Teaching or coaching style – pertains to how the instructor delivers the activity. For example, using appropriate physical assistance – guide a participant’s body parts through a movement and using visual aids; 2) Rules changing. For example, allowing for more bounces of ball (e.g., tennis) and more hits (e.g., volleyball); or reducing the number of players in the team in order to increase the chances of getting involved; or to allow to roll the ball instead of hitting it; or modify the distances for pitching; 3) Changing the environment – making changes to the activity space. For example, reduce net, hoop or goal height and width; 4) Allow the use of equipment – changing the devices used to play the game. For example, change the size, weight, color, and length of equipment (e.g., use balls that bounce less) (40, 41).

BOT2’s ability to discriminate between children with TBI and ABI-PF

This study also examined the BOT2 ability to discriminate between children with ABI because of ABI-PF and TBI. According to ROC analysis, BOT2 can be usefully used to discriminate between children with different ABI locations (see Figs. 1 and 2). The higher motor level of children with TBI can be explained ABI-PF injury mechanism. Taken together, BOT2 is sensitive to ABI location and therefore can assist with program evaluation in this population. For example, the BOT2 can be used effectively by clinicians to screen for motor impairment and determine the need for further intervention, make placement decisions regarding placement in physical education programs, and evaluate motor training programs. However, the two domains that presented the best discriminative ability are Balance and Running Speed and Agility total cores (AUC = 0.83). Therefore, professionals in the community (e.g., adapted physical education teachers) that may not have access to the child’s medical record who are interested to better understand the child’s mechanism of injury, using specifically the aforementioned two BOT2 domains is recommended.

Although the BOT2 has discriminative validity, among the TBI group, most children score within two standard deviations from the norm’s mean in all domains assessed (Table 2). Therefore, it may be appropriate to use a more challenging motor assessment in this sub-group of children with ABI. For instance, Wong and colleagues (2014)(42) developed a 20 items scale (the Acquired Brain Injury Challenge Assessment) to assess the advanced motor skills of children with ABI. The authors reported that the new assessment tool displayed excellent reliability and initial evidence of validity. Another assessment of interest in children and adolescents with TBI is the High-level Mobility Assessment Tool (HiMAT). The HiMAT demonstrated excellent inter-rater reliability, re-test reliability and responsiveness to change among children and adolescents with TBI (N = 52) (43).

Factors associated with motor ability.

In both the ABI-PF and TBI groups, no significant associations were observed between time post-injury and motor function. Similarly, child’s age correlated only with several motor functions (in ABI-PF with 2/5 functions and in TBI with 3/5 functions). Considering that children in this study were on average 3.03 (2.71) years post-injury the results suggest limited improvements in motor function with time, especially in the ABI-PF group. Accordingly, Ewing-Cobbs and colleagues (44) reported that recovery from severe ABI may be limited to the skills (e.g., walking) that the child already established at the time of injury. This information regarding motor development is particularly important when evaluating children who have sustained an ABI at a young age, especially before the age of 5 years, a period in which there is a peak in neurological maturation. Similarly, Andruskow et al (45), in a sample of 135 children with TBI, physical long-term outcome was not associated with the patient’s age.

Study limitations: Our study has several limitations to generalization. First, study participants consisted of children during the chronic phase of ABI recovery (≥ six months post-injury). Therefore, our findings may not be generalized to individuals during the acute and sub-acute phases of recovery. Second, in the current study, we have a relatively heterogenic group in terms of age. Therefore, for better generalizability, future studies with larger sample sizes are warranted.

Conclusion

Motor deficits years post-ABI in children are prevalent. However, in comparison to the TBI group, deficits are more severe and more prevalent in the ABI-PF group. Moreover, in comparison to the two-standard deviations method, the extent of motor deficiency is greater when using the age-equivalent method in both study groups. BOT2 was able to discriminate between the two etiology groups. Consequently, BOT2 is a valid measure of physical performance for children in the chronic phase of ABI. Age is associated with only a few several motor functions and mainly in the TBI group. It is important to consider the child’s post-ABI motor deficits as they might have cardinal implications on their ability to reenter school and partake in activities with their peers, beyond their deficits in
cognitive and academic functions. Study's results may contribute to clinicians and therapeutic sports experts, as knowledge on motor abilities of children post-ABI is important when choosing intervention/activity type.

**Declarations**

**Ethics approval and consent to participate**

This study had received scientific and ethical approval from the institution's (Tel-Hashomer Hospital) scientific and ethics committee prior to its initiation. This is a retrospective study. Therefore, the ethics committee gave waiver from informed consent.

**Consent for publication**

Not applicable

**Availability of data and materials**

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Competing interests**

The authors declare that they have no competing interests.

**Funding**

This study did not receive any fundings.

**Authors' contributions**

SB – methods development, writing first and final draft, statistical analyses.

TY – data collection, writing first draft

EE – data collection, methods development, writing first draft

SAL – data collection, methods development, writing first draft

JL – methods development, reviewing final draft

AB – methods development, reviewing first and final draft

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**References**


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Figures

Figure 1

Coordination sub-scales: discriminative ability by brain injury etiology

a- Discriminative validity of upper limb coordination sub-scale

b- Discriminative validity of bilateral coordination sub-scale

Legends: AUC=area under the curve; SE=sensitivity; SP=specificity
Figure 2

Balance, running speed and agility and strength: discriminative ability by brain injury etiology

Figure 2a- Discriminative validity of balance sub-scale

Figure 2b- Discriminative validity of running speed and agility sub-scale

Figure 2c- Discriminative validity of strength sub-scale.

Legends: AUC=area under the curve; SE=sensitivity; SP=specificity