Balance function and sensory integration after mild traumatic brain injury

Li-Fong Lin1,2,3, Tsan-Hon Liou2,4, Chaur-Jong Hu5, Hon-Ping Ma6, Ju-Chi Ou6, Yung-Hsiao Chiang7, Wen-Ta Chiu4, Shin-Han Tsai4, & Woei-Chyn Chu1

1Graduate Institute of Biomedical Engineering, National Yang-Ming University, Taiwan ROC, 2Department of Physical Medicine and Rehabilitation, Shuang Ho Hospital, 3Institute of Gerontology and Health Management, 4Graduate Institute of Injury Prevention and Control, 5Department of Neurology, Shuang Ho Hospital, 6Department of Emergency, Shuang Ho Hospital, Taipei Medical University, Taiwan ROC, and 7Department of Neurosurgery, Taipei Medical University Hospital, Taiwan ROC

Abstract

Objective: This study examined the disparities in balance functions and sensory integration in patients with mild traumatic brain injuries (mTBIs) and healthy controls.

Participants: One hundred and seven patients with mTBI and 107 age- and sex-matched controls were recruited for this study.

Primary measures: Symptoms of dizziness, balance functions and the ability to perform daily activities were assessed using the dizziness handicap inventory (DHI). This study also performed the postural-stability test and a modified clinical test of sensory integration by using the Biodex Stability System (BBS).

Results: DHI scores (functional, emotional, physical and total self-reported scores) were substantially increased in patients following an mTBI compared with the scores of the controls (p < 0.001). The postural-stability test indices (anterior-posterior) (p = 0.045) and the sensory-integration test index (eyes-open-firm-surface index) (p = 0.006) were substantially lower in patients with mTBI than in the controls. However, indices of two other postural-stability test indices (overall and medial-lateral) and three other sensory-integration tests indices (eyes-closed-firm-surface, eyes-open-foam-surface and eyes-closed-foam-surface) measured for the mTBI group did not differ from those of the control group.

Conclusion: Activities of daily living, balance in postural stability and sensory integration were strongly impaired in patients with mTBI.

Introduction

Traumatic brain injuries (TBIs) have been shown to result in hospitalization or death for more than 10 million people per year worldwide [1]. A mild TBI (mTBI) is the most common head injury, accounting for 70–90% of all TBIs. The annual incidence of mTBI treated in hospitals has been estimated to be 100–300 per 100,000 in the general population and epidemiological data have shown that the incidence is highest amongst young males [2]. In Taipei, ~82.2% of TBIs are classified as mTBIs [3]. Patients typically recover rapidly from an mTBI and most patients are asymptomatic after 3 weeks [4]. However, certain studies have reported that most patients recover in 3–12 months and that 10–40% of patients continue to experience physical, cognitive and emotional symptoms and functional impairment for at least 3 months following an mTBI [5]; in some cases, symptoms can persist for up to 2 years [6].

Balance-function problems are common physical symptoms after an mTBI [7–10]. Thus, gauging the balance response of patients following mTBIs is critical. People with mTBIs can exhibit impaired postural dynamics compared with people without mTBIs [11]. Previous studies have demonstrated that balance might be impaired immediately (within <48 hours), shortly (after 3 months) or following a long delay (of 1–4 years) after an mTBI [9, 12–15]. In a study performed by Kaufman et al. [9] patients with TBI scored lower than healthy participants did under all the posturography sensory-organization testing conditions. This study has demonstrated that objective measurements can quantify the patient’s functional deficits and should be used to assess the clinical complaints of imbalance from patients with TBI [9]. Balance-impairment symptoms including dizziness, visual-spatial deficits, selective inattention and abnormal postural control have been reported following an mTBI, which could be partially recovered within 3 weeks [11, 16]. In acute rehabilitation care settings, the severity of balance impairment during admission...
is strongly associated with age, multiple measures of severity and acute-care medical complications following a TBI. Being aged <50 years has also been strongly associated with normal sitting and standing balance [17]. In rehabilitation centres, patients with brain injuries can develop motor-slowing adaptive strategies to optimize dual-task performance [18]. Grossly impaired dynamic sitting or standing balance has been noted amongst patients with mTBI after discharge from rehabilitation settings; these patients require assistance with locomotion, transfers, eating and self-care at 1-year following injury [19]. Patients with mTBIs might complain of balance impairment and postural instability, despite the absence of neurological deficits as assessed through standard clinical examinations [7].

Several evaluation tools are used to assess balance and sensory organization. Force-plate balance measurement is known as computerized posturography testing (CPT) [20]. The balance of the postural-stability test and the modified clinical test of sensory integration and balance (mCTSIB) were performed using the Biodex Stability System (BSS) [21]. Balance deficits were assessed using the modified version of the Balance Error Scoring System (BEVS) and the rapid and simple bedside test exhibited a higher correlation with force-plate measurement [22]. The BEVS reveals static balance deficits immediately (within 3–5 days) after concussion. Recent studies have suggested that learning effects and decreased sensitivity over time affect the reliability of the BEVS [22–24]. Additional objective measures are required to assess the recovery of balance impairment post-concussion [25].

This study assessed sensory integration and balance functions, including those specifically related to sway direction, amongst patients with mTBI in Taiwan. It examined the variations in balance function and sensory integration that occur within 1 week following an mTBI and compared the differences with those observed in healthy control participants.

**Materials and methods**

**Study participants**

This study was approved by the Institutional Human Studies Committee of the Taipei Medical University Joint Institutional Review Board. All participants provided written informed consent.

**mTBI group**

Patients who were older than 18 years of age and were diagnosed with mTBIs were recruited from Shuang Ho Hospital between July 2011 and July 2013. The diagnosis of mTBI was established by physicians in the emergency department and was based on criteria established by the American Congress of Rehabilitative Medicine. According to these criteria, mTBI is required to be traumatically induced and involve the physiological disruption of brain function manifested by at least one of the following conditions: any period of loss of consciousness; any loss of memory for events immediately before or after the accident; any alteration in mental state at the time of the accident; and focal neurologic deficits that may or may not be transient. The severity of the injury must be characterized by the following: loss of consciousness for <30 minutes, a Glasgow coma scale score of 13–15, and post-traumatic amnesia <24 hours [26]. Patients were excluded if they had moderate or severe TBIs, a history of epilepsy, cerebrovascular disease, mental retardation, neurodegenerative disorders, a prior TBI or a severe systemic illness. Patients were also excluded if they were using psychoactive medications. The patients were recruited from consecutive series in an emergency department. Subsequently, the researchers conducted chart reviews and linked the mTBIs and called patients to determine whether they were interested in returning for the study the following day. Of the 119 participants who satisfied the eligibility criteria, 12 were subsequently excluded because the patients claimed that they had recovered and no had desire to return to participate in the study. This resulted in a final sample size of 107 (90%) participants with mTBI who provided complete data. The patients who meet eligibility criteria and ~90% patients agreed to participate in the study. The most common mechanism of injury was road accidents (48.6%), followed by fall injuries (30.5%), force attacks (beaten head when brawl) (14.5%), sport injuries (2.5%), domestic violence (2%), fainting (1.5%) and unexplained (0.25%).

**Control group**

Hospital employees were recruited as control participants through in-house advertisements and these patients were matched, based on age and sex, with the patients with mTBI.

**Cognitive and memory function**

All participants were administered the Mini-Mental State Examination (MMSE) and digit span. Digital span is a short-term memory test measuring how many numbers a participant can remember in sequence.

**Outcome measurements**

**Measurements of self-reported activities of daily living**

This study assessed the self-reported consequences of mTBIs on activities of daily living (ADL) by using the dizziness handicap inventory (DHI). The DHI is a standardized, validated, 25-item questionnaire that is used to assess the severity of the effects of dizziness and unsteadiness on the physical, emotional and functional aspects of daily living [27].

**Measurements of balance and sensory-integration test**

The balance of postural-stability test and the modified clinical test of sensory integration and balance (mCTSIB) were performed using the Biodex Stability System (BSS; Biodex Medical Systems, Shirley, NY), which enables objective assessments of neuromuscular control and somatosensory input [21].

The BSS consists of a moveable balance platform that provides up to 20° of surface tilt. The participants were asked to assume a comfortable position on the platform of the BSS and maintain a slight flexion in the knees (15°). The participants were instructed to maintain a forward-facing
posture, to hold their arms close to their torso and to maintain their original foot position co-ordinates throughout each testing session. All participants wore footwear during the tests and stood on the platform for a 1-minute acclimation period, which was followed by three practice trials to reduce the effects of learning the system on the test trials. Following the practice sessions, three test sessions were performed to evaluate balance parameters, with a 1-minute rest between each test session.

Balance of postural-stability test

The balance of postural stability was tested according to three stability indices (overall stability, OA; anterior-to-posterior stability, AP; and medial-to-lateral stability, ML) and was conducted during the first week following the injury. The balance of the postural stability test included a stability index that was defined as the average position relative to the centre of the platform and, thus, did not indicate how much a patient swayed. When a participant was positioned on the BSS in a manner that biased his or her average position relative to the centre, the value of the stability index was high. However, a greater sway results in higher standard deviations. This postural stability test was executed using a standard software configuration: a static platform in the anterior–posterior and medial–lateral axes, three trials of 20 seconds each, with a 10-second rest between each trial. Eight springs located underneath the outer edge of the platform provided the resistance to movement (stability level of the platform). Resistance levels ranged from 8 (most stable) to 1 (least stable). The stability level of the platform was set to 8. These indices represented fluctuations around a zero point that was established before testing when the platform was stable. In the postural-stability test, a high OA index score indicated poor balance and was considered the strongest indicator of the overall ability of a patient to balance on the platform.

Modified clinical test of sensory integration and balance

The mCTSIB, which includes four sway indices, was conducted during the first week following the mTBI. The mCTSIB provides a detailed and varied assessment that can be compared with healthy controls and used to identify the relationships amongst sensory integration and visual, somatosensory and vestibular stimuli. The mCTSIB is a standardized test used to assess balance on a static surface. The participants were evaluated with their eyes open and eyes closed and when they stood on a firm platform and on an unstable foam platform. A mean score was calculated from three test evaluations conducted for each separate set of conditions. The participants were positioned on a stable platform and instructed to maintain a stable vertical posture under the following four sensory conditions: (1) eyes open whilst standing on a firm surface (EOFIS); (2) eyes closed whilst standing on a firm surface (ECFIS); (3) eyes open whilst standing on an unstable (foam) surface (EOFOS); and (4) eyes closed whilst standing on an unstable (foam) surface (ECFOS). The sway index was defined as the standard deviation of the stability index, with the index representing fluctuations around a zero point that was established before testing when the platform was stable; higher sway-index values indicate greater levels of instability during testing.

Statistical analysis

The data gathered for the mTBI and control groups were evaluated using either a t-test or the Mann-Whitney U-test based on the normality of the data-sets. The Kolmogorov-Smirnov test was performed to verify the normality of the continuous data. In each test, the level of statistical significance was set at $p \leq 0.05$. After adjusting for multiple tests (Type I errors were corrected), the $p$ value was divided by the number of analyses. The SPSS statistical software package, Version 19 (IBM, Chicago, IL), was used for performing all the statistical analyses.

Results

Patients with mTBI were tested an average of 3.7 ± 1.2 days after injury. The mTBI group comprised 107 patients and the control group comprised 107 healthy participants. Chi-square tests were used for categorical variables (sex ratio) and non-parametric equivalents and the Mann-Whitney U-test was used for continuous variables (age, years of education, MMSE and digit span total score). The mean age of the patients with mTBI was 34.8 ± 14.8 years and did not differ substantially from that of the control group (32.9 ± 11.1 y) ($p = 0.251$). The male-to-female ratio was 75:32 in both the mTBI group and the control group ($p = 1.0$). The years of education in the mTBI group was 15.8 ± 2.1 and did not differ substantially from that of the control group (14.7 ± 2.8 years) ($p = 0.26$). The Glasgow Coma Scale score was 15 in the mTBI group. The data of loss of consciousness (LOC) were no loss: 47 mTBIs, <5 minutes: 30 mTBIs, 5~29 minutes: 27 mTBIs, unknown: three mTBIs (total = 107 mTBIs). The post-traumatic amnesia data are not available. The Mini-Mental State Examination (MMSE) score in the mTBI group was 27.4 ± 6.8 and did not differ substantially from that of the control group (28.9 ± 1.7) ($p = 0.24$). The digit span in the mTBI group was 22.7 ± 5.0 and did not differ substantially from that of the control group (22.4 ± 4.9) ($p = 0.44$) (Table I).

The Kolmogorov-Smirnov test was performed to verify the normality of the continuous data, whereas the Mann-Whitney

<table>
<thead>
<tr>
<th>Age, years (SD)</th>
<th>mTBI</th>
<th>Control</th>
<th>$p$ Value</th>
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</thead>
<tbody>
<tr>
<td>34.8 (12.8)</td>
<td>32.9 (11.1)</td>
<td>0.430</td>
<td></td>
</tr>
<tr>
<td>Sex ratio (Male/Female)</td>
<td>75/32</td>
<td>75/32</td>
<td>1.0</td>
</tr>
<tr>
<td>Years of education (SD)</td>
<td>15.8 (2.1)</td>
<td>14.7 (2.8)</td>
<td>0.26</td>
</tr>
<tr>
<td>GCS</td>
<td>15</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>LOC (n)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;5 minutes: 30</td>
<td>no: 47</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>5~29 minutes: 27</td>
<td>Unknown: 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MMSE (SD)</td>
<td>27.4 (6.8)</td>
<td>28.9 (1.3)</td>
<td>0.24</td>
</tr>
<tr>
<td>Digit span (total score) (SD)</td>
<td>22.7 (5.0)</td>
<td>22.2 (4.4)</td>
<td>0.44</td>
</tr>
</tbody>
</table>

Data are expressed as mean and SD (standard deviation) except in the case of sex ratio; $p < 0.05$ was considered statistically significant. GCS, Glasgow Coma Scale; LOC, Loss of consciousness <30 minutes; MMSE, Mini-Mental State Examination.
Table II. Dizziness handicap inventory of the patients with mTBI (n = 107) during the first week following injury and that of the control participants (n = 107).

<table>
<thead>
<tr>
<th>Effect size r</th>
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<tbody>
<tr>
<td>mTBI</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>Functional</td>
</tr>
<tr>
<td>Emotional</td>
</tr>
<tr>
<td>Physical</td>
</tr>
</tbody>
</table>

Data are expressed as mean and SD (standard deviation); p < 0.05 was considered statistically significant.

DHI, Dizziness Handicap Inventory; ‘Total’ is the sum score of functional, emotional and physical components.

Discussion

The primary findings of this study were the impairment of self-reported ADL (DHI) and balance problems (detected in postural stability and sensory integration) in patients with mTBIs (within 1 week following the injury). This is the first study to evaluate balance functions and the sensory-integration system in patients with mTBI by using the BBS. It determined that the DHI assessment scores were significantly increased (p = 0.000) amongst patients with mTBIs (Table I) and that most of the postural-stability and sensory-integration indices were also significantly increased amongst patients with mTBIs, when compared with the indices of the healthy controls (Table II).

Previously, the AP and ML sway in patients with mTBI has been reported to be >50% higher than that in controls [7]. Patients with mTBIs showed less displacement in the AP direction and increased displacement in the ML direction [9]. When postural demands were increased, the mTBI group exhibited increased control in the AP direction, whereas the control group appeared to demonstrate enhanced control in the ML direction. The mTBI and control groups applied distinct postural strategies during the balance task [11]. In this study, at the same level of difficulty, patients with mTBI exhibited greater displacement in the AP and ML sway directions than the control participants did. The AP sway was influenced more than the ML sway in the mTBI and control groups, thus differing from results reported previously [9], possibly because of the use of dissimilar evaluation modalities and parameters. EOFIS is a baseline condition that provides accurate information about the visual, vestibular and somatosensory systems. Measuring EOFIS might confound the somatosensory system because it imposes additional challenges on the musculoskeletal system. An ankle strategy (which is indicated by ankle dorsiflexion whilst the centre of gravity is shifted backwards) should be used for primary balance control on firm surfaces; in contrast, a hip strategy (which is indicated by hip flexion whilst the centre of gravity is shifted backwards) should be used on unstable surfaces [28]. Thus, patients with mTBIs might have lower-extremity musculoskeletal problems whilst standing on the foam surface with their eyes open. The patients with TBI scored lower than healthy participants did under all the posturography sensory-organization testing conditions [9]. The lower scores of patients with TBI indicated that they exhibited poorer balance than the control participants did, a result that agrees with this study. The mTBI patients’ EOFIS and EOFOS (eyes open) indices were lower (indicating less sway and effective postural control) than their ECFIS and ECFOS (eyes closed) indices, which indicates that visual information played a critical role in postural control. Moreover, the EOFIS indices measured for patients with mTBIs were substantially greater than those of the control participants. One possible explanation for the altered postural control in the patients with mTBI is that visuospatial attention and the neural processes governing visuospatial attention were affected by the mTBIs. Thus, using visual information to control balance might be challenging for patients with mTBI. The eyes-closed balance tasks were also challenging for the healthy participants: both patients with mTBI and healthy participants swayed more
when their eyes were closed than when their eyes were open, demonstrating the reliance on visual input to maintain postural control. The results of BSS analysis showed that patients with mTBIs exhibited impaired balance and sensory integration, which was indicated by the markedly higher scores of the patients than of the control participants in the OA, AP, ML, and EOFIS indices.

The mCTSIB test administered using the BSS provides a valuable, objective assessment of neuromuscular control and somatosensory inputs, which are critical for maintaining balance. Standing on an unstable surface poses biomechanical and musculoskeletal challenges more demanding than standing on a firm surface. The mCTSIB targets sensory-integration deficits including sensory disorganization, sensory loss, improper sensory perception, selected abnormal internal representations and sensorimotor adaptation. Posturography platforms can be used to be a rehabilitation programme enhancing the ability of patients to adjust to altered platform stability and sensory conditions [29]. Maintaining postural balance involves co-ordinating and integrating multiple sensory, motor and biomechanical components [30]. Poor balance can result in various clinically negative consequences such as falls. Therefore, clinicians must address each of the aforementioned components to prevent injury, re-injury or further trauma. The centre-of-gravity sway scores indicate how effectively a patient maintains balance, with lower scores representing less movement and higher scores representing more movement. This study showed that both self-reported problems and objective measurements of balance and sensory-integration components differed between the patients with mTBI and the healthy control participants.

This study recruited a healthy control group, but lacked a minor injury trauma control group (non-head injury control groups). Information processing (postural instability due to visual, somatosensory and vestibular integration information) may be more impaired among a patient group with minor injuries sustained through deceleration forces than among patients who sustained their minor injuries through non-decelerative mechanisms. The disadvantages were that postural control and sensory integration would be influenced by the slower speed of information processing of those exposed to deceleration forces. However, post-concussive symptoms and neuropsychological impairment are not specific to mTBI but can result from pre-existing psychosocial and psychiatric problems, expectancy effects and diagnosis threat. It’s very important to use prospective studies with orthopaedic trauma controls in future investigations of mTBI to control for these confounding factors [31].

The objective analysis techniques used in this study have not been employed routinely to assess instability in patients with mTBIs. Computerized dynamic posturography can reveal abnormal postural responses to changing sensory conditions and perturbations that are not readily detected during clinical examinations [32]. This study provides another method to be considered in follow-up clinical assessments of balance in patients who have experienced mTBI. The strength of the study was the results (especially those regarding AP direction sway) can serve as a reference for establishing rehabilitation exercise programmes designed to enhance the recovery of balance and functional activity and ameliorate dizziness. Non-aerobic exercise interventions in cases of mild-to-moderate TBIs in ambulatory patients can improve balance and functional activity, including gait [33]. Vestibular rehabilitation can reduce dizziness and improve gait and balance functions following concussion in both children and adults [34]. Severe balance dysfunction resulting from TBI might be particularly evident following exercise or intense work. Thus, therapists should progressively increase the challenge levels of tasks and monitor the perception of exertion accordingly [35]. Specific advanced balance training such as AP- and ML-direction balance training and vestibular rehabilitation and sensory-integration training such as visual, somatosensory and vestibular-adaptation training should be added to rehabilitation programmes developed for patients with mTBIs to reduce the risk of falls.

Limitation

This study recruited a healthy control group, but lacked a minor injury trauma control group (non-head injury control groups). Larger cohorts and longer follow-up periods than those used here should be used in future studies of mTBI to confirm the findings.

Conclusion

This study used self-report assessment and postural-control and sensory-integration tests to show that balance function is markedly impaired during the first week following an mTBI. Balance function assessment and training should be considered to assess the risk of falls in monitoring and rehabilitation programmes designed for patients with mTBI.

Acknowledgements

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Declaration of interest

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