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Abstract

Objective—To examine postural instability in children acutely following concussion, using the Wii Balance Board. We hypothesized that children with traumatic brain injury would have significantly worse balance relative to children without brain injury.

Design—Prospective case-control pilot study

Setting—Emergency department of a tertiary urban pediatric hospital

Participants—Cases were a convenience sample aged 11 to 16 years old who presented within six hours of sustaining concussion. Two controls, matched on gender, height, and age, were enrolled for each case that completed study procedures. Controls were children who presented for a minor complaint that was unlikely to affect balance.

Interventions—Not applicable

Main Outcome Measure—The participant's postural sway, expressed as the displacement in centimeters of the center of pressure during a timed balance task. Balance testing was performed using four stances (single or double limb, eyes open or closed).

Results—Three of the seventeen (17.6%) cases were too dizzy to complete testing. One stance, double limbs eyes open, was significantly higher in cases vs. controls (85.6 vs 64.3 centimeters, p=0.04).

Conclusions—A simple test on the Wii Balance Board consisting of a two-legged standing balance task with eyes open discriminated children with concussion from non-injured controls. The low cost and feasibility of this device make it a potentially viable tool for assessing postural stability in children with concussion for both longitudinal research studies and clinical care.

Keywords

concussion; postural control; assessment; children; path length

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Introduction

Approximately 700,000 children are medically evaluated in the emergency department (ED) following traumatic brain injury (TBI) annually in the United States, with countless more being assessed and managed on sidelines by medical professionals. The vast majority of these ED visits are classified as mild traumatic brain injury (mTBI) or concussion[1], and sports injuries are the most commonly reported etiology.[2] Dizziness and postural instability have been reported in 40–50% of children following concussion,[3] although this is likely an underestimate given that patients with TBI tend to under-report imbalance.[4,5] Accurate identification of imbalance acutely following head injury is recommended by the 2012 consensus statement from the International Conference on Concussion in Sport (ICCS),[6] and it would allow clinicians to provide precise guidance about a safe return to play, thereby reducing the risk of re-injury. Additionally, acute dizziness and imbalance have been correlated with a prolonged concussive recovery in young athletes, so early identification of these symptoms may provide prognostic utility.[3,7]

Clinicians lack an objective tool that can quickly and accurately assess a patient's balance. Commonly performed physical balance measures, such as gait assessment and tandem walking, can be inaccurate and insensitive.[4] The Balance Error Scoring System test is a tool that has been shown to be both reliable and valid when administered by trained scorers, although its reliability is highly variable depending on the scorer, making its implementation into a side line or outpatient setting that has heterogeneous staffing limited.[8] Computerized posturography is an objective measure of postural instability that requires an electronic force platform[4] and dynamically records center of pressure sway. Larger distances reflect more sway and are conventionally believed to reflect greater postural instability. Posturography is typically an expensive method, often not portable, and it is primarily reserved for research purposes.[9]

The Nintendo™ Wii Balance Board (WBB) has been compared to a laboratory-grade force platform in various populations, including young healthy adults, demonstrating good to excellent intra-class correlation coefficients for both test-retest reliability (0.66–0.94) and construct validity (0.77–0.89).[10,11] More recently, the WBB was found to have superior validity and test-retest reliability versus the BESS when the two modalities were compared with a force platform.[12] Additional evidence has been published demonstrating the WBB's utility in postural rehabilitation in both adult and pediatric trauma patients.[13,14] The WBB is a cost effective and portable option to objectively evaluate balance, costing a small fraction of other force platforms and weighing only 3.5 kilograms. One prior study has examined its use as an assessment tool in pediatrics, which demonstrated an ability to discriminate between four year old children who were born very pre-term and those born at term.[15] Despite this promising preliminary evidence, no studies have examined its utility in the acute injury setting, nor specifically examined the optimal balance assessment to perform in a pediatric population with concussion.

The purpose of this pilot study was to determine if the WBB was a feasible tool to assess balance in a pediatric cohort and discern postural differences between children with and without a concussion. These findings could be used to inform larger scale research studies,

and possibly guide the translation of typically laboratory-restricted posturographic assessments into standard clinical practice. We hypothesized that children with concussion would demonstrate larger WBB sway measurements, indicative of more instability, relative to matched control patients without concussion, in each of the balance tasks. The secondary aim was to explore the association between subjective complaints and objective WBB measurements of postural instability in children with concussion. Based on prior research,[5] we hypothesized that there would not be an association between complaints and direct measurements of postural instability in children with concussion.

METHODS

Subjects

This was a prospective case-control study, in which a convenience sample of children presenting to an ED at an urban level-one trauma pediatric hospital was enrolled over thirteen months. Written informed consent explaining risks involved with study participation were obtained from the parents and patients before any testing procedures were performed. Cases were eligible if simultaneously enrolled into a parent study (unpublished observations) with an age requirement of 11–16 years, which evaluated the diagnostic and prognostic utility of biomarkers in pediatric concussion. For study inclusion, cases had to present to the ED within six hours of sustaining a witnessed head injury and meet the American Congress of Rehabilitation Medicine's definition of a concussion: a blow to the head or acceleration/deceleration movement of the head resulting in one or more of the following: (1) loss of consciousness <30 minutes, (2) amnesia, (3) or any alteration in mental state at the time of the injury.[16] Exclusion criteria for cases included: a Glasgow Coma Scale of 13 or less at the time of ED presentation, history of head injury or baseline neurologic impairment, altered mental status due to toxin ingestion, >2 extracranial injuries, a significant lower extremity injury that would inhibit balance testing, or non-English speaking. The control group included children presenting to the ED for a minor complaint, who were otherwise healthy, and matched a case in age (+/− 365 days), gender, and height (+/− 10 centimeters). "Minor complaints" were identified by the ED's triage system, and confirmation of the complaint severity, as well as medical clearance, were obtained from the patient's ED clinician prior to approaching for enrollment. Medical clearance was based on clinician acumen, as well as review of an eligibility checklist, excluding children with a chief complaint that would inhibit balance testing (e.g. lower extremity injury, dehydration, fever). Exclusion criteria for controls included any acute or chronic condition that may have resulted in poor balance such as recent head injury, pre-existing neurologic impairment or cognitive disorder or any other physical reason that would inhibit balance testing (e.g. fever, ear infection, dehydration, extremity injury requiring immobilization, lower extremity injury).

Procedures

Children were identified and enrolled in the ED by either the primary investigator or a trained clinical research coordinator. Patient demographics, chief complaint for control patients, and injury descriptors (e.g. presenting signs and symptoms and mechanism of injury) for concussion patients were collected from the electronic medical record and

through patient interview. All patients completed the Post-Concussion Symptom Scale (PCSS), a validated 22 item questionnaire designed to measure the severity of concussive symptoms.[17] Each item is scored using a seven point scale ranging from 0 (absent) to 6 (severe). The scores from two questions evaluating "dizziness" and "balance problems" were computed together to obtain the PCSS Balance Subscore (PCSS-B) and assess the patient's perceived level of postural instability. This self-reported PCSS-B ranged from 0 to 12.

In the ED, patients then underwent balance testing involving the WBB interfaced with specialized software (Labview 2009 National Instruments, Austin, TX, U.S.A.) via Bluetooth. Prior to each attempt the WBB was zeroed and then dynamic measurements of the patient's postural stability were recorded by the software, a technique which has been described in detail previously.[10] The WBB testing protocol was based on a previously documented protocol using four balance stances: single limb standing (dominant limb) with eyes closed, single limb standing (dominant limb) with eyes open, double limb standing with eyes closed and feet together and double limb standing with eyes open and feet apart.[10] Our study varied from that previously described, in that the data were collected for a longer period, with single limb trials being 30 seconds and double limb trials being 60 seconds, versus 10 and 30 seconds, respectively. In keeping with the prior protocol,[10] a total of three completed attempts were performed for each of the four stances; these three measurements were then averaged to obtain the stance's mean score. This combination of longer trial durations and attempts were implemented in accordance with prior research, showing that increasing the duration and number of trials improves reliability, and provided a reasonable trade-off between optimizing reliability and clinical practicality.[18]

Balance testing took approximately 15 minutes in total. Each WBB measurement yielded the subject's center of pressure sway, expressed as the total path length in centimeters (cm) that a subject's center of pressure was displaced during balance testing. Various orders of the balance stances were distributed throughout numbered envelopes and then randomly assigned to cases. Control patients used the same order of WBB stances that their matched case had been assigned. A failed attempt was defined as coming off the WBB and/or placing a foot down during a single limb trial. Our primary outcome variables were the mean WBB balance measurements for each of the four stances detailed above. The secondary outcome variable was the PCSS-B.

Statistical Analysis

All statistical analyses were conducted using the statistical package SAS® (SAS Institute Inc. Version 9.3, Cary, North Carolina, USA). Significant results were identified using a p-value of equal to or less than 0.5. Descriptive statistics including frequency distributions, means, and standard deviations were generated for demographic and injury characteristics. Feasibility was assessed by percent of cases that completed all measurements. The t-test was used to compare WBB mean measurements between concussion and control patients for each of the four stances. We further investigated the strength of group differences by calculating Cohen's d effect sizes for each assessment. Given the exploratory nature of this pilot, we also evaluated the intra-subject variability by reporting the range and the average range among the three attempts for each of the four stances. We conducted an independent

samples Kruskal-Wallis test to compare the average intra-personal range of WBB values between the two groups.

Four general linear models were built to evaluate if the PCSS-B score was associated with each of the WBB mean measurements in the concussion patients. The models were created using the PCSS-B score as the independent variable. The dependent variables were the mean WBB measurements for each of the four stances.

ETHICAL CONSIDERATIONS

All procedures were approved by our Institutional Review Board, and there were no protocol deviations. Informed consent was provided by all participants and study participation did not affect clinical care.

RESULTS

Seventeen concussion patients were enrolled, three were excluded from this analysis since they were too dizzy to complete the WBB balance testing, and one was excluded due to inability to collect data due to technical malfunctions. There were no significant demographic differences between cases and controls (Table 1).

The majority of cases had a GCS of 15 upon ED arrival (92.3%), although about half (53.9%) were noted to be acting confused per physician report. Most of the children (69.2%) had been injured while playing sports: three during basketball, three during American football, two during soccer, and one while wrestling. Eleven (84.6%) of these children reported participating in organized sports. Loss of consciousness and vomiting occurred in five children (38.5%), while eleven (84.6%) complained of headache. The three youth that were too dizzy to use the WBB were white, male, and injured while playing sports.

The control group's chief complaints varied, including abdominal pain (30.7%), musculoskeletal pain or injury (26.9%), sore throat (11.5%), cough (11.5%), skin or nail infection (7.8%), laceration (7.8%) and rash (3.8%). There were no injury-related chief complaints that included head injury or required extremity immobilization. All controls were deemed well appearing and appropriate for balance testing by their ED clinician.

The means, standard deviations, and effect sizes for the WBB measurements of the four balance stances (single limb eyes open, single limb eyes closed, double limb eyes open, double limb eyes closed) are shown in Table 2. Of the four stances, only double limb eyes open yielded significantly different measurements between the two groups ($p = 0.04$, $d=0.83$). When comparing the average intra-personal range of WBB values between groups, cases had significantly more variability, relative to controls, for the two stances using double limbs (Table 3).

To address our secondary exploratory aim, PCSS-B scores were calculated for the concussion patients. One score was missing, and of the remaining twelve cases, the mean PCSS-B score was 5.2 with a standard deviation of 3.7. The PCSS-B scores were not significantly predictive of any of the WBB mean measurements for the four stances: double

limb eyes open (p=0.43), double limb eyes closed (p=0.40), single limb eyes open (p=0.37), and single limb eyes closed (p=0.81).

DISCUSSION

This prospective pilot study explored the potential utility of the WBB for identifying postural instability in children acutely following concussion. While our results are consistent with prior studies in demonstrating postural instability with posturography following concussion, this study is one of the first to evaluate children within hours of injury.[19] Although three children were too dizzy to complete balance testing, the majority (76%) of children successfully completed all three attempts of the four different stances. Our COP measurements reflected the cumulative displacement during each task, rather than a measure of excursion restricted to the peak amplitude of sway in one axis of movement. Given our task times were longer than prior studies (30 and 60 seconds vs 15 and 30 seconds, respectively), our measurements are typical of those expected in this cohort, which when normalized the assessment duration falls between those observed in younger children[15] and adults.[10] Children with concussion demonstrated postural instability, relative to controls, on the simplest of the four WBB stances: eyes open with two legs and feet apart. Our study did not find a significant association between subjective complaints of imbalance and posturography measurements of imbalance, similar to prior research, which provides further support for the clinical utility of objective posturography.[5]

Our initial hypothesis was that patients with concussion would demonstrate increased postural instability, as reflected by larger sway measurements, on all four stances using the WBB. Interestingly, the greatest difference between youth with and without concussion was only found using the easiest balance stance: eyes open with two legs and feet apart, which is similar to what Lin et al[20] found when comparing over 100 concussion patients and healthy controls. Balance relies on successful neurological integration of the available information acquired from the visual, vestibular and somatosensory systems. Complicated tests either remove (visual input when eyes are closed) or emphasize (somatosensory when standing on one leg) input from one system, and these additional challenges may mask the effect of the neurological impairment incurred from the concussion, especially in a pediatric population whose postural control system has not yet fully reached maturity.[21] Our findings of moderate to strong effect sizes for the eyes open stances, in contrast with minimal effect sizes for the eyes closed stances, also suggests that balance tasks performed without visual input were challenging for both groups and may have washed out the effect of the concussion on postural sway. This is a particularly important finding with respect to clinical practicality, as it shows that the simplest balance test may be the most effective one, which reduces the possible floor effect in comparison with more difficult assessments and could shorten testing time.

While utility of the WBB has been well reported in the rehabilitation setting,[13,14] this is the first study to apply its use in the acute injury setting with children. The WBB has clinical utility as a balance assessment in that it is objective, portable, and inexpensive. The WBB may improve the accuracy of evaluating postural stability in the acute injury setting, an evaluation that is recommended by the 2012 ICCS consensus statement.[6] Furthermore,

trainers and clinicians can repeat WBB measurements at subsequent evaluations to track symptom recovery, which would allow for a safe return to play.

While our sample size was small, it is not surprising that the PCSS-B was not predictive of performance on WBB testing in patients with concussion, as imbalance can be a difficult symptom for children to articulate. The field of pediatric concussion continues to lack a validated questionnaire that sufficiently detects imbalance; regardless however, experts agree that symptoms should be assessed in context of objective testing to improve management.[6]

The most obvious limitation to our pilot study is the small sample size, which was due to the linkage with a parent study that included neuroimaging. Additionally, within our small sample size, the youth with the most pronounced balance problems were excluded from analysis, reducing our ability to detect differences between groups. Despite these limitations, we were still able to identify a statistically significant difference between our cohorts, therefore warranting further investigation of the WBB's diagnostic utility in the concussion population, as well as delineation of the most sensitive yet practical testing protocol. Ideally each child would have served as their own control to improve the accuracy of post-concussion symptom diagnosis, but since children did not have pre-injury WBB measurements, we utilized a well appearing matched control group. While balance can be an acquired skill and there is always a degree of inter-subject variability, we attempted to minimize this by controlling for age, gender, and height. Future studies would be strengthened by controlling for these measures, as well as athleticism. Additionally, given the exploratory nature of this pilot, children were randomized to different stance orders, which hindered our ability to assess how fatigability and stance order affected performance. Finally, although our testing with the WBB is limited to static balance testing, other measures that evaluate dynamic testing, such as the Bruininks-Oseretsky Test of Motor Proficiency subtest,[22] have proven useful and potentially practical for outpatient clinical settings and may be considered as an adjunct for further studies. Our secondary aim was limited by the lack of a validated pediatric inventory to detect symptoms of imbalance, although future work may benefit by obtaining this metric in control patients for comparison.

CONCLUSIONS

Acutely following concussion, children demonstrated postural instability while standing on the WBB during a simple two-legged standing balance test with eyes open. The WBB is a potential tool for assessing postural instability following head injury that has a low cost and wide availability. Following concussion, self-reports of imbalance were not significantly associated with objective measurements of imbalance. It is imperative to assess postural instability in children following concussion, and its diagnosis is essential for a safe return to activities, especially sports. Research to further validate the WBB using a larger population with baseline balance measurements would significantly contribute to the diagnosis and management of postural instability following concussion.

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Clinical Relevance

These pilot data suggest that the Wii Balance Board is an inexpensive tool that can be used on the sideline or in the outpatient setting to objectively identify and quantify postural instability.

Table 1

Characteristics of study patients

Patient Characteristics	Concussion Cases (N=13)	Controls (N = 26)
Age (mean +/− SD in years) [*]	12.8 +/− 1.5	13.1 +/− 1.6
Sex (male/female) [*]	12(92%)/1(8%)	24(92%)/2(8%)
Race (white/black) [*]	8(62%)/5(38%)	16(62%)/10(38%)
Height (mean +/− SD in cm) [*]	162.1 +/− 14	163.2 +/− 10.7
Weight (mean +/− SD in kg) [*]	56.1 +/− 16.7	56.5 +/− 13.3
Concussion Characteristics		
Loss of Consciousness	5 (38.5%)	N/A
Headache	11 (84.6%)	N/A
Vomiting	5 (38.5%)	N/A
Glasgow Coma Scale of 15	12 (92.3%)	N/A
Sports as Mechanism of Injury	9 (69.2%)	N/A
PCSS (mean +/− SD)	43.5 +/− 20.4	N/A

cm = centimeters, kg = kilograms, N/A= not applicable, PCSS= Post-Concussion Symptom Scale (ranges 0–132)

[*] Not statistically different (p>0.05) based on t-test

Table 2

Comparing postural sway (cm) between case and control patients

WBB Stance	Concussion Cases Mean +/− SD	Controls Mean +/− SD	p-value	Cohen's d Effect Size
Double Limb Eyes Open	85.6 +/− 32.5	64.3 +/− 16.5	0.04 [*]	0.83
Double Limb Eyes Closed	123.6 +/− 39.6	123.3 +/− 35.7	0.98	0.01
Single Limb Eyes Open	144 +/− 50.1	125.6 +/− 30.4	0.24	0.44
Single Limb Eyes Closed	265.5 +/− 80.1	245.6 +/− 54.6	0.43	0.29

cm = centimeters

[*] Statistically significant p-value (p 0.05) based on t-test

Table 3

Comparing intra-personal ranges of postural sway (cm) between case and control patients

WBB Stance	Concussion Cases Mean (Min-Max)	Controls Mean (Min-Max)	p-value
Double Limb Eyes Open	32.1 (9–121)	11.6 (2–39)	<0.001[*]
Double Limb Eyes Closed	31.4 (7–82)	18.0 (3–49)	0.04[*]
Single Limb Eyes Open	50.0 (5–225)	24.4 (3–61)	0.28
Single Limb Eyes Closed	83.8 (11–283)	51.5 (7–141)	0.44

cm = centimeters, max = maximum, min = minimum

[*] Statistically significant p-value (p 0.05) based on Kruskal-Wallis test