

## Investigating the Feasibility and Utility of Bedside Balance Technology Acutely after Pediatric Concussion: A Pilot Study

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1 **Title:** Investigating the feasibility and utility of bedside balance technology acutely following  
2 pediatric concussion: A pilot study

3

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25

26 **Abstract**

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

30 **Design:** Prospective case-control pilot study

31 **Setting:** Emergency department of a tertiary urban pediatric hospital

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

36 **Interventions:** Not applicable

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

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

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

47

48 **Keywords:** concussion, postural control, assessment, children, path length

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

52 **Introduction**

53 Approximately 700,000 children are medically evaluated in the emergency department (ED)  
54 following traumatic brain injury (TBI) annually in the United States, with countless more being  
55 assessed and managed on sidelines by medical professionals. The vast majority of these ED  
56 visits are classified as mild traumatic brain injury (mTBI) or concussion<sup>1</sup>, and sports injuries are  
57 the most commonly reported etiology.<sup>2</sup> Dizziness and postural instability have been reported in  
58 40-50% of children following concussion,<sup>3</sup> although this is likely an underestimate given that  
59 patients with TBI tend to under-report imbalance.<sup>4,5</sup> Accurate identification of imbalance acutely  
60 following head injury is recommended by the 2012 consensus statement from the International  
61 Conference on Concussion in Sport (ICCS),<sup>6</sup> and it would allow clinicians to provide precise  
62 guidance about a safe return to play, thereby reducing the risk of re-injury. Additionally, acute  
63 dizziness and imbalance have been correlated with a prolonged concussive recovery in young  
64 athletes, so early identification of these symptoms may provide prognostic utility.<sup>3,7</sup>  
65 Clinicians lack an objective tool that can quickly and accurately assess a patient's balance.  
66 Commonly performed physical balance measures, such as gait assessment and tandem walking,  
67 can be inaccurate and insensitive.<sup>4</sup> The Balance Error Scoring System test is a tool that has been  
68 shown to be both reliable and valid when administered by trained scorers, although its reliability  
69 is highly variable depending on the scorer, making its implementation into a side line or  
70 outpatient setting that has heterogeneous staffing limited.<sup>8</sup> Computerized posturography is an  
71 objective measure of postural instability that requires an electronic force platform<sup>4</sup> and  
72 dynamically records center of pressure sway. Larger distances reflect more sway and are  
73 conventionally believed to reflect greater postural instability. Posturography is typically an  
74 expensive method, often not portable, and it is primarily reserved for research purposes.<sup>9</sup>

75 The Nintendo™ Wii Balance Board (WBB) has been compared to a laboratory-grade force  
76 platform in various populations, including young healthy adults, demonstrating good to excellent  
77 intra-class correlation coefficients for both test-retest reliability (0.66-0.94) and construct validity  
78 (0.77-0.89).<sup>10,11</sup> More recently, the WBB was found to have superior validity and test-retest  
79 reliability versus the BESS when the two modalities were compared with a force platform.<sup>12</sup>  
80 Additional evidence has been published demonstrating the WBB's utility in postural  
81 rehabilitation in both adult and pediatric trauma patients.<sup>13,14</sup> The WBB is a cost effective and  
82 portable option to objectively evaluate balance, costing a small fraction of other force platforms  
83 and weighing only 3.5 kilograms. One prior study has examined its use as an assessment tool in  
84 pediatrics, which demonstrated an ability to discriminate between four year old children who  
85 were born very pre-term and those born at term.<sup>15</sup> Despite this promising preliminary evidence,  
86 no studies have examined its utility in the acute injury setting, nor specifically examined the  
87 optimal balance assessment to perform in a pediatric population with concussion.  
88 The purpose of this pilot study was to determine if the WBB was a feasible tool to assess balance  
89 in a pediatric cohort and discern postural differences between children with and without a  
90 concussion. These findings could be used to inform larger scale research studies, and possibly  
91 guide the translation of typically laboratory-restricted posturographic assessments into standard  
92 clinical practice. We hypothesized that children with concussion would demonstrate larger  
93 WBB sway measurements, indicative of more instability, relative to matched control patients  
94 without concussion, in each of the balance tasks. The secondary aim was to explore the  
95 association between subjective complaints and objective WBB measurements of postural  
96 instability in children with concussion. Based on prior research,<sup>5</sup> we hypothesized that there

97 would not be an association between complaints and direct measurements of postural instability  
98 in children with concussion.

99

## 100 **METHODS**

### 101 *Subjects*

102 This was a prospective case-control study, in which a convenience sample of children presenting  
103 to an ED at an urban level-one trauma pediatric hospital was enrolled over thirteen months.

104 Written informed consent explaining risks involved with study participation were obtained from  
105 the parents and patients before any testing procedures were performed. Cases were eligible if

106 simultaneously enrolled into a parent study (unpublished observations) with an age requirement  
107 of 11-16 years, which evaluated the diagnostic and prognostic utility of biomarkers in pediatric

108 concussion. For study inclusion, cases had to present to the ED within six hours of sustaining a  
109 witnessed head injury and meet the American Congress of Rehabilitation Medicine's definition

110 of a concussion: a blow to the head or acceleration/deceleration movement of the head resulting  
111 in one or more of the following: (1) loss of consciousness <30 minutes, (2) amnesia, (3) or any

112 alteration in mental state at the time of the injury.<sup>16</sup> Exclusion criteria for cases included: a

113 Glasgow Coma Scale of 13 or less at the time of ED presentation, history of head injury or

114 baseline neurologic impairment, altered mental status due to toxin ingestion, >2 extracranial

115 injuries, a significant lower extremity injury that would inhibit balance testing, or non-English

116 speaking. The control group included children presenting to the ED for a minor complaint, who

117 were otherwise healthy, and matched a case in age (+/- 365 days), gender, and height (+/- 10

118 centimeters). "Minor complaints" were identified by the ED's triage system, and confirmation

119 of the complaint severity, as well as medical clearance, were obtained from the patient's ED



120 clinician prior to approaching for enrollment. Clinician medical clearance was based on clinical  
121 acumen, as well as review of an inclusion/exclusion criteria checklist. This included exclusion of  
122 patients having a chief complaint that would inhibit balance testing (e.g. lower extremity  
123 pain/injury, dehydration, fever, ear infection). Exclusion criteria for controls included any acute  
124 or chronic condition that may have resulted in poor balance such as recent head injury, pre-  
125 existing neurologic impairment (e.g. stroke) or cognitive disorder (e.g. developmental delay), or  
126 any other physical reason that would inhibit balance testing (e.g. fever, ear pain or infection,  
127 dehydration, extremity injury requiring immobilization, lower extremity injury).

### 128 ***Procedures***

129 Children were identified and enrolled in the ED by either the primary investigator or a trained  
130 clinical research coordinator. Patient demographics, chief complaint for control patients, and  
131 injury descriptors (e.g. presenting signs and symptoms and mechanism of injury) for concussion  
132 patients were collected from the electronic medical record and through patient interview. All  
133 patients completed the Post-Concussion Symptom Scale (PCSS), a validated 22 item  
134 questionnaire designed to measure the severity of concussive symptoms.<sup>17</sup> Each item is scored  
135 using a seven point scale ranging from 0 (absent) to 6 (severe). The scores from two questions  
136 evaluating “dizziness” and “balance problems” were computed together to obtain the PCSS  
137 Balance Subscore (PCSS-B) and assess the patient’s perceived level of postural instability. This  
138 self-reported PCSS-B ranged from 0 to 12.

139 In the ED, patients then underwent balance testing involving the WBB interfaced with  
140 specialized software (Labview 2009 National Instruments, Austin, TX, U.S.A.) via Bluetooth.  
141 Prior to each attempt the WBB was zeroed and then dynamic measurements of the patient’s  
142 postural stability were recorded by the software, a technique which has been described in detail

143 previously.<sup>10</sup> The WBB testing protocol was based on a previously documented protocol using  
144 four balance stances: single limb standing (dominant limb) with eyes closed, single limb  
145 standing (dominant limb) with eyes open, double limb standing with eyes closed and feet  
146 together and double limb standing with eyes open and feet apart.<sup>10</sup> Our study varied from that  
147 previously described, in that the data were collected for a longer period, with single limb trials  
148 being 30 seconds and double limb trials being 60 seconds, versus 10 and 30 seconds,  
149 respectively. In keeping with the prior protocol,<sup>10</sup> a total of three completed attempts were  
150 performed for each of the four stances; these three measurements were then averaged to obtain  
151 the stance's mean score. This combination of longer trial durations and attempts were  
152 implemented in accordance with prior research, showing that increasing the duration and number  
153 of trials improves reliability, and provided a reasonable trade-off between optimizing reliability  
154 and clinical practicality.<sup>18</sup>

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

### 163 *Statistical Analysis*

164 All statistical analyses were conducted using the statistical package SAS® (SAS Institute Inc.  
165 Version 9.3, Cary, North Carolina, USA). Significant results were identified using a p-value of

166 equal to or less than 0.5. Descriptive statistics including frequency distributions, means, and  
167 standard deviations were generated for demographic and injury characteristics. Feasibility was  
168 assessed by percent of cases that completed all measurements. The t-test was used to compare  
169 WBB mean measurements between concussion and control patients for each of the four stances.  
170 We further investigated the strength of group differences by calculating Cohen's d effect sizes  
171 for each assessment. Given the exploratory nature of this pilot, we also evaluated the intra-  
172 subject variability by reporting the range and the average range among the three attempts for  
173 each of the four stances. We conducted an independent samples Kruskal-Wallis test to compare  
174 the average intra-personal range of WBB values between the two groups.  
175 Four general linear models were built to evaluate if the PCSS-B score was associated with each  
176 of the WBB mean measurements in the concussion patients. The models were created using the  
177 PCSS-B score as the independent variable. The dependent variables were the mean WBB  
178 measurements for each of the four stances.

179

## 180 **ETHICAL CONSIDERATIONS**

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

184

## 185 **RESULTS**

186 Seventeen concussion patients were enrolled, three were excluded from this analysis since they  
187 were too dizzy to complete the WBB balance testing, and one was excluded due to inability to

188 collect data due to technical malfunctions. There were no significant demographic differences  
189 between cases and controls (Table 1).

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

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

202 The means, standard deviations, and effect sizes for the WBB measurements of the four balance  
203 stances (single limb eyes open, single limb eyes closed, double limb eyes open, double limb eyes  
204 closed) are shown in Table 2. Of the four stances, only double limb eyes open yielded  
205 significantly different measurements between the two groups ( $p = 0.04$ ,  $d=0.83$ ). When  
206 comparing the average intra-personal range of WBB values between groups, cases had  
207 significantly more variability, relative to controls, for the two stances using double limbs (Table  
208 3).

209 To address our secondary exploratory aim, PCSS-B scores were calculated for the concussion  
210 patients. One score was missing, and of the remaining twelve cases, the mean PCSS-B score

211 was 5.2 with a standard deviation of 3.7. The PCSS-B scores were not significantly predictive of  
212 any of the WBB mean measurements for the four stances: double limb eyes open ( $p=0.43$ ),  
213 double limb eyes closed ( $p=0.40$ ), single limb eyes open ( $p=0.37$ ), and single limb eyes closed  
214 ( $p=0.81$ ).

215

## 216 **DISCUSSION**

217 This prospective pilot study explored the potential utility of the WBB for identifying postural  
218 instability in children acutely following concussion. While our results are consistent with prior  
219 studies in demonstrating postural instability with posturography following concussion, this study  
220 is one of the first to evaluate children within hours of injury, versus days to weeks following  
221 injury.<sup>19</sup> Although three children were too dizzy to complete balance testing, the majority (76%)  
222 of children successfully completed all three attempts of the four different stances. Our COP  
223 measurements reflected the cumulative displacement during each balance task, rather than a  
224 measure of excursion restricted to the peak amplitude of sway in one axis of movement. Given  
225 our task times were slightly longer than prior studies (30 and 60 seconds vs 15 and 30 seconds,  
226 respectively), the values reported in our study are typical of those expected in this cohort, which  
227 when normalized the assessment duration falls between those observed in younger children<sup>15</sup> and  
228 adults.<sup>10</sup> Children with concussion demonstrated postural instability, relative to controls, on the  
229 simplest of the four WBB stances: eyes open with two legs and feet apart. These findings  
230 provide evidence of the potential utility of the WBB in assessing postural stability in the clinical  
231 setting. Our study did not find a significant association between subjective complaints of  
232 imbalance and objective posturography measurements of imbalance, similar to prior research,  
233 which provides further support for the clinical utility of objective computerized posturography.<sup>5</sup>

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

252 While utility of the WBB has been well reported in the rehabilitation setting,<sup>13,14</sup> this is the first  
253 study to apply its use to the acute injury setting as a balance measure for children. The WBB  
254 has clinical utility as a balance assessment in that it is objective, portable, and inexpensive. The  
255 WBB may improve the accuracy of evaluating postural stability in the acute injury setting, an  
256 evaluation that is recommended by the 2012 consensus statement from the ICCS.<sup>6</sup> Furthermore,

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

259 While our sample size was small, it is not surprising that the PCSS-B was not predictive of  
260 performance on WBB testing in patients with concussion, as imbalance can be a difficult  
261 symptom for children to articulate. The field of pediatric concussion continues to lack a  
262 validated questionnaire that is sufficiently sensitive to detect imbalance in this population,  
263 regardless however, experts agree that subjective symptoms should be assessed in context of  
264 objective testing to improve management.<sup>6</sup>

265 The most obvious limitation to our pilot study is the small sample size, which was due to the  
266 linkage with a parent study that included neuroimaging. Additionally, within our small sample  
267 size, the youth with the most pronounced balance problems were excluded from analysis,  
268 evidence of a floor effect and reducing our ability to detect differences between groups. Despite  
269 these limitations, we were still able to identify a statistically significant difference between our  
270 cohorts, therefore warranting further investigation of the WBB's diagnostic utility in the  
271 concussion population, as well as delineation of the most sensitive yet practical testing protocol.

272 Additionally, given the pilot nature of the study, children were randomized to difference stance  
273 orders, which hindered our ability to assess how fatigability and order stance affected balance  
274 performance. Ideally each child would have served as their own control to improve the  
275 accuracy of post-concussion symptom diagnosis, but since children did not have pre-injury WBB  
276 measurements, we utilized a well appearing matched control group. While balance can be an  
277 acquired skill and there is always a degree of inter-subject variability, we attempted to minimize  
278 this by controlling for age, gender, and height. Future studies would be strengthened by  
279 controlling for these measures, as well as athleticism. Additionally, although our testing with the

280 WBB is limited to static balance testing, other measures that evaluate dynamic testing, such as  
281 the Bruininks-Oseretsky Test of Motor Proficiency subtest<sup>22</sup>, have proven useful and potentially  
282 practical for outpatient clinical settings and may be considered as an adjunct for further studies.  
283 Finally, our secondary aim was limited by the lack of a validated pediatric inventory to detect  
284 symptoms of imbalance, although future work may benefit by obtaining this metric in control  
285 patients for comparison.

286

## 287 **CONCLUSIONS**

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

297

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