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Validity Of The Nintendo Wii Balance Board To Assess Weight Bearing Asymmetry During Sit-To-Stand And Return-To-Sit Task

Sumayeh Abujaber[a,d], **Gregory Gillispie**[b], **Adam Marmon**[a], and **Joseph Zeni Jr**[a,c]

[a]Biomechanics and Movement Science Program, University of Delaware, Newark, DE, United States

[b]Department of Kinesiology and Applied Physiology, University of Delaware, Newark, DE, United States

[c]Department of Physical Therapy, University of Delaware, Newark, DE, United States

[d]Department of Physiotherapy, Faculty of Rehabilitation Sciences, The University of Jordan, Amman, Jordan

Abstract

Weight bearing asymmetry is common in patients with unilateral lower limb musculoskeletal pathologies. The Nintendo Wii Balance Board (WBB) has been suggested as a low-cost and widely-available tool to measure weight bearing asymmetry in a clinical environment; however no study has evaluated the validity of this tool during dynamic tasks. Therefore, the purpose of this study was to determine the concurrent validity of force measurements acquired from the WBB as compared to laboratory force plates. Thirty-five individuals before, or within 1 year of total joint arthroplasty performed a sit-to-stand and return-to-sit task in two conditions. First, subjects performed the task with both feet placed on a single WBB. Second, the task was repeated with each foot placed on an individual laboratory force plate. Peak vertical ground reaction force (VGRF) under each foot and the inter-limb symmetry ratio were calculated. Validity was examined using Intraclass Correlation Coefficients (ICC), regression analysis, 95% limits of agreement and Bland-Altman plots. Force plates and the WBB exhibited excellent agreement for all outcome measurements (ICC =0.83–0.99). Bland-Altman plots showed no obvious relationship between the difference and the mean for the peak VGRF, but there was a consistent trend in which VGRF on the unaffected side was lower and VGRF on the affected side was higher when using the WBB. However, these consistent biases can be adjusted for by utilizing regression equations that estimate the force plate values based on the WBB force. The WBB may serve as a valid,

Corresponding author: Sumayeh Abujaber. PT, MS, University of Delaware, 540 South College Avenue, STAR Campus - Suite 210Z, Newark, DE 19713, Phone: +1- 302-831-6460, Fax: +1- 302-831-4234, sumayah@udel.edu.

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There is no conflict of interest.

suitable, and low-cost alternative to expensive, laboratory force plates for measuring weight bearing asymmetry in clinical settings.

Keywords

Wii Balance Board; Weight Bearing Asymmetry; Concurrent Validity; Force Plate; Sit To Stand

1. Introduction

Asymmetrical movement patterns are common in patients with unilateral weakness or pain. Individuals with unilateral lower limb musculoskeletal pathologies such as osteoarthritis, or after procedures such as total joint arthroplasty or anterior cruciate ligament reconstruction, preferentially unload the affected side and shift the weight to the non-affected side during sit-to-stand and squat tasks[1–9]. These asymmetries are particularly concerning in patients before and after total joint arthroplasty because weight bearing asymmetry is related to worse functional performance [9]. Restoring movement symmetry is an important component of rehabilitation for patients after total joint arthroplasty; however methods to quantify inter-limb differences in loading during functional tasks are not always available or feasible in clinical settings.

Research-grade force plates in motion analysis laboratories are the “gold-standard” for accurate measurement of weight bearing asymmetry. Using these force plates, the vertical ground reaction force (VGRF) under each foot can be precisely measured. This equipment is not available in most rehabilitation centers because it is expensive, difficult to transport and requires technical expertise to operate. Recently, the Nintendo Wii Balance Board (WBB) has been suggested as a commercially-available and low-cost tool to measure loading patterns, balance and force symmetry in a clinical environment [6,10–14]. In recent studies, the WBB has been interfaced with custom and commercially available software, to evaluate weight bearing asymmetry in healthy individuals and people with neurological or musculoskeletal conditions [6,10–12]. Although the WBBs have excellent test–retest reliability for measuring weight bearing asymmetry [12], the validity of the force measures acquired from the WBB have not been examined.

WBBs are becoming more common as a rehabilitation tool to both measure interlimb force symmetry and provide feedback to patients about interlimb force symmetry during dynamic activities [6,10–12,15,16]. However, there is little information on the accuracy of the WBB force measurements compared to research-grade force plates. Previous work has evaluated the use of two WBBs, with one under each foot. While this may be useful in a research setting, transporting and setting up two force plates has less utility in a clinical or home-based setting. Therefore, the purpose of this study was to determine the validity of force measurements acquired from a single WBB as compared to force measurements acquired from force plates in a motion analysis laboratory. We hypothesized that peak VGRF and inter-limb VGRF symmetry ratios would show absolute agreement between the WBB and force plates during a sit-to-stand and return-to-sit task (STS-RTS) in patients before and after total joint arthroplasty.

2. Methods

2.1. Participants

Individuals were recruited for this study before and after total joint arthroplasty. Subjects participated in the testing sessions 2–4 weeks prior to, or within 1 year of total hip arthroplasty (THA) or total knee arthroplasty (TKA). These subjects were recruited from a pool of participants enrolled in on-going observational studies evaluating functional performance and movement patterns before and after THA or TKA. Subjects were excluded if they had 1) neurological, vascular or other lower extremity musculoskeletal conditions that affected gait or functional performance, 2) self-reported lack of sensation in the foot or lower extremity, 3) uncontrolled hypertension, 4) history of cancer in the lower extremity, or 5) were unable to walk short distances (10 m) without an assistive device. All subjects included in this analysis were scheduled for or underwent unilateral THA or TKA. The study was approved by the Human Subjects Review Board of the University of Delaware and all subjects signed an informed consent prior to participation.

2.2. Procedures

Subjects performed the STS-RTS task in two conditions. In condition one, subjects performed the STS-RTS with each foot placed on an individual force plate (Bertec Corporation, Columbus, OH) (Figure 1A). In the second condition, subjects placed both feet on a single WBB (Nintendo of America Inc, Redmond, WA) (Figure 1B). In both conditions, subjects were seated on an armless and backless chair. The height of the chair was set to the subject’s knee joint line to allow for 90 degrees of knee flexion when sitting. To account for the additional height of the WBB compared to the force plates that were embedded into the floor, the chair was secured to a wooden platform that was the same height as the WBB. During each trial, subjects were asked to stand from the chair at their self-selected pace, stand for 3 seconds, then return to sit. After returning to a sitting position, subjects lifted their feet from the WBB or the force plates. Subjects lifted their feet so the investigators could determine the end of the trial and to ensure there was no offset in the force data. The feet were repositioned by the investigator after each trial. No restrictions were made on foot position when the task was performed on the force plates, but in the WBB condition foot placement was standardized by asking the subject to place each foot on WBB an equal distance from the center line of WBB inside the rectangular borders defined imprinted on the board. The investigator also ensured that each foot was an equal distance from the front border of WBB. Before each trial on the WBB, foot position was visually checked to ensure appropriate foot placement. During each trial, subjects were asked to hold the arms in their lap and not to use their arms to assist with rising from the chair. A total of 6 trials were collected from each subject; 3 trials on the WBB and 3 trials on the force plate, preceded by two practices for each condition. The subjects were allowed to rest as needed between trials.

The force plates were calibrated in accordance with the manufacturer’s recommendations. In the force plate condition the VGRF was collected for each limb independently from two separate force plates at 1080 Hz. VGRF were then low-pass filtered at 40 Hz using a second-order, phase-corrected Butterworth filter. The WBB was interfaced with a laptop computer using custom-written software (Labview 8.5 National Instruments, Austin, TX, U.S.A.) to collect vertical force data from the four individual strain-gauge type load cells of the WBB. Data were acquired through the standard Bluetooth connection on the laptop computer. The software acquisition rate for the force data was 100 Hz, although the actual output rate of the WBB has been shown to be variable, but on the order of 30–50 Hz [17]. Force under each foot was measured by summing the force values from the two load cells under each foot (right and left sides of the WBB). No modifications were made to the WBB and the WBB force data were not filtered.

2.3 Data analysis

VGRF data were time-normalized to 100 points. Start and end of the STS-RTS task were determined by the minimum VGRF values. The sit-to-stand (STS) phase was defined as the first 25% of the task and the return-to-sit (RTS) phase was defined as the last 25% (Figure 2). Peak VGRF under each limb and the symmetry ratio were calculated and used in this analysis. Peak VGRF during both the STS and RTS phases were calculated in Newtons (N). Interlimb force symmetry was calculated using the symmetry ratio, which was defined as the (peak force of the affected limb / peak force of the unaffected limb) * 100. This value was expressed as a percentage where a value of 100 implies perfect symmetry between limbs. Values less than 100 indicate greater force on the unaffected limb and values greater than 100 indicate greater force on the affected limb. These measures were computed during both conditions (force plate and WBB) for each trial. The average values from the 3 trials were used for the analysis. All outcome measures were collected and analyzed during STS and RTS phases, separately.

2.4 Statistical analysis

Mean and standard deviation for all outcome variables were calculated. For concurrent validity, a two-way, mixed effects, average measure (mean of the three trials), Intraclass Correlation Coefficients (ICC(3,3)) with 95% confidence intervals (CI) were used to measure the absolute agreement between the outcome measurements (i.e. peak force under each limb and symmetry ratio) obtained with the force plates and WBB. Univariate linear regression analysis was used to quantify the relationship between the force measurements from the force plates and WBB, as well as to develop equations that may account for the difference in force between the two methods. Agreement between the two devices for the peak force measurements were also examined by 95% limits of agreement. Bland-Altman plots were created to examine the spread of the error and to examine for systematic bias. Intra-session reliability of both the WBB and force plates was also assessed. Consistency of peak forces and symmetry indices across all 3 trials was examined using Cronbach’s alpha. Reliability was assessed using intra-class correlation coefficient (ICC(3,1)) to test the absolute agreement of peak force and symmetry indices between the first and the last trial. All statistical analyses were conducted using the Statistical Package for the Social Sciences (IBM SPSS 21.0, Chicago, IL)

3. Results

Thirty-five subjects participated in this study. There were 16 men and 19 women with a mean (standard deviation) age of 66.4 (8.3) and mean body mass index of 29.1 (9.6). Eleven subjects participated prior to arthroplasty and twenty-four participated after arthroplasty. There were 27 subjects with hip osteoarthritis and 8 subjects with knee osteoarthritis. The left side was the affected side in 15 subjects (43%) and the right side was the affected side in 20 subjects (57%).

ICCs revealed excellent agreement between two methods for measuring the peak VGRF under the affected side (ICC(3,3) =0.97–0.98), under the unaffected side (ICC(3,3) =0.99), and for the symmetry ratio (ICC(3,3) =0.83–0.88), during the STS and RTS phases (Table 1). Regression analysis showed strong relationship between force plates and WBB measurements with R^2 values ranging from 0.64 to 0.97 (Figure 3). Regression equations that estimate the relationship between two methods are presented on each regression graph (Figure 3). Bland-Altman plots showed no obvious relationship between the difference and the mean for the peak VGRF under either affected or unaffected sides (Figure 4). There was evidence of fixed bias that favored less peak VGRF on the unaffected side (mean difference=14 N & 12 N during STS and RTS, respectively) on the WBB. Similarly, there was a consistent trend toward more force on the affected side (mean difference=21 N & 25 N during STS and RTS, respectively) when the task was performed on the WBB (Figure 4) & (Table 1). These differences between two methods showed a consistent trend across subjects; 80% and 83% of subjects showed increase of the peak force on the affected side during STS and RTS phases respectively, while 69% and 71% of subjects had reduction of the peak force on the unaffected side during STS and RTS phases respectively, when using WBB (Figure 4).

For intra-session reliability, Cronbach's alpha revealed excellent agreement for all measures across three trials on the WBB (0.844 to 0.995) and the force plates (0.914 to 0.994) for the STS and RTS phases of the task (Table 2). The agreement of peak force between the first and third trial was also very high when measured by using intra-class correlations. ICC(3,1) values ranged from 0.958 to 0.979 during the STS and RTS phases for the WBB and from 0.963 to 0.986 for the force plates. For the symmetry index; ICC(3,1) ranged from 0.738 to 0.779 for the WBB and 0.805 to 0.876 on the force plates (Table 2).

4. Discussion

Previous studies have used the WBB to measure the force under each foot and the inter-limb symmetry ratio[6,10–12]; however none of these studies assessed the accuracy of WBB force measurements compared to laboratory force plates during dynamic tasks. The ability to use a portable, low-cost and valid tool to assess weight bearing asymmetry is of substantial clinical importance, but the utility of this tool is dependent on its accuracy. We hypothesized that force magnitude and symmetry ratios obtained through the WBB would be comparable to the same metrics obtained through research grade force plates. The exceptionally high ICC values and high R^2 values show the excellent agreement and strong relationships of WBB measurements with force plates, and indicate that using the WBB may be appropriate for clinical applications. Importantly, the Bland-Altman plots revealed a random spread in error, suggesting differences between measurement devices do not depend on the magnitude of the force under foot. This finding indicates that our results can likely be extrapolated to individuals with high and low degrees of asymmetry between limbs. However, in most all cases, subjects had greater force symmetry on the WBB than on the force plates (Table 1). This discrepancy between devices is likely attributed to two factors: 1) the method in which left and right force data is acquired from a single WBB and 2) the need to place the feet in a symmetrical and standardized position during the WBB trials.

The primary difference between how the WBB and force plates can be used to acquire force data is that the force plates measure the force under each limb separately, while the forces obtained from the WBB must be calculated as the relative weight on the load cells from the right and left sides. Because the two sides of the WBB are not independent, some force from the left foot may be captured by the load cells on the right side and vice versa. This phenomenon contributes to the fixed bias when measuring the magnitude on the affected and unaffected limbs, even though the WBB was designed for bilateral use during game play on the Nintendo console. When using the WBB there was a 12 to 14 N decrease on the unaffected side and 21 to 25 N increase on the affected side and these differences were consistent across the majority of subjects. The transfer of force between sides and load cells in the WBB likely contributes to the higher symmetry ratios observed when using this device. However, these consistent biases can be adjusted for by using the regression equations that estimate the force plate values based on the magnitude of the WBB force. Previous studies have used two WBBs at the same time (one under each foot) to independently measure the vertical force from each foot and avoid the error associated with side-to-side transfer of force [6,10–12].

The small and systematic differences in force measurement between the force plates and WBB may also be attributed to the necessary constraints in foot position using the WBB. The force plates in the laboratory measured 60 by 90 cm for each plate, while the space on top of the WBB measured only 52 by 33.5 cm and subjects on the WBB were constrained to placing the feet equidistant from the center of the device.

These positional constraints were necessary because a shift in the foot placement towards one side increases the resultant force that is recorded under that limb when using the WBB, which is not a problem when using two force plates. The symmetrical foot placement may also have forced the subjects to adopt a more symmetrical loading pattern when performing the STS-RTS task when compared to the force plates. Our current findings suggest that while only one WBB can be used to measure force asymmetry, clinicians using the WBB in a clinical setting should be aware that the measures of asymmetry during an unconstrained STS-RTS task may be slightly greater than those calculated from the WBB.

Our study adds to the building base of literature supporting the clinical utility of the WBB. A recent study by Bartlett et al reported measurement error of the WBB force to be within ±9.1 N when compared to a laboratory force plate [18], which is smaller than the current study. However, Bartlett's study quantified the accuracy of WBB measurements by applying static loads to each of the four cell loads of the WBB independently then estimated the total error, while the current study evaluated the accuracy of the force under each limb computed by summing the forces of left or right load cells during a dynamic task performance. Other recent studies have shown that WBB is a reliable and valid tool for measuring center of pressure (COP) during standing task [12–14]. Findings from previous research may be extrapolated to conclude that a single WBB can accurately assess force distribution, given that the COP is calculated based on force distribution between the right and left load cells of a single WBB. However, it is important to note that COP in these studies was assessed during static tasks (i.e. single-leg stance or double-leg standing) [13,14] or during simulated dynamic postural sway [19]. No previous work has directly examined the forces under each limb and force symmetry during sit to stand, which is a common activity of daily living and an action that is often assessed during the course of clinical treatment. Therefore, we believe that this present study provides novel and important information of using a single WBB for measuring forces in a population in which weight bearing asymmetry is a persistent impairment [9,20]. Additionally, although the intra-session reliability was performed for data that collected in the same day and within a single testing session, we were able to see moderate to very high agreement between trials collected on the WBB and the reliability measures were very similar to those for the force plates. The results support the reliability of using the WBB to measure force outcomes, however; inter-session and intra-tester reliability studies should be performed to substantiate these findings.

This present study is not without limitations. Although we asked subjects to keep their feet an equal distance from the midline of the WBB across the three trials, we did not objectively measure the distances and foot orientation during the task. A study by Genthon et al [21] showed that identical orientation of feet is essential to obtain accurate measure for weight bearing distribution when using a single force plate. Consequently, any change in the orientation or change in the distance between the feet may affect the accuracy of weight bearing distribution on a single WBB. However, our current study indicates high agreement between devices and reliability across trials on the WBB that is similar to reliability for the force plates. Future work should assess the test-retest reliability of WBB measurements across sessions and between testers.

The WBB is a valid method to measure peak VGRF under each limb and the inter-limb symmetry ratio during STS and RTS tasks in subjects prior to or after joint arthroplasty. The WBB may serve as a suitable, low-cost alternative to expensive, laboratory force plates for measuring weight bearing asymmetry in a clinical or home-based setting. Clinicians utilizing this device must be aware that additional movement constraints that are required during the WBB task may inflate measures of movement symmetry. Clinicians interested in the absolute force values that occur in unconstrained conditions can utilize regression equations to improve accuracy of the measures. It is recommended that the same WBB should be used to longitudinally track changes in weight bearing asymmetry for the same individuals, rather than using different WBBs, as using the same WBB provides better repeatability of a single force measurement compared to force repeatability across different boards [18]. Finally, it is important that clinicians who integrate this technology into practice maintain a consistent foot position and orientation when evaluating changes over time. This consistency could be achieved by putting shaded footprints or markings on the WBB to standardize foot placement each trial.

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- We examine the concurrent validity of force measurements of Wii balance board (WBB)
- WBB and laboratory force plates show high agreement in force measurements
- Clinicians can use WBB as a valid tool to measure forces and force symmetry ratio

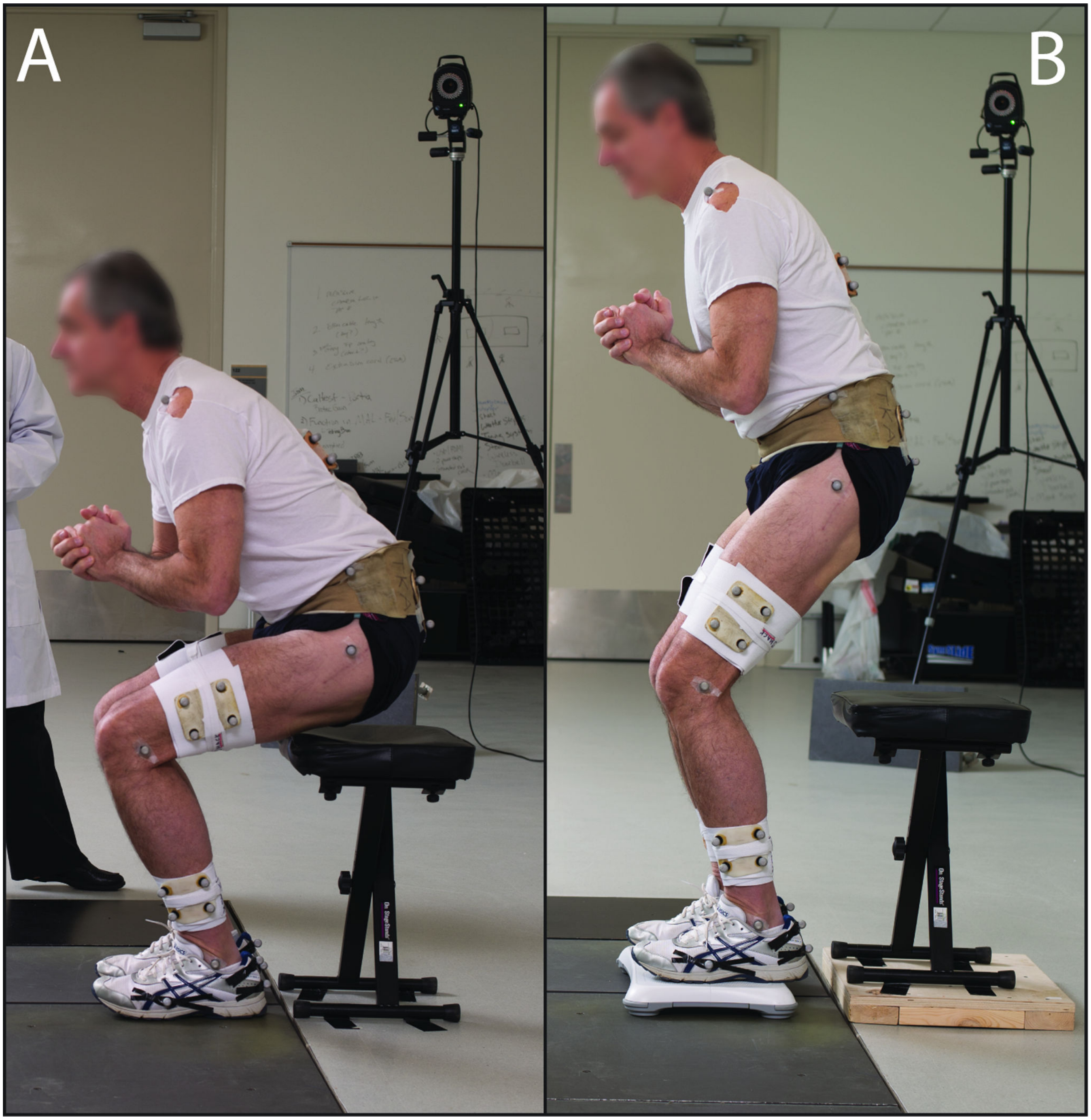

Figure 1.
Subjects performed the STS-RTS task while data from each foot was acquired from the force plates (A) or from the Wii Balance Board (B).

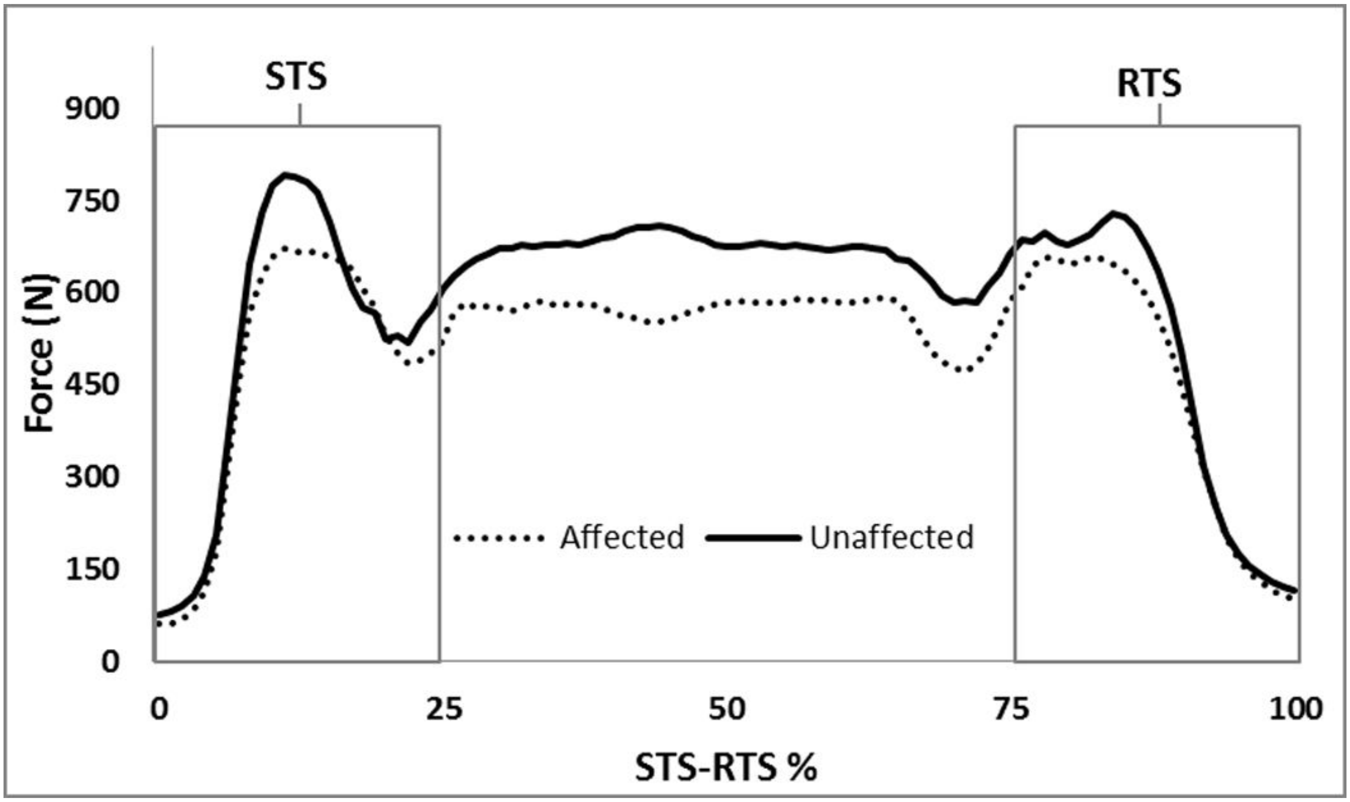

Figure 2.

Example of vertical ground reaction force for both limbs throughout the sit to stand-return to sit (STS-RTS) task. Data were time-normalized to 100 points. The STS phase was defined as the first 25% of the task and RTS phase was defined as the last 25%.

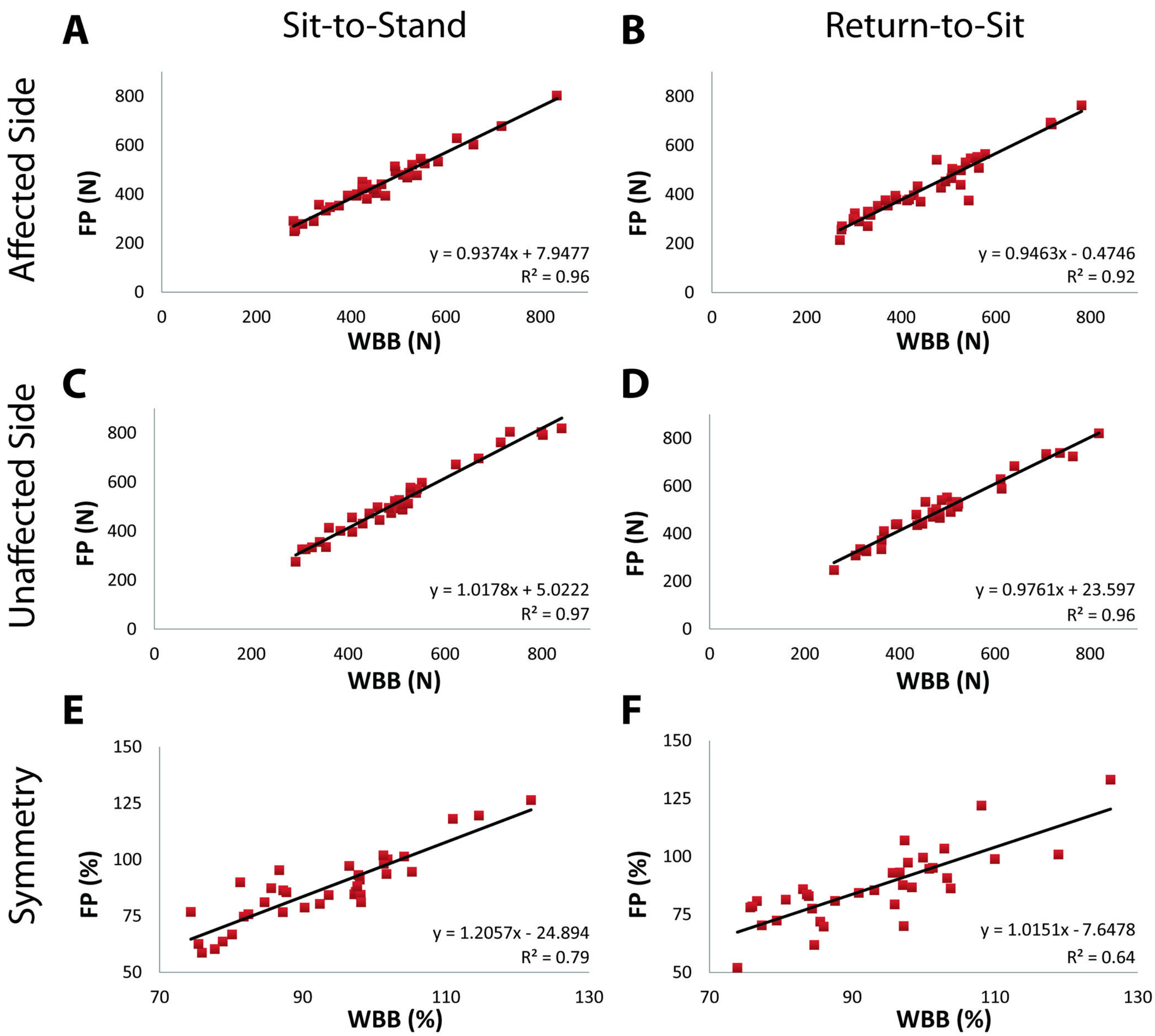

Figure 3.

Scatter plot illustrating the relationship between the VGRF measured using the Wii balance board (WBB) and force plates (FP) for the affected and unaffected sides (A,B and C,D), as well as for the Symmetry Ratio of VGRF (E and F) during Sit-to-Stand and Return-to-Sit phases.

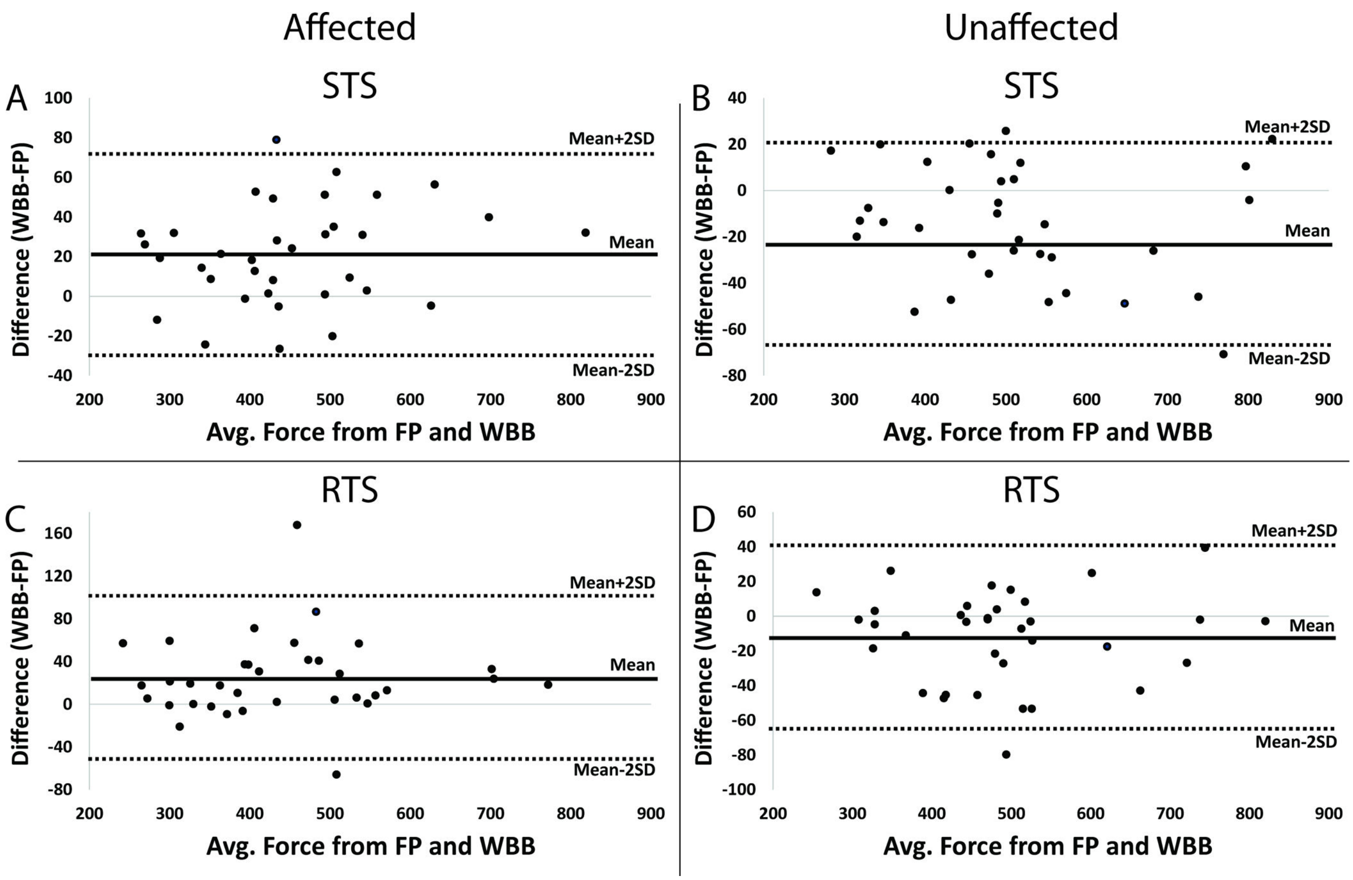

Figure 4.

Bland–Altman plots representing comparisons between the laboratory-grade force platform (FP) and the Wii Balance Board (WBB) during STS phase: (A) for the affected side; (B) for the unaffected side; and during RTS phase (C) for the affected side; (D) for the unaffected side. The mean line represents the mean difference between the devices, with the upper and lower lines representing the limits of agreement (two standard deviations).

Table 1

Peak VGRF in Newton (N) and Symmetry Ratio (affected/unaffected) during STS and RTS

	Force Plate Mean (SD)	WBB Mean (SD)	Mean diff. (95% CI)	ICC3,3 (95% CI)
STS phase				
Affected (N)	441.9 (119.7)	463.9 (125.1)	21 (12.6, 29.4)	0.98 (0.91,0.99)
Unaffected (N)	519.1 (148.5)	505.1 (143.8)	−14 (−5.6, −22,3)	0.99 (0.97,0.99)
Symmetry Ratio (%)	86.9 (15.7)	92.7 (11.5)	5.8 (3.2, 8.3)	0.88 (0.57,0.95)
RTS phase				
Affected (N)	426.4 (128.6)	451.1 (130.1)	25 (12.1, 37.3)	0.97 (0.90,0.99)
Unaffected (N)	496.1 (131.7)	484.1 (132.3)	−12 (−3.2, −20.7)	0.99 (0.97,0.99)
Symmetry Ratio (%)	86.8 (15.75)	92.9 (12.45)	6.1 (2.9, 9.3)	0.83 (0.52,0.93)

WBB: Wii Balance Board; CI: confidence interval; Mean diff.: mean difference between two methods; STS: sit to stand; RTS: return to sit; SR: symmetry ratio

Table 2

Intra-session reliability measures

Cronbach's Alpha				
	WBB		**Force plates**	
Variable	**STS**	**RTS**	**STS**	**RTS**
Vertical Force- Affected side	0.993	0.987	0.984	0.985
Vertical Force- Non-affected side	0.995	0.992	0.994	0.99
Interlimb force Symmetry index	0.935	0.844	0.951	0.914
Intraclass Correlation Coefficient ($ICC_{3,1}$)				
	WBB		Force plates	
Variable	STS	RTS	STS	RTS
Vertical Force- Affected side	0.976	0.958	0.963	0.964
Vertical Force- Non-affected side	0.979	0.977	0.986	0.971
Interlimb Force Symmetry index	0.779	0.738	0.876	0.805

STS: sit to stand, RTS: return to sit, WBB: Wii Balance Board