Validity and Application of a Portable Force Platform in Assessment of Dynamic Balance Ability

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Research

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Abstract

Background: Dynamic balance assessment, which requires a specialized device, is crucial in clinic to evaluate postural control comprehensively. The Nintendo Wii Balance Board (WBB), a portable force platform may be a suitable alternative to the expensive “gold standard”- the laboratory-grade force platform (FP). However, its validity in assessment of dynamic balance is still unclear. The purpose of this study is to demonstrate the validity of the WBB in dynamic balance assessment.

Methods: We performed three static and dynamic balance tests, including open eyes single-leg stand, close eyes single-leg stand and Limitation of Stability, on the WBB for 34 healthy participants. Trajectories of center of pressure (COP) were recorded synchronously and used to compute seven characteristics. To quantify the consistency of the two devices, we used intraclass correlation coefficient (ICC) as well as visual evaluation of Bland–Altman plots.

Results: The data showed a high consistency between the two devices (ICC = 0.92-0.98) under static and dynamic balance assessments, and the visual evaluation result from Bland–Altman plot was acceptable between device agreement. Moreover, in the dynamic balance task (Limitation of Stability test), the typical ranges of COP-based postural sway distances for healthy adults in medial-lateral and anterior-posterior measured by the WBB were 27.17 ± 3.88 cm and 21.13 ± 2.33 cm, respectively, indicating the validity of the WBB in assessing COP under both static or dynamic balance tasks.

Conclusion: With the advantages of portability and low-cost, the valid WBB can facilitate the popularization of quantitative balance evaluation to basic hospitals. Our results provide valuable reference for clinical evaluation of balance ability.

Background

Balance evaluation is widely used to assess risks of falls, the second leading cause of injury-related death in the elderly [1]. According to the WHO, the fall rate is high (28-35%) in the elderly over age 65, which directly causes more than \$30 billion medical costs [2]. The subtle changes in balance are difficult to be detected using a subjective scale due to low capture capacity [3]. The laboratory-grade force platform (FP) is considered as a gold standard for assessing balance performance by recording the center of pressure (COP) trajectories. However, it is not widely applied in clinic because of the exorbitant price and heavy weight. Although various subjective assessment tools [4] are available, such as Berg Balance test [5] and Time Up and Go test (TUG), they also have limitations including ceiling effects [6] and a lack of ability to detect subtle changes.

Consequently, an inexpensive, portable, and accurate device is urgently needed in clinic. The advent of a portable and available force platform - Wii Balance Board (WBB, Nintendo, Kyoto, Japan) may be a substitute to the laboratory FP. The WBB is designed to capture subjects' body sway in the video game WiiFit connected via Bluetooth [7]. The WBB has four transducers to capture the postural change derived from center of pressure (COP) trajectories [8], which is similar to the FP. Furthermore, the WBB is priced at around \$100, a very small fraction of FP, so the cost of devices in hospital departments can be reduced.

A recent review [9], which includes 25 validity studies about the WBB, shows the modest-excellent consistency of the WBB in static balance assessment. Scaglioni-Solano et al. [10] investigated the reliability and validity of the WBB by comparing COP motion with laboratory-grade FP in older adults under five standing tasks. Clark et al. [7] suggested that the WBB is a valid and reliable device in static balance assessment in healthy and young adults. However, to the best of our knowledge, most of the previous studies are focused on static balance assessment, such as single-leg stand with eyes open and eyes closed in different situations [11–13]. However, the validity of WBB in dynamic balance assessment which can detect the balance capacity degrades earlier is still unclear. In terms of dynamic balance validity, one of the recent articles has compared the consistency between the WBB and Sensory Organization Test (SOT) (NeuroCom®, Pleasanton, U.S.A.) [14] in separate trials, but they were unable to extract COP data simultaneously and to eliminate the errors within trials. Our work is to demonstrate the validity and consistency of the WBB, comparing with the laboratory-grade FP in a simultaneous data extraction during both static and dynamic balance evaluation in healthy adults. We hypothesize that the WBB have a good-excellent consistency with laboratory-grade FP, and could meeting the clinical needs in balance assessment.

Methods

Participants

Refer to previous studies, thirty-four (17 men:17 women) healthy adults (age= 24.3 ± 2.1 years, height= 167.7 ± 6 cm, weight= 57.2 ± 9.1 kg) were recruited. The dominant leg in all subjects was the right leg (the leg used for kicking the ball [15]). To be eligible, participants were required: Age >18 years old, healthy college student, no lower limb injuries in recent 3 months, no lower limb diseases, and no neuropathic diseases or other diseases that may influence the ability of balance. Participants were excluded from the study if they could not complete single-leg stand for 30s with open or closed eyes. The study was approved by the institution's Human Research Ethics Committee of Shanghai University of Sport(102772021RT041). All participants provided informed consent.

Procedures

Participants performed three balance tasks (Figure 1.) with a posture of both hands pronated: 1) single-leg stand with eyes opened (EO); 2) single-leg stand with eyes closed (EC); 3) Limitation of Stability (LOS) test. Each task included 3 trails and a total of 9 trials. Single-leg stand test asked participant to raise their un-supporting leg with the toe higher than the ankle of the supporting leg. Both legs were not allowed to touch together during testing, otherwise the test failed. To ensure all the participants perform standardly, researchers explained each task in detail before formal data acquisition. Both EO and EC single-leg stand need to be maintained for 30 s [10, 16]. The LOS test needs to be maintained for 5 s at the end of the maximum range in each direction. There was a rest time of 30 s between each test to avoid fatigue.

Balance ability of each participant was assessed during three balance tasks by two devices: the “gold standard”- a laboratory-grade FP (Kistler 9286 BA model, Kistler Instruments, Amherst, NY, USA 600mm×400mm×35mm) mounted flush with the laboratory floor and the WBB (Nintendo, Kyoto, Japan, 450 ×

265 × 32 mm) located on the FP for overlapping of the two geometric centers. The devices' relative position is shown in Figure 1. The FP was also calibrated (zeroed) to eliminate the weight of the WBB before each test.

Data processing

The WBB was interfaced with a laptop computer by Bluetooth using recommended software (Labview 8.5 National Instruments, Austin, TX, U.S.A.). For the raw data acquisition of the FP, we used the software Bioware3.0 configured by manufacturer with the sampling rate at 1000HZ [17]. A custom MATLAB program was designed for raw data processing. The raw data from both devices were filtered by a second order Butterworth filter with a lowpass cut-off frequency of 12 Hz [18]. Because the sampling rate of the WBB was inconsistent, we resampled the raw data of both devices to 80Hz. Since there was no external synchronization port to link the WBB and the FP, we taped the surface of the WBB to label the acquisition of the sampling sequence synchronously. Considering high variability of COP motion in the beginning and ending stages, 15 s (from 5s to 20s) and 10 s (from 5s to 15s) were selected from the middle stage for analyses of EO and EC single-leg stand tasks, respectively. For the same task, we calculated the average value of three trials.

Based on previous studies [13, 16, 19], which validated the WBB in the static balance assessment, we selected seven characteristics calculated from COP in three-dimension to describe the balance ability: 1) sway length of COP, 2) sway area of COP, 3) COP total sway velocity, 4) COP sway distance in anterior-posterior (A-P) direction, 5) COP sway distance in medial-lateral (M-L) direction, 6) COP sway velocity in A-P direction, and 7) COP sway velocity in M-L direction.

Statistical analysis

All Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS Inc. Version 25, Chicago, IL, U.S.A.). The validity of the WBB was determined by the consistency of the seven characteristics between the WBB and the FP, analyzed using Intraclass correlation coefficient (ICC) and Bland-Altman(B-A) method. For ICC, a two-way, random-effects and single measure (mean of the three trials) model (ICC (2,1) was used. The ICCs were interpreted as follows: excellent (0.75–1), modest (0.4–0.74), and poor (0–0.39) [20]. Bland–Altman plots were plotted for the seven COP characteristics to show the difference of the means from two devices.

Results

Validity between WBB and FP

Table 1 presents the result of the validity analysis in static and dynamic balance tasks. For the sway length, the mean differences in eyes open single stand, eyes closed single stand and LOS were: 11.4 cm (ICC=0.98), 18.06 cm (ICC=0.99) and 32.83 cm (ICC=0.97), respectively. For the M-L sway distance, the mean differences of those three tasks were: 0.34 cm (ICC=0.96), 0.71 cm (ICC=0.99) and 4.33 cm (ICC=0.98), respectively. The mean differences of the A-P sway distance for those three tasks were: 1.08cm (ICC=0.92), 1.85cm (ICC=0.97) and 5.02cm (ICC=0.96), respectively. We found that all three characteristics in LOS were larger than other

tasks obviously. The larger swing trajectory the task showed, the greater mean difference between the two devices. However, the ICC values were always in a high consistency level.

Table 1
Validity analysis of 3 COP sway characteristics in static and dynamic balance assessments.

characteristics	task	FP mean (S.D.)	WBB mean (S.D.)	mean diff (95% CI)	ICC (95% CI)
Sway Length	Eyes open single stand	65.69(15.05)	77.13(17.8)	11.44(-12.54,-10.34)	0.98(0.96,0.99)
	Eyes close single stand	99.08(26.76)	117.15(31.02)	18.06(-19.69,-16.43)	0.99(0.97,0.99)
	Limitation of Stability	143.99(27.95)	176.82(34.67)	32.83(-35.41,-30.25)	0.97(0.95,0.99)
M-L Sway Distance	Eyes open single stand	2.99(1.18)	3.33(1.4)	0.34(-0.47,-0.22)	0.96(0.93,0.98)
	Eyes close single stand	4.62(1.52)	5.33(1.76)	0.71(-0.81,-0.62)	0.99(0.97,0.99)
	Limitation of Stability	22.84(3.2)	27.17(3.88)	4.33(-4.59,-4.07)	0.98(0.96,0.99)
A-P Sway Distance	Eyes open single stand	3.53(0.66)	4.61(0.85)	1.08(-1.18,-0.99)	0.92(0.85,0.96)
	Eyes close single stand	6.02(1.59)	7.86(2.03)	1.85(-2.01,-1.68)	0.97(0.93,0.98)
	Limitation of Stability	16.12(1.78)	21.13(2.33)	5.02(-5.22,-4.81)	0.96(0.92,0.98)
COP: center of pressure; S.D.: standard deviation; A-P: anterior-posterior; M-L: medial-lateral; ICC: intraclass correlation coefficient; FP: force platform; WBB: Wii Balance Board					

Table 2 shows the results of validity analysis in dynamic balance assessment (LOS) with seven characteristics of COP. The mean differences and ICC values in seven COP sway characteristics were acceptable: sway length 32.83 cm (ICC=0.97), area 17.95 cm² (ICC=0.91), COP velocity 1.58 cm/s (ICC=0.97), M-L Sway Distance 4.33 cm (ICC=0.98), A-P Sway Distance 5.02 cm (ICC=0.96), M-L Sway Velocity 0.72 cm/s

(ICC=0.98), and A-P Sway Velocity 1.19 cm/s (ICC=0.97). The ICC values ranged from 0.91 to 0.98, keeping an excellent level of consistency.

Table 2
Validity analysis of 7 COP sway characteristics in dynamic balance assessment.

characteristics	task	FP mean (S.D.)	WBB mean (S.D.)	mean diff (95% CI)	ICC (95% CI)
Sway Length	Limitation of Stability	143.99(27.95)	176.82(34.67)	32.83(-35.41,-30.25)	0.97(0.95,0.99)
Area	Limitation of Stability	31.66(20.14)	49.61(30.29)	17.95(-21.8,-14.1)	0.91(0.82,0.95)
COP Velocity	Limitation of Stability	6.95(1.28)	8.53(1.6)	1.58(-1.71,-1.46)	0.97(0.94,0.99)
M-L Sway Distance	Limitation of Stability	22.84(3.2)	27.17(3.88)	4.33(-4.59,-4.07)	0.98(0.96,0.99)
A-P Sway Distance	Limitation of Stability	16.12(1.78)	21.13(2.33)	5.02(-5.22,-4.81)	0.96(0.92,0.98)
M-L Sway Velocity	Limitation of Stability	4.25(0.86)	4.97(1.01)	0.72(-0.79,-0.65)	0.98(0.95,0.99)
A-P Sway Velocity	Limitation of Stability	4.22(0.84)	5.42(1.08)	1.19(-1.28,-1.11)	0.97(0.93,0.98)
COP: center of pressure; S.D.: standard deviation; A-P: anterior-posterior; M-L: medial-lateral; ICC: intraclass correlation coefficient; FP: force plate; WBB: Wii Balance Board.					

The Bland-Altman plot in Figure 3 shows the relations of the two devices' mean and mean differences for the three characteristics of COP: sway length, A-P sway distance and M-L sway distance in tasks of open eyes single-leg stand and close eyes single-leg stand. Meanwhile, the Bland-Altman plot in Figure 4 shows the same relations within devices in the task of LOS for each characteristics: 1) COP sway length, 2) COP sway area, 3) COP total sway velocity, 4) COP sway distance in A-P direction, 5) COP sway distance in M-L direction, 6) COP sway velocity in A-P direction, and 7) COP sway velocity in M-L direction. The mean differences of all characteristics were within an acceptable range and proportional to the mean values.

Normal ranges of 7 characteristic detected by WBB

Meanwhile, Table 1 and Table 2 also show the normal range of balance tasks acquisitioned by the WBB in static and dynamic assessments in healthy people. In terms of the static balance task, normal range of M-L sway distance and A-P sway distance in eyes open single stand were 3.3 ± 1.4 cm and 4.61 ± 0.85 cm,

respectively; the characteristics in the task with eyes closed single stand were 5.33 ± 1.76 cm and 7.86 ± 2.03 cm, respectively. In terms of dynamic balance task with LOS, values of M-L sway distance and A-P sway distance were 27.17 ± 3.88 cm and 21.13 ± 2.33 cm, respectively.

Discussion

This study demonstrated the validity of the portable force platform-the WBB in balance assessment by comparison with the laboratory-grade force platform (FP). In order to evaluate the consistency between the WBB and the FP comprehensively, we selected three assessment tasks consist of static and dynamic balance tests which are commonly used in clinical balance evaluation. Furthermore, there seven characteristics of COP to describe the participants' balance performance. Moreover, we also stacked the WBB on top of FP and acquisitioned data simultaneously, not only eliminated the learning effect [21] and fatigue effect, but also made a direct comparison between two devices.

Subjective scales for scoring are usually used in clinic to assess balance ability [22], such as Berg Balance Scale [23], Time Up and Go [24], Single-Leg Stand Test [25], etc. Although the scales are convenient to use, they have limitations on detecting underlying proactive and reactive responses. Additionally, all these tools have a ceiling effect in balance assessment [26–28] that could not detect the changes of balance capacity when subjects reach a certain level. On the contrary, the quantity equipment – force platform can not only detect the underlying information and subtle changes that subjective tools cannot find, but also provide objective and quantitative results [29]. Therefore, the FP is considered the gold standard tool to assess balance ability. Since the FP is expensive and cumbersome to transport, it is rarely used in clinic. Recently, the advent of a portable force platform designed for an electronic games – the WBB, becomes a potential complement of the FP to meet the clinical needs of objective and quantified balance assessments. However, most of the previous studies investigated the validation of the WBB in static balance assessment [7, 30–32], and there is no previous valid studies about dynamic balance assessment comparing WBB with the laboratory-grade force platform.

Several studies had demonstrated WBB's validity in static balance [7, 31, 33, 34]. Clark et al. [7] and Park et al. [35] used a laboratory-grade FP to demonstrate WBB's validity in healthy people with ICC ranging from 0.731 to 0.89. Holmes et al. [30] and Llorens et al. [9, 36] selected patients with Parkinson's disease and stroke to explore WBB's validity and gained consistency degrees from bad to excellent. The characteristics of COP they used were total path length, total path velocity, COP sway distance in M-L and A-P directions. Our results show better consistency in the same three characteristics in static balance assessment with ICC values ranging from 0.96 to 0.99. An improvement of the experiment setting is the stacking of devices to acquire data simultaneously due to portability of the WBB.

Dynamic balance ability illustrates the stability of postures maintained by the center of mass within the base of support while moving [37]. Hageman et al. [38] suggested that the performance of the dynamic balance task (such as Limitation of Stability) degrades earlier because of loss of balance capacity, while that of the static balance assessment goes down with advancing age when significant functional declines occur. Additionally, Takeshima et al. [39] concluded that the body's postural control system is under more stress in dynamic tasks, which could help finding greater balance losses. Given the limited research in validation of the

WBB's dynamic balance assessment, we designed to use the reliable Limitation of Stability (LOS) test to assess the dynamic balance ability [40]. COP sway distance in A-P and M-L directions is commonly used as a characteristic while performing LOS. In our data, the maximum M-L sway distance in healthy adults was 27.27 cm in the WBB, which was 4.33 cm deviating from the FP. The maximum A-P sway distance was 21.13 cm with a 5.02cm deviation from the FP. We concerned about the WBB's low and erratic sampling rate that was not competent to the assessment of dynamic balance [8]. However, the consistency of all the seven COP sway characteristics between two devices in LOS test was excellent (ICC: 0.91-0.98). Our results demonstrate that WBB's sensitivity in balance assessment is stable enough while participants performing various dynamic balance tasks. Furthermore, the sampling frequency is sufficient for clinical balance assessments. Our results suggest the WBB as a valid and potential tool to assist the clinicians to make treatment plan, and the data of COP characteristics may be a reference for clinicians to diagnose balance deficits.

Although Bland–Altman plots reveal a mean-deviation between the two devices, the difference may be from the stacking of the two devices. While the FP calculates its COP characteristics, the influence of the height of the WBB cannot be eliminated even though we have zeroed out WBB's weight before each trail. As a result of increasing the torque of FP in Z-axis, the COP of the FP is smaller than its actual value. The calculation formula is shown in Figure 5 and the adjustment between the two devices is quantifiable and relatively stable: The COP value of the WBB is approximately 1.2 times as the value of FP. By taking ICC values into account, these two statistical metrics show that the WBB is stable and in good agreement with FP.

Study Limitations

The limitations of this study are as follows: First, we cannot eliminate the influence of the height of the WBB on the axial torque of FP through subsequent algorithm processing. The results and trajectories from the WBB still show an excellent consistency with the FP. Second, this study only verified the validity of the WBB in healthy people. We will carry out further studies based on patients with specific diseases. Third, we were unable to acquire the WBB and the FP data synchronously by internal synchronization trigger, which is mainly due to a lack of external synchronization port on the WBB. In the future, we can cooperate with relevant personnel to develop synchronization ports, so that the device can synchronize in acquisition with other devices, such as optical motion analysis system, surface electromyography, etc.

Conclusions

the balance ability of the WBB has an excellent consistency with the gold standard and acceptable precision both in static and dynamic assessments. It could be applied in the community to prevent the risk of falls in elders and may be a reference in clinical balance evaluation. Even though there is an error with the FP, the results of WBB are stable and valid. The lack of a professional and portable device is the main reason that the dynamic balance assessment cannot be quantified objectively in clinic. The cheap and portable WBB is a perfect solution to meet clinical needs. Our results of the COP sway distance in anterior-posterior and medial-lateral direction may be a normal reference range for further balance evaluation.

List Of Abbreviations

WBB Wii Balance Board

FP Force Platform

COP Center of Pressure

ICC Intraclass Correlation Coefficient

WHO World Health Organization

TUG Time Up and Go Test

SOT Sensory Organization Test

EO Eyes Opened

EC Eyes Closed

LOS Limitation of Stability

A-P Anterior-posterior

M-L Medial-lateral

Declarations

- **Ethics approval and consent to participate**

The study was approved by the institution's Human Research Ethics Committee of Shanghai University of Sport (102772021RT041). All participants provided informed consent.

- **Consent for publication**

We have obtained the consent for publication from that participant showed in the figure 1.

- **Availability of data and materials**

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

- **Competing interests**

The authors declare that they have no competing interests

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- **Authors' contributions**

Jinpeng Lin was a major contributor in writing the manuscript. Fang Wang, Yaqi Zhao, Jixin Li and Junjie Li were the major contributors in acquisition and analysis data from the two devices. Fei Tian was a major contributor interpretation of data. Hua Zhai and Shaobai Wang were the major contributors in design of the work and provided all the guidance throughout. All authors read and approved the final manuscript.

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Figures

A. Static balance tasks (single-leg stand with eyes closed and opened)

B. Dynamic balance task (Limitation of Stability test)

Figure 1

Balance tasks of static and dynamic balance assessments.

Figure 2

Representative example of center of pressure trajectories for WBB and FP data on EO (A), EC (B), and LOS (C).

Figure 3

Bland–Altman plots comparing the force platform (FP) with the Wii Balance Board (WBB) during the static balance assessments (eyes open single leg stand and eyes close single leg stand) in 3 characteristics: 1) COP sway length, 2) COP sway distance in A-P direction, 3) COP sway distance in M-L direction. The mean line represents the mean difference between devices (WBB–FP), with upper and lower lines representing the limits of agreement (mean+2SD, mean–2SD).

Figure 4

Bland–Altman plots comparing the force plate (FP) with the Wii Balance Board (WBB) during the dynamic balance assessments (Limitation of Stability test) in 7 characteristics: 1) COP sway length, 2) COP sway area, 3) COP total sway velocity, 4) COP sway distance in A-P direction, 5) COP sway distance in M-L direction, 6) COP sway velocity in A-P direction, 7) COP sway velocity in M-L direction.

$$ax = (Fx \cdot az_0 - My) / Fz$$

$$ay = (Fy \cdot az_0 + Mx) / Fz$$

ax: X-Coordinate of force application point (COP)
 ay: Y-Coordinate of force application point (COP)
 Fx: Medial-lateral force
 Fy: Anterior-posterior force
 Fz: Vertical force
 az₀: top plane offset (negative value)
 Mx: Plate moment about X-axis
 My: Plate moment about Y-axis

(A)

(B)

Figure 5

Plot (A) shows the formulas of FP to calculate ax and ay which presented force application point (COP) in X-Coordinate and Y-Coordinate; Plot(B) shows the structure of FP (kistler9286BA, above picture is taken from kistler's instruction manual). a, b presented sensors offset (positive values), az₀ presented top plane offset (negative value); The used az₀ is small than its real value, so that the value of ax and ay is small than it actually is.

Supplementary Files

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