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Llorens Rodríguez, R.; Grau Latorre, J.; Noe, E.; Keshner, EA. (2015). Posturography using the Wii Balance Board. A feasibility study with healthy adults and adults post-stroke. Gait and Posture. 43:228-232. doi:10.1016/j.gaitpost.2015.10.002.

The final publication is available at

http://dx.doi.org/10.1016/j.gaitpost.2015.10.002

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Posturography using the Wii Balance Board™. A feasibility study with healthy adults and adults post-stroke

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Word count abstract: 241

Word count text: 2634

Number of references: 30

Number of tables: 3

Number of figures: 0

Supplemental data: Supplemental material to this article is provided in a separate file.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

This study was funded by project NeuroVR (TIN2013-44741-R) of the Ministerio de Economía y Competitividad (Madrid, Spain).

Abstract

Background

Posturography systems that incorporate force platforms are considered to assess balance and postural control with greater sensitivity and objectivity than conventional clinical tests. The Wii Balance Board (WBB) system has been shown to have similar performance characteristics as other force platforms, but with lower cost and size.

Objectives

To determine the validity and reliability of a freely available WBB-based posturography system that combined the WBB with several traditional balance assessments, and to assess the performance of a cohort of stroke individuals with respect to healthy individuals.

Methods

Healthy subjects and individuals with stroke were recruited. Both groups were assessed using the WBB-based posturography system. Individuals with stroke were also assessed using a laboratory grade posturography system and a battery of clinical tests to determine the concurrent validity of the system. A group of subjects were assessed twice with the WBB-based system to determine its reliability.

Results

A total of 144 healthy individuals and 53 individuals with stroke participated in the study. Concurrent validity with another posturography system was moderate to high. Correlations with clinical scales were consistent with previous research. The reliability of the system was excellent in almost all measures. In addition, the system successfully characterized individuals with stroke with respect to the healthy population.

Conclusions

The WBB-based posturography system exhibited excellent psychometric properties and sensitivity for identifying balance performance of individuals with stroke in comparison with healthy subjects, which supports feasibility of the system as a clinical tool.

Keywords: Posturography; Balance assessment; Wii Balance Board; Stroke; Feasibility

Introduction

The high incidence and prevalence of balance disorders after stroke and their implications for most daily activities make assessment and rehabilitation of balance a priority [1]. Severity of balance deficits have been traditionally assessed using clinical scales [2], which are usually easy to administer in the clinic and not time-consuming. However, balance scales and tests can be influenced by subjective bias and they provide limited sensitivity to, and information about, sensory integration [3].

In the last decade, quantitative assessment has become available through static and dynamic posturography testing [3]. Posturography systems are based on force-plate platforms that estimate the center of pressure (COP) of the subject under study, and evaluate its changes with respect to those from a matched healthy sample. Computerized posturography systems can assess balance and postural control with greater sensitivity and objectivity than clinical instruments, while also quantifying reactions under altered sensory conditions [4]. The negative is that posturography systems are expensive and require a dedicated space in the clinic, which can limit their widespread use [4].

The off-the-shelf Nintendo® Wii Balance Board™ (WBB) is an inexpensive and portable force platform aimed toward allowing users to interact with videogames through postural changes [5]. Interestingly, the WBB has been shown to have validity and reliability similar to the laboratory grade force platforms used in posturography systems [6, 7], whose cost is several orders of magnitude higher. This fact has motivated an increasing number of studies involving the WBB either as a rehabilitation [5] or as an assessment tool [6, 8]. Estimations of the path length and the speed of the COP using the WBB have generally shown excellent correlation with those using laboratory-grade platforms [6, 7, 9, 10], across different activities and populations [6, 8, 10].

Measurements made with the WBB have also shown moderate to excellent reliability [10, 11]. A preliminary study has shown promising results at assessing balance and weight-bearing asymmetry following stroke [11]. However, the unavailability of the software, the limited stroke sample, and the absence of a healthy pattern to compare the results could compromise the clinical relevance of these results.

We have designed a web-based tool that allows clinicians to carry out posturographic assessments using the WBB [12]. Benefits of this tool are that it is freely available to the public and that results can be shared among sites. In order to confirm that the tool is a reliable substitution for currently marketed posturography systems, we performed this study to determine the concurrent validity of the WBB-based system with other posturography and clinical tests. Reliability of our tool was quantified through inter and intra-rater reliability, the standard error of measurement, and its minimal detectable change. Finally, we evaluated a cohort of patients with stroke with respect to a group of healthy controls to determine the sensitivity of the WBB-system to motor disability.

Methods

Subjects

To determine the healthy response pattern, individuals older than ten years old with no known musculoskeletal or vestibular disease and/or prosthetic surgery were recruited. Individuals with stroke were recruited from the outpatient service of the neurorehabilitation unit of the medical center. Inclusion criteria in this group were 1) age ≥ 18 and ≤ 80; 2) ability to stand unassisted for 30 seconds; and 3) ability to understand instructions (Mini-Mental State Examination [13] > 23). Exclusion criteria were 1) individuals with severe aphasia (Mississippi Aphasia Screening Test [14] < 45); 2) individuals with permanent fixed contracture of joints in the legs; 3) individuals with arthritic or orthopedic conditions affecting the lower limbs; and 4) individuals with severe hemispatial neglect. Ethical approval for the study was granted by the Institutional Review Board of the medical center. All eligible candidates who agreed to take part in the study were required to provide informed consent.

Instrumentation

A WBB-based posturography system was developed that included three standardized assessment protocols: the modified Clinical Test of Sensory Interaction on Balance (mCTSIB), the Limits of Stability (LOS), and the Rhythmic Weight Shift (RWS) (see Supplementary Material for additional details). The mCTSIB is a simplified version of the Sensory Organization Test [15] that can be carried out using fixed force plates. The test can detect the presence of sensory impairments by analyzing COP motion during quiet stance under four different conditions: eyes opened and closed on a flat surface, and eyes opened and closed on foam. Outcome measures of this test are the speed and the maximum excursion of the COP in the medial-lateral and anterior-posterior axis. The LOS test quantifies maximum displacement of the COP in eight directions while the plantar surface of the feet remains in contact with the platform. Directional control is assessed as a ratio between the extent of movement in the intended direction and the total amount of movement. The outcome measures of this test are the maximum distance and directional control in each direction. Finally, the RWS assesses the ability to rhythmically move the COP in the medial-lateral (ML) and anterior-posterior (AP) planes at three different speeds. The outcome measure of this test was the directional control in both planes at the different speeds.

Procedure

Healthy individuals were assessed with the three tests of the WBB-based posturography system to describe a healthy response pattern. Subjects were classified in seven decade groups from 10 to 80 years and the average performance of each group in all the tests was computed. Individuals with stroke were also assessed with the WBB-based system and their performance was compared to that of the corresponding age-matched group. In addition, subjects were assessed with the NedSVE/IBV posturography system [16] and with a battery of balance scales to determine concurrent validity of the experimental assessment tool. Posturography assessments were performed barefoot, keeping the feet 20 cm apart in the WBB-based posturography system and placing their feet with the heels together and the toes separated, thus forming a V-shape, in the NedSVE/IBV system, as specified in the manual. Clinical instruments included the Berg Balance Scale (BBS) [17], the Functional Reach Test (FRT) [2], the Step Test with the paretic (STp) and non-paretic leg (STnp) [18], the 30 second Chair-to-Stand Test (30CST) [19], the Timed "Up-and-go" Test (TUG) [20], the Timed Up and Down Stair Test (TUDST) [21], and the 10 Meter Walking Test (10MWT) [22]. All assessments took place within five days.

In addition, ten subjects post-stroke were assessed by two different physical therapists to determine inter-rater reliability on the WBB-based system, and other ten subjects were assessed twice by the same physical therapist to determine intra-rater reliability. These tests were performed within the same day.

Statistical analysis

Pearson correlation coefficients were calculated to determine concurrent validity of the WBB-based posturography with other posturographic and clinical tests. Two statistical indices were used to measure inter and intra-rater reliability. First, paired t-tests were performed to examine the changes for statistical significance. Second, a one-way random effects model intra-class correlation coefficient (ICC) was used to summarize the strength of the reliability. Values 0.8 or higher were accepted as indicating excellent reliability. Values in the range of 0.6–0.8 and 0.4-0.6 indicated high and moderate reliability, respectively. The standard error of measurement (SEM) and the minimal detectable change (MDC) were also obtained. MDC scores>30% were considered poor, from 10% to 30% were considered acceptable, and <10% were considered excellent.

Finally, as it was previously mentioned, healthy controls were categorized into age groups by decade. For each age range, a cumulative frequency distribution of the raw scores of each posturographic measure was estimated. Raw scores of individuals with stroke on each posturographic measure were converted to percentile scores derived from the frequency distribution of the age-matched healthy sample, thus representing their position with respect to the normative values. Percentile scores above the 16^{th} percentile were considered not altered. Percentile scores between the 16^{th} and the 2^{nd} were considered mildly altered. Percentile scores below the 2^{nd} percentile were considered severely altered. All statistical analyses were performed using IBM SPSS Statistics version 22 (IBM, New York, NY). Two-sided P values of <0.05 were considered statistically significant.

Results

Subjects

A total of 144 healthy individuals (62 men and 82 women) aged 43.3±18.6 years old were enrolled (see Supplementary Material for additional details). A cohort of 53 individuals with stroke (38 men and 15 women) were included in the study. The stroke group was aged 52.1±13.7 years old, had a chronicity of 788.7±692.1 days, and presented with both ischemic (n=24) and hemorrhagic stroke (n=29) etiology. Participants had a Motricity Index of 60.3±21.1.

Concurrent validity

Moderate to high correlations between both posturographic systems were seen in the mean displacement of the COP during the mCTSIB in the ML. (r=0.708; p<0.01) and in the AP plane (r=0.873; p<0.01). The mean speed of the COP in the mCTSIB measured by both systems exhibited excellent correlation (r=0.911; p<0.01). The correlation between the maximum displacement registered in the LOS by both systems was moderate (r=0.649; p<0.01).

Significant correlations emerged between the WBB-based system and standardized clinical tests (Table 1). The sign of the correlation was consistent with the idea that better performance in the WBB-based was associated with better performance in the clinical scales. For instance, the lower the mean speed of the COP during the mCTSIB, the higher (better) the scores achieved on the BBS, the FRT, the ST and 30CST, and lower (better) the scores achieved in the timed tests (TUG, TUDST, and 10MWT).

Inter and intra-rater reliability

Inter and intra-rater reliability, the SEM, and the MDC are shown in Table 2. Results indicate excellent inter and intra-rater reliability for all the measures but for those assessing directional control. MDC scores were poor to acceptable for the mCTSIB tests, acceptable for the COP displacement but poor for the directional control during LOS, and acceptable to excellent for the RWS measures.

Clinical utility

The distribution of altered responses on each measured variable in individuals with stroke relative to those of healthy subjects in each experimental condition are presented in Table 3. The suppression of the visual input had a severe impact on the performance of the participants with stroke in the mCTSIB, as shown by the decrease in the number of participants classified as not altered with the eyes-closed compared to the eyes-open condition. However, alteration of proprioceptive input was not as dramatic as for healthy individuals. This result is reflected by the slight increase of participants classified as not altered. Percentages reveal that the WBB-based system was able to identify mild and severe changes within each decade of age on the measured variables suggesting good sensitivity of the system to balance dysfunction.

Discussion

The comparison between both posturography systems revealed that the WBB-based system is a reliable tool that can be used to assess balance of individuals post-stroke with comparable performance to laboratory-grade platforms. Particularly encouraging is that measures of the speed of the COP during the mCTSIB, which represent the mean displacement during the test, had the highest correlations between both posturographic systems, in accordance with previous studies [9, 10]. Lower but still high correlations were achieved between maximum displacements suggesting that the mCTSIB test quantifies the maximum reaction to instability that can vary in different assessments. Correlations between maximum displacements during the LOS were moderate, which might have been due to the different foot placements required on the NedSVE/IBV system. The effect of foot position could have significantly altered the maximum displacement that participants were able to do [23], while having a limited effect during the mCTSIB [24]. It is important to highlight that the hardware architecture, the acquisition of the COP data, and the post-acquisition processing can vary greatly with different posturography systems, thus restricting their comparability [25]. Our results support the clinical use of the WBB-based system as an alternative to laboratory-grade systems, while benefiting from the low-cost and portability of the WBB [5] and the free-of-charge posturography [12].

Comparison between the outcomes of the WBB-based posturography and the clinical tests revealed limited but consistent correlations, in agreement with previous reports. Moderate correlations have been reported not only between posturography and clinical tests [26], but also among clinical scales [27]. Previous correlations of COP measures using the WBB and clinical scale have been shown to support our results [11]. In addition, the tendency for low or high scores shown by the sign of the correlation was consistent with previous research [26, 27]. The limited correlation values (overall in the directional control measures), motivated by the different nature of the tests, indicated that the WBB-based posturography assessment can provide additional data not reflected in clinical tests and scales, thus supporting its use for complementing the balance assessment in individuals with stroke [28].

The WBB-based posturography showed excellent results for both the inter-rater and intra-rater reliability in the mCTSIB scores, which supports findings from previous studies [10, 11], and in the displacement during LOS, which could be explained by the fact that this measure quantifies maximum displacements that should not significantly vary in consecutive assessments. As previously suggested [26], the performance dependence of the measures of directional control restricted their reliability. According to the SEM, the accuracy of the measures of the WBB-based posturography is similar to laboratory grade systems [29], and similar to that reported in previous studies [11]. MDC scores were poor to acceptable in the mCTSIB tests, excellent in the displacement during LOS but poor in the directional control, and excellent in RWS. Even though these results are comparable to those described for laboratory grade systems [25], changes in the balance condition of individuals with stroke detected using the WBB-based posturography should take these properties into account [11].

With regards to the clinical utility, the distribution of the individuals with stroke depicted the characteristics of our sample. The performance in the LOS elicited limited range of movement in the ML axis, presumably due to asymmetry in the body weight distribution [28]. Most of the participants were classified as not altered by the RWS, demonstrating similar performance as healthy individuals. This could be explained by the nature of the task, which could was extremely difficult for both healthy subjects and individuals with stroke.

These results support the use of the WBB-based posturography system for reporting the performance of individuals post-stroke with those from an age-matched healthy sample (see Supplementary Material for additional details).

The limitations of our study must be taken into account when accepting these results. The characteristics of the sample are inherently linked to the specialized neurorehabilitation service where the study took place, which could restrict the generalization of the results. Also, the effective area defined by the force sensors of the WBB restricts the measurable displacement of the COP, which can lead those subjects who are able to perform greater displacements to a ceiling effect in the AP axis.

In conclusion, this study presents a freely available web-based tool that allows clinicians to carry out posturographic assessments using the WBB. The WBB-based posturography showed remarkable properties, both in validity, as measured by the concurrent validity with posturography and clinical tests, and in reliability, as measured by the inter and intra-rater reliability, the SEM, and the MDC. A sample of healthy subjects and individuals with stroke were assessed with the system and compared, as a proof of the clinical utility of the assessment tool. In spite of the fact that the WBB seems to not be as accurate as laboratory grade force platforms [30], it appears sufficient for detecting postural reactions during posturography tests. However, the particular hardware architecture of each posturography system can lead to different measurements [30], therefore the WBB-based posturography system should be used for relative rather than for absolute measurements.

Conclusions

The WBB-based posturography proved to be a valid, reliable, and feasible tool to assess the balance condition of individuals with stroke.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Tables

Table 1. Correlations between the Wii Balance Board™-based posturography and standardized clinical tests

Test	BBS	FRT	STp	STnp	30CST	TUG	TUDST	10MWT
mCTSIB: mean speed	-0.560**	-0.415**	-0.451**	-0.451**	-0.447**	0.496**	0.395**	0.470**
mCTSIB: mean maximum displacement ML	-0.465**	NS	-0.395**	-0.351*	-0.411**	0.391**	0.317*	0.468**
mCTSIB: mean maximum displacement AP	NS	NS	NS	NS	NS	NS	NS	NS
LOS: mean displacement	0.661**	0.514**	0.622**	0.597**	0.645**	-0.558**	-0.618**	-0.532**
LOS: mean directional control	NS	NS	NS	NS	NS	NS	-0.280*	-0.365**
RWS: mean directional control ML	0.282*	0.394**	NS	NS	0.434**	NS	NS	NS
RWS: mean directional control AP	NS	NS	NS	NS	NS	NS	NS	NS

NS: no significant; *: $p<0.05$; **: $p<0.01$.

Table 2. Distribution of the individuals with stroke with respect to healthy controls

Test	Inter-rater reliability	Intra-rater reliability	SEM	MDC (%)
mCTSIB: mean speed	0.840**	0.855**	0.091	0.253 cm/s (34.6 %)
mCTSIB: mean maximum displacement ML	0.835**	0.925**	0.137	0.379 cm (20.6 %)
mCTSIB: mean maximum displacement AP	0.877**	0.852**	0.419	1.162 cm (36.4 %)
LOS: mean displacement	0.975**	0.919**	0.586	1.625 cm (17.9 %)
LOS: mean directional control	0.691*	0.448	10.268	28.461 % (48.5 %)
RWS: mean directional control ML	0.723*	0.718**	1.912	5.299 % (6.3 %)
RWS: mean directional control AP	0. 351	0.367	4.113	11.401 % (13.7 %)

*: $p<0.05$; **: $p<0.01$.

Table 3. Distribution of the individuals with stroke with respect to healthy controls

Test	Condition	Not altered (%)	Mildly altered (%)	Severely altered (%)
mCTSIB: speed	REO	40.0	15.0	45.0
	REC	35.0	17.5	47.5
	REOF	27.5	15.0	57.5
	RECF	37.5	10.0	52.5
mCTSIB: maximum displacement MLs	REO	42.5	20.0	37.5
	REC	32.5	22.5	45.0
	REOF	45.0	17.5	37.5
	RECF	42.5	15.0	42.5
mCTSIB: maximum displacement AP	REO	60.0	15.0	25.0
	REC	55.0	25.0	20.0
	REOF	55.0	17.5	27.5
	RECF	57.5	20.0	22.5
LOS: displacement	Forward	56.1	24.4	19.5
	Right	31.7	22.0	46.3
	Backward	43.9	39.0	17.1
	Left	24.4	22.0	53.7
LOS: directional control	Forward	63.4	29.3	7.3
	Right	84.2	15.8	0.0
	Backward	90.0	10.0	0.0
	Left	62.5	17.5	20.0
RWS:directional control ML	Slow speed	80.5	14.6	4.9
	Medium speed	87.8	12.2	0.0

	Fast speed	87.8	12.2	0.0
RWS: directional control AP	Slow speed	97.6	2.4	0.0
	Medium speed	85.4	12.2	2.4
	Fast speed	97.6	2.4	0.0

REO: Romberg Test with Eyes Open; REC: Romberg Test with Eyes Closed; REOF: Romberg Test with Eyes Open on Foam; RECF: Romberg Test with Eyes Closed on Foam.

Highlights

- The low-cost and a laboratory grade system showed moderate to high correlations
- Concurrent validity of the low-cost system with clinical tests were consistent
- The low-cost system showed excellent inter and intra-rater reliability
- The system successfully assesses subjects in comparison with a healthy matched sample
- The low-cost posturography system is freely available worldwide