A low-cost Wii Balance Board™-based posturography system: an efficacy study with healthy subjects and individuals with stroke

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***Abstract*—The high cost and space required by laboratory grade posturography systems prevents their adoption in most clinics. We have developed a low-cost posturography system that is based on three different exercises commonly used in posturography testing and uses the Nintendo® Wii Balance Board™ as a force platform. This paper describes: a) a study of the performance of 144 healthy individuals on the experimental system; and b) concurrent validity of the experimental system with a laboratory grade posturography system and with several standardized clinical tests in a cohort of 53 stroke survivors. Concurrent validity with the laboratory grade system ranged from moderate to high across the three exercises. Correlations with clinical tests were consistent with previous research. These findings support the use of this accessible system to compare postural behaviors of individuals with stroke with those of healthy subjects.**

Keywords—balance; posturography; stroke; Wii Balance Board

I. Introduction

Disorders of balance are common sequelae of stroke [1, 2]. Motor impairments such as hemiparesis, and sensory changes such as the loss of proprioceptive sensibility in the ankle joint [1], can have a severe impact on balance and, consequently, affect performance of activities of daily living [2]. Balance recovery is, therefore, one of the primary goals of physical therapy interventions [3]. Accurate assessment of balance is needed to quantify an individuals' progression and to establish adequate goals. The state of balance in individuals following a stroke is commonly assessed in the clinic through standardized scales and tests [4]. These tools often evaluate the ability of the subjects to perform tasks that challenge balance and compare their results with those from a sample of healthy individuals. Differences from the performance of the healthy sample indicates possible alterations in balance function [5]. Balance assessment tools are, in general, easily and quickly administered in the clinical setting. However, ratings are somewhat dependent on the judgment of the raters, and the multiple components that affect balance are not well isolated.

Posturography assessments aim to objectively assess balance in individuals under different sensory conditions [6]. Subjects are exposed to sensory conflict while on a force platform that tracks the responses of their center of pressure (COP). Components of sensory integration for balance can be evaluated separately from objective data derived from the responses of the COP. However, the space required in the clinic and the high cost of these posturography systems limits their use in clinical assessment.

The inexpensive Nintendo® Wii Balance Board™ (WBB) has been shown to be a valid and reliable tool for tracking COP with results comparable to laboratory grade posturography systems [7]. Specifically, the WBB has been shown to accurately quantify the path length and speed of the COP with different activities and populations [7-9]. Moreover, the WBB is wireless, portable, and small, which could contribute to its adoption in clinical settings. However, even though its features are commonly used in posturography testing [6], the potential of the WBB for posturography assessment remains somewhat unexplored.

We have designed a freely accessible web-based system that allows therapists to perform posturography assessments using the WBB [10]. The objective of this study was twofold: first, to determine the performance of a sample of healthy individuals on the posturography tasks; and second, to quantify the concurrent validity of the WBB-based posturography system with a laboratory grade system and with standardized clinical tools.

II. Methods

A. Participants

Performance of a healthy population on the posturography tasks was recorded from individuals older than ten years having no known musculoskeletal or vestibular disease and/or prosthetic surgery. Individuals with stroke were also recruited in order to determine concurrent validity of the experimental system,. All outpatients undergoing stroke rehabilitation in the neurorehabilitation unit of a large metropolitan hospital were potential candidates for participation in this study. Subjects were included if they were 1) able to stand unassisted for 30 sec; and 2) able to understand simple instructions (Mini-Mental

State Examination > 23 [11]). Subjects with the following characteristics were excluded: 1) individuals with severe aphasia (Mississippi Aphasia Screening Test < 45 [12]); 2) individuals with an arthritic or orthopedic condition affecting the lower limbs; and 3) individuals with severe hemispatial neglect. All eligible candidates who agreed to take part in the study provided informed consent. Ethical approval was granted by the Institutional Review Board of NISA Valencia al Mar Hospital.

B. Instrumentation

Software: Our posturography system is controlled by an accessible webpage [10] that guides users throughout the process (Fig. 1). It runs the exercises, compares performance with that of a matched sample (defined in this paper) that is stored on the database, and finally, reports the results. A locally installed program is required to run the exercises, retrieve the data from the WBB, and upload results to the webpage.

The web platform was programmed in ASP.NET using Visual Studio (Microsoft®, WA). SQL Server (Microsoft®, WA) was used to develop the database. The virtual environment (VE) portraying the exercises was designed using 3D GameStudio (Conitec Datensysteme GmbH, Germany). The WBB is connected with a computer via Bluetooth technology using the Service Discovery Protocol.

Fig. 1. Flow chart of the posturography system.

During the exercises, the system provides visual feedback, consisting of simplified 2D graphics and audio cues, which indicate the start and end of each trial. Three exercise protocols are included in the WBB-based posturography system: the modified Clinical Test of Sensory Interaction on Balance (mCTSIB), the Limits of Stability (LOS) test, and the Rhythmic Weight Shift (RWS) test.

The mCTSIB is a simplified version of the Sensory Organization Test [13] that can be implemented with fixed force plates as on the WBB. Thus, the mCTSIB can detect the presence of sensory impairment, but it is not capable of determining the source of the dysfunction, as is the original Sensory Organization Test. The mCTSIB requires subjects to stand as still as possible for 30 sec under four different sensory conditions: eyes open on a flat surface (REO), eyes closed on a flat surface (REC), eyes open on foam (REOF), and eyes closed on foam (RECF). Three repetitions of each condition are needed to estimate mean speed and the mean maximum excursion in the medial-lateral (ML) and in the anterior-posterior (AP) axes. During this test, a red circle is presented in the upper center of the screen (Fig. 2) for gaze stabilization during the eyes-open conditions. Performers rely on audio cues in the eyes-closed condition.

Fig. 2. Snapshot of the modified Clinical Test of Sensory Interaction on Balance.

The LOS test estimates the maximum distance that the subject can shift his/her COP in eight directions of space (0º, 45º, 90º, 135º, 180º, 225º, 270º, and 315º). Subjects must transfer their weight while their feet are separated 20 cm and their insoles remain in contact with the surface of the platform. Directional control is also evaluated as a percentage representing the quantity of movement in the intended direction with respect to the total intended movement excursion. The VE in this exercise projects a crosshair, which represents the COP of the subject, and a red circle indicating the target they should attempt to reach (Fig. 3).

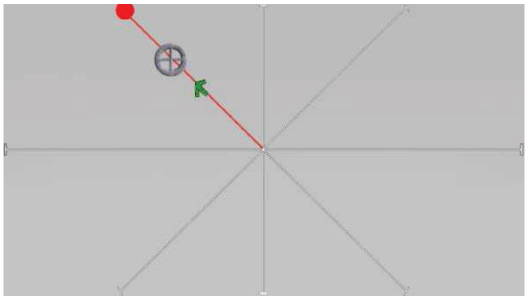
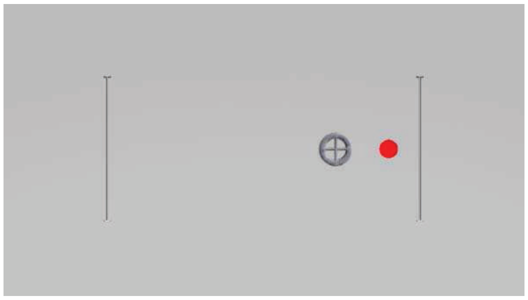


Fig. 3. Snapshot of the Limits of stability test.

The RWS test requires that subjects rhythmically displace their COP in the ML and AP planes at three different speeds while reaching 80% of their limit of stability in each direction. The LOS must be performed before this exercise in order to identify these limits. Subjects stand on the WBB barefoot with feet separated by 20 cm. The RWS estimates the directional control for each speed and direction. As with the LOS, the VE in this exercise shows a crosshair, which represents the COP of the subject, and a red circle representing the target to reach. Brackets represent the limits for the range of movement that were identified by the LOS test (Fig. 4).



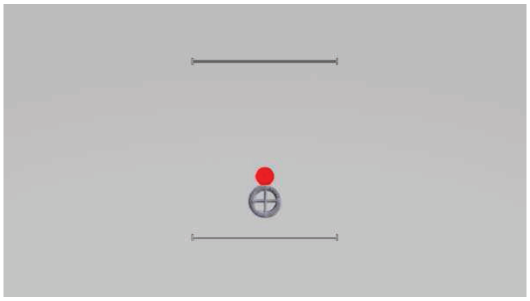


Fig. 4. Snapshot of the Rhytmic Weight Shift.

Hardware: the posturography system uses the WBB as a force platform. The device has four sensors placed on its four corners (TL, TR, BR, BL) that detect the pressure on the surface (Fig. 5). In the developed posturography system, the WBB transfers those data and the weight of the subjects at 40 Hz to a computer. The COP is estimated according to [7].

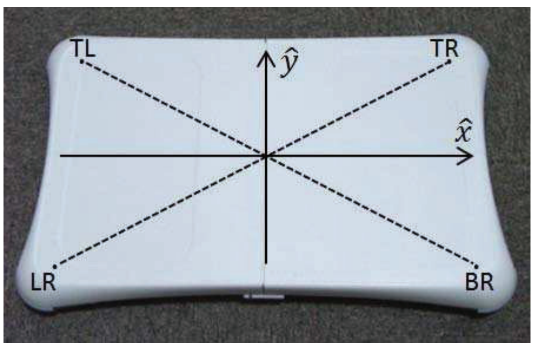


Fig. 5. Coordinate system of the Wii Balance Board™.

A computer with no special requirements, besides Bluetooth connectivity, and internet access are also needed. In the study presented in this paper, a laptop with an Intel® Core™2 T6600 @2.2GHz, 4 GB of RAM, and a AMD Radeon™ HD 4570 video card running Windows 7 was used to collect the data.

C. Procedure

All participants were assessed on the three tests of the WBB-based posturography system. Participants performed these tests barefoot with the feet separated 20 cm. The assessments took place in a dedicated area of the physical therapy unit of NISA Hospital Valencia al Mar (Valencia, Spain). Individuals with stroke were also assessed with a laboratory grade posturography system, the NedSVE/IBV (Instituto de Biomecánica de Valencia, Spain) [6], and with a battery of clinical instruments that included the Berg Balance Scale [14] (BBS), the Functional Reach Test [15] (FRT), the Timed "Up-and-go" Test [16] (TUG), and the 10 Meter Walking Test [17] (10MWT). Posturography assessment with the laboratory grade system required that participants stand barefoot with the heels together, toes separated 20 cm, and the knees together, thus forming a V shape with their feet. Assessments of individuals with stroke were completed within five days of their assessment on the WBB.

D. Statistical analysis

Healthy controls were categorized by decade into seven separate age groups. Pearson correlation coefficients were calculated to determine the concurrent validity of the WBB-based posturography system with the commercial system and the clinical tests. Since directional control is not defined in the same way for both systems, this measure was excluded from the analysis. All statistical analyses were performed using IBM® SPSS Statistics version 22 (IBM®, NY). Two-sided *p* values of <0.05 were considered statistically significant.

III. Results

A. Participants

Participant characteristics are described in TABLE I.

TABLE I. CHARACTERISTICS OF THE PARTICIPANTS

Characteristic	Healthy individuals	Individuals with stroke
Gender (n, %)		
Males	62 (43.1 %)	38 (71.7 %)
Females	82 (56.9 %)	15 (28.3 %)
Age[a] (years)	43.34 ± 18.59	52.11 ± 13.70
Chronicity[a] (days)	-	788.75 ± 692.15
Etiology (n, %)	-	
Ischemic stroke		24 (45.3 %)
Hemorrhagic stroke		29 (54.7 %)

a. Age and chronicity are expressed in terms of mean and standard deviation.

B. Performance of healthy individuals

Performance of healthy individuals on the posturography assessment is shown in Fig. 6. The mCTSIB revealed an almost symmetrical distribution in all outcome measures. Curves reveal a V-shape that began to ascend from the minimum values with the group ranging from 40 to 49 years old. Interestingly, this effect was accentuated as more sensory inputs were altered. The youngest and oldest group exhibited similar results for all the sensory conditions with the exception of maximum displacement in the ML axis. In this measure, the oldest group performed more poorly than individuals in their sixties.

Maximum displacement of COP during the LOS test decreased with age in all directions in space, with a steeper decline appearing over age fifty. During RWS, all age groups exhibited similar results (~85-90 %) in directional control at low and medium speeds. The performance of all subjects worsened (~70 %) at the fast speed, particularly in the older subjects in the ML direction.

C. Concurrent validity

Correlations with the outcome measures of the laboratory grade system were moderate to high. Specifically, the correlation between the maximum displacement during the mCTSIB in both systems was r=0.708 (p<0.01) in the ML axis and r=0.873 (p<0.01) in the AP axis. The mean speed during this test revealed the highest correlation of r=0.911 (p<0.01). In contrast, correlation between the LOS test, r=0.649 (p<0.01), was the lowest of all the measures.

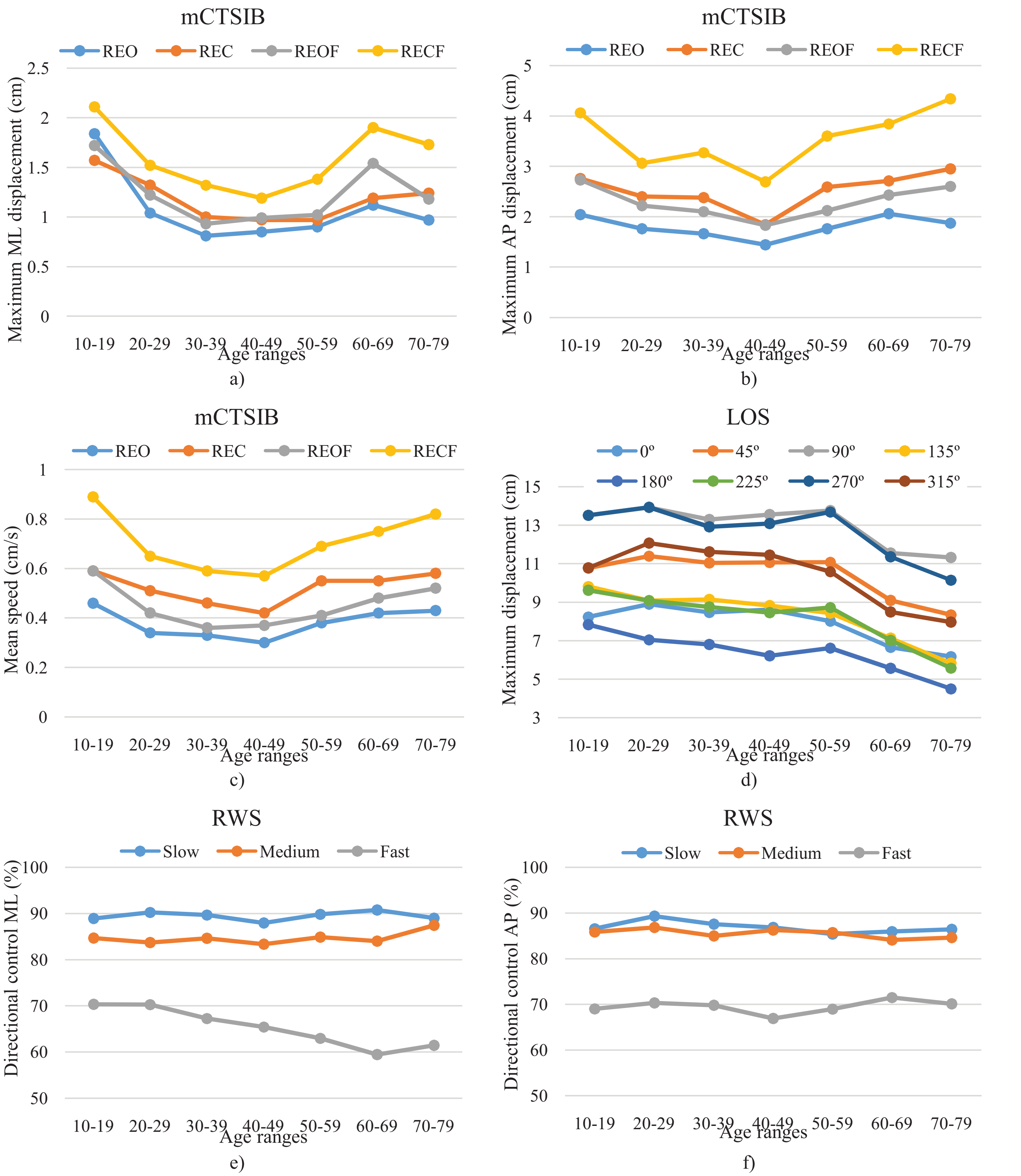


Fig. 6. Distribution of the performance of healthy individuals in the posturography assessment with age: a) maximum displacement in the ML axis during the mCTSIB; b) maximum displacement in the AP axis during the mCTSIB; c) mean speed during the mCTSIB; d) maximum displacement of the COP during the LOS; e) directional control in the ML exercise of the RWS; and f) directional control in the AP axis of the RWS.

TABLE II. CONCURRENT VALIDITY OF THE WII BALANCE BOARD™-BASED POSTUROGRAPHY AND CLINICAL TESTS

Test	BBS	FRT	TUG	10MWT
mCTSIB: mean speed	-0.560**	-0.415**	0.496**	0.470**
mCTSIB: mean maximum displacement ML	-0.465**	NS	0.391**	0.468**
mCTSIB: mean maximum displacement AP	NS	NS	NS	NS
LOS: mean displacement	0.661**	0.514**	-0.558**	-0.532**
LOS: mean directional control	NS	NS	NS	-0.365**
RWS: mean directional control ML	0.282*	0.394**	NS	NS
RWS: mean directional control AP	NS	NS	NS	NS

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

The experimental system also had low to moderate correlations with standardized clinical tests (TABLE II). All significant correlations were directionally consistent with the definition of each of the measures.

IV. DISCUSSION

Our first goal was to characterize the postural response performance of a sample of healthy individuals on the WBB-based posturography system. We found great consistency in the responses of our subjects with age as the primary factor for score differences. Poorer performance in our youngest (10-20 years) and oldest subjects on the mCTSIB would be expected [18], and suggests that the WBB posturography system serves as a good predictor of postural performance in healthy individuals. The absence of differences in directional control across ages during the low and medium speeds of RWS implies a low sensitivity of this particular exercise to weight shifting performance of healthy individuals.

The WBB-system exhibited moderate to high correlations with the laboratory grade system even though both systems were remarkably different. Poor correlations between the maximum displacements of COP during the mCTSIB in both planes could be explained by the fact that this measure represents maximum values of momentary postural adjustments that significantly vary with each repetition. In contrast, the mean speed of the COP during this test, determined by the path length of the COP and not its maximum excursion, had an excellent correlation between both systems. This finding supports those of previous studies that reported good reliability of the WBB to quantify path length of the COP in different tasks [9, 19, 20]. A concurrent correlation of both systems during the LOS test was the poorest of all measures. The different foot position in both systems might explain this disagreement. Interestingly, the position of the feet has been previously reported to affect limits of stability [21], while having lesser impact on performance in the mCTSIB [22]. The different characteristics of both systems, in terms of hardware and signal processing, could also have reduced the correlations.

The WBB-system also exhibited low to moderate correlations with the standardized clinical balance tests. Remarkably, measures of directional control and maximum displacement in the AP plane during the mCTSIB were rarely significant, implying that these measures represent aspects of balance that are not measured by the clinical tests. Signs of the correlations were consistent with expectations of the clinical instruments. For example, lower sway (i.e. lower mean speed) during the mCTSIB was inversely proportional to scores on the BBS where higher values indicate better balance. Correlation scores on the LOS were directional proportional to the FRT, which would be expected because both tests measure maximum reachable distances, either with the arms (FRT) or through weight transference (LOS) in very similar conditions.

In general, the different nature of each test, either posturographic or clinical, may have limited the strength of the correlations. Previous research, has shown moderate correlations between posturography and clinical tests[23] and clinical scales [24]. It is important to recognize that instrumented systems and clinical tests could be measuring different components of balance [25], and the use of posturography assessment is recommended as an addition to conventional clinical tests rather than as a substitute.

The limitations of our study must be taken into account when analyzing these results. First, generalization of these results may be limited by the characteristics of the population sample that are intrinsically linked to the specialized neurorehabilitation service where the study took place. Second, the effective area defined by the force sensors of the WBB (43.5 x 24 cm) restricts the measurable displacement of the COP, which could produce a ceiling effect in those subjects who are able to perform greater displacements. This would be seen mostly in the AP plane because it offers the shortest range (Fig. 5).

However, the results presented in this paper are in accord with previous research in the field and, therefore, support the use of the WBB-based posturography system as a low-cost alternative to laboratory grade platforms. It is important to highlight that the posturography system presented here is freely available for clinicians as well as scientists [10].

V. CONCLUSIONS

This paper describes a low-cost posturography system that uses the WBB as a force platform to study the performance of a sample of healthy individuals and concurrent validity of the experimental system with a laboratory grade system and clinical instruments. Results indicated moderate to high correlations with the laboratory grade system and low to moderate correlations with the clinical tests as previously reported. Our findings suggest that the WBB-based posturography system could be used as a feasible tool to perform posturography assessments in individuals with stroke. The system is freely available to clinicians.

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