# Validation of the Wii Balance Board to assess balance modifications induced by increased respiratory loads in healthy subjects

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## ABSTRACT

*Background:* There is a link between breathing and balance and posture. When the inspiratory loads are increased by pathologies, there is a decrease of postural control. The increase of the inspiratory load on respiratory muscles is a common feature in various chronic pulmonary pathologies. Consequently, the balance of those patients is likely affected.

*Research question:* The aim of this study is to validate the use of the Nintendo Wii Balance Board (WBB) to assess balance modifications induced by increased respiratory loads in healthy subjects.

*Methods:* Thirty-seven healthy young participants (25 ± 4 years old, 17 women) participated in this study. Five different conditions were tested: without anything (control), throughout a mouthpiece, and throughout three inspiratory threshold loads (ITL) at 10% (low), 40% (mid) and 60% (high) of the maximal inspiratory pressure. Each trial lasted for 60 s. Nine parameters were extracted based on center of pressure displacement based on a previously-validated method. ANOVA tests were used to compare the different conditions followed by Bonferroni's corrections.

*Results:* Highly statistically significant differences (all $p < 0.01$) and large effect sizes (all $\omega^2 > 0.24$) were obtained for all parameters between the different loads and the mouthpiece condition. There is a linear relationship between the load and balance perturbation.

*Significance:* In this study, we demonstrated the validity of the WBB to detect the effect of the inspiratory load on balance in young healthy subjects. Further studies are needed to determine if such a kind of evaluation can be used in clinics with patients suffering from chronic respiratory disease.

## 1. Introduction

Breathing pattern influences balance and posture [1–3]. Both tidal volume increase [1] and inspiratory muscles fatigue [2] have a negative impact on the balance. On the other hand, tidal volume decrease, during a cognitive task, decreases the postural sway [3]. Moreover, when a subject breathes through an inspiratory resistance or is voluntary focused on breathing and locomotion, the postural control is altered [4]. This increase of the inspiratory load on respiratory muscles is a common feature in various chronic pulmonary pathologies (e.g. COPD, asthma, etc.) [5]. Consequently, the balance of those patients is

likely affected. In this context, it appeared important to develop and validate a tool assessing the impact of the inspiratory load on the postural control.

The Nintendo Wii Balance Board™ (WBB) has been extensively studied in recent years for research purposes, i.e. balance assessment during static conditions [6,7], and for clinical applications, i.e., assessment of elderly patients [8] or of patients suffering from various diseases. A recent systematic review summarized all the studies about the validation of the WBB, the authors concluded that evidence suggests that the WBB can be used as a reliable and valid tool for assessing standing balance [9].

**Table 1**

Mean (std) results for the studied parameters under the five different conditions. *p*-values are the results of the ANOVA (post-test for linear trend), and $\omega^2$ is the measure of the effect size ($\omega^2 < 0.01$ = small, between 0.01 and 0.06 = medium, $\omega^2 > 0.14$ = large). For low, mid, and high conditions values are also expressed in percentage of the mouthpiece conditions (in italic, normalized values) in order to compare more easily the influence of the loads on the different studied parameters. Note that these data are given for information purposes, the statistics have been processed on the raw data.

| Variables | Control | Mouthpiece | Low | Mid | High | p-value | $\omega^2$ |
|---|---|---|---|---|---|---|---|
| *DOT (mm)* | 1076 (401) | 951 (323) | 942 (266) *99* | 1168 (359) *123* | 1522 (401) *160* | < 0.001 | 0.31 |
| *Area (mm²)* | 3178 (2303) | 2461 (1507) | 2909 (1781) *118* | 5623 (4671) *228* | 7437 (4366) *301* | 0.002 | 0.24 |
| *ML RoM (mm)* | 36 (13) | 31 (10) | 36 (13) *114* | 50 (22) *161* | 56 (22) *181* | 0.007 | 0.24 |
| *AP RoM (mm)* | 146 (49) | 131 (46) | 132 (33) *100* | 171 (60) *130* | 216 (56) *165* | < 0.001 | 0.31 |
| *ML SD (mm)* | 6.0 (2.9) | 5.2 (1.9) | 5.9 (2.2) *112* | 8.1 (3.6) *154* | 9.6 (3.3) *183* | 0.004 | 0.26 |
| *AP SD (mm)* | 28.1 (10.7) | 25.3 (9.1) | 24.4 (7.0) *96* | 29.9 (9.8) *119* | 39.5 (10.2) *156* | < 0.001 | 0.29 |
| *ML velocity (mm/s)* | 2.6 (0.6) | 2.5 (0.4) | 2.7 (0.3) *110* | 3.3 (0.9) *130* | 3.7 (1.0) *149* | 0.010 | 0.28 |
| *AP velocity (mm/s)* | 5.7 (1.7) | 5.3 (1.2) | 5.8 (1.1) *112* | 7.4 (2.6) *143* | 9.1 (3.0) *174* | 0.002 | 0.31 |
| *TMV (mm/s)* | 6.8 (1.9) | 6.3 (1.3) | 7.0 (1.2) *111* | 8.8 (3.0) *141* | 10.9 (3.7) *175* | 0.001 | 0.32 |

Therefore, the WBB appears suitable to assess the balance of patients suffering from various clinical conditions. The main advantage of the WBB compared to laboratory force plate is that the WBB is transportable, therefore assessment can be done in the hospital or directly at the patients' homes which makes assessments easier and can be done more regularly.

However, to the authors' best knowledge, there is currently no study focusing on the use of WBB to assess balance under various inspiratory loads. The aim of this study is, therefore, to validate the use of the WBB to assess balance modifications induced by increased respiratory loads in healthy subjects.

## 2. Material and methods

Thirty-seven healthy young participants (25 ± 4 years old, 170 ± 20 cm, 70 ± 20 kg, 17 women) participated in this study. This study was approved by the Ethical Committee of Erasme Hospital (SRB_201801_068) and written informed consent was obtained from all subjects prior to their participation. Exclusion criteria included neurological conditions, respiratory disease, balance deficits, or orthopedic disorders in the last six months.

Before the experiments the maximal inspiratory capacity was measured starting from the inhalation close to the residual volume following the guidelines of the American Thoracic Society and European Respiratory Society [10]. The maximal inspiratory pressure was measured throughout an occluded mouthpiece (hand-held spirometer/USB Pocket-Spiro® MPM100 MEC Medical Electronic Construction R&D Manufacturer : "M.E.C. R&D sprl, Brussels, Belgium). The maximal inspiratory pressure was determined as the highest pressure sustained for 1 s during the best of three consecutive attempts (mean maximal inspiratory pressure of the participants is 116 ± 33 cm $H_2O$). Subjects were asked to stand on the middle of the WBB (45 × 26.5 cm) as quiet as possible arms relaxed along the body without moving their feet during the protocol and fix a target located on a wall at two meters. Five different conditions were tested: without anything (control), throughout the mouthpiece, and throughout three inspiratory threshold loads (ITL) (MAS Philips Respironics Threshold IMT Lung Muscle Trainer Adjustable Constant Pressure and POWERbreathe Plus Medium

Resistance Breathing Muscle Trainer) at 10% (low), 40% (mid), and 60% (high) of the maximal inspiratory pressure. For all conditions subjects were equipped with a nose clip to avoid nasal compensation. The mouthpiece was attached to a microphone stand to minimize potential compensatory motions and subjects were asked to stay as quiet as possible. Each trial lasted for 60 s, and the order of the trials was randomly defined.

The WBB was connected to a laptop (Intel Core I5, Windows 7, 6 GB RAM) through a Bluetooth connection; data were retrieved using custom-written software based on the WiimoteLib software. The data collection frequency was 100 Hz.

Previous works have shown that the time interval between samples of WBB was inconsistent [7], therefore, linear interpolation of the raw signals of WBB sensors was applied to obtain a regular sample rate. Based on center of pressure (COP) displacements in the antero-posterior (AP) and mediolateral (ML) directions recorded during the different conditions, nine variables were processed using custom-made MATLAB code (The Mathworks, Natick, RI) based on a previously-validated method [11]: the total displacement of sway (DOT); the area of the 95% prediction ellipse (often referred to as the 95% confidence ellipse) (area); the distance between the maximum and minimum COP displacement (RoM AP and RoM ML); the dispersion of COP displacement from the mean position (SD AP and SD ML); the mean velocity of COP displacement (MV AP and MV ML); and the AP and ML displacements of the total COP sway divided by the total duration of the trial (TMV). Equations are presented in Supplementary Material 1.

Data were analyzed during the 5th and the 55th seconds of each trials.

The normality of each parameter was checked using graphical methods (boxplots, histograms, and QQ-plots) and homogeneity of variances using the Levene test. One-way repeated measures ANOVA tests were applied to compare the five conditions. Omega-squared were computed to estimate the effect size [12]. Bonferroni tests were used to correct for multiple comparisons in our post-hoc analysis. Statistical analyses were performed at an overall significance level of 0.05. Statistics have been conducted in RStudio (version 1.1.442) with R version 3.4.4.
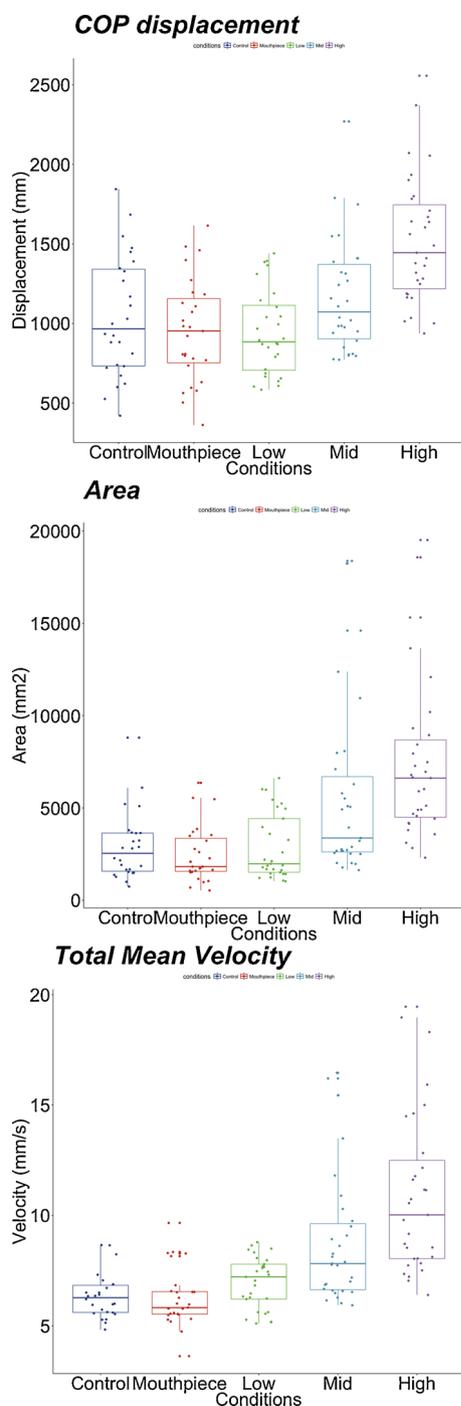
## COP displacement



## Area



## Total Mean Velocity



**Fig. 1.** Results for COP displacement (DOT), area, and TMV for the different conditions.

## 3. Results

Results are presented in Table 1 and Fig. 1. Since no statistically significant difference was found after Bonferroni correction between the control and mouthpiece conditions. ANOVA tests showed differences between the conditions for all parameters. Since both the loads and the balance related parameters are increasing we applied post-test for linear trends.

There are highly statistically significant differences between the different loads for all the studied parameters. Individual results of the different condition comparisons after Bonferroni correction are presented in Table 2. There is an increase in all balance-related parameters with the loads. Large effect sizes were obtained for all parameters ($\omega^2 > 0.24$).

## 4. Discussion

The present study confirmed the relationship between balance perturbations and increased inspiratory resistance [4] and revealed the WBB's ability to detect these impairments. This was observed for all measured parameters related to COP displacements (DOT, Area, AP and ML RoM, AP, and ML SD) and speed (AP and ML velocities, TMV). Moreover, the detected balance impairment was proportional to the amplitude of the inspiratory load.

However, wearing a nose-clip and breathing through a mouthpiece was previously shown to increase the tidal volume [13] which, in turn, may have affected the balance [1]. This potential change was not detected by the WBB, which may indicate a relative lack of sensibility to small balance perturbations, or the fact that there is no such effect with young, healthy subjects.

The results of this study clearly showed that substantial changes in balance control were captured by the WBB, which is promising for the clinical applications. Notably, COPD patients have an increased inspiratory load [5] and a greater activation of inspiratory muscles than the healthy subjects [14]. They also present an altered postural control, especially those with important inspiratory muscle weakness [15]. In this respect, the WBB could help give an objective score of the impact of these phenomena on the balance of patients. This could also allow designing specific rehabilitation protocols adapted to the specific needs of patients.

A limitation of this study is the lack of tidal volume measurement for each of the different conditions. Our observations are, thus, a net result of inspiratory resistance increase without discriminating between the effects of the resistance per se and its indirect effect through breathing pattern change.

In this study we demonstrated the validity of the WBB to detect the effect of the inspiratory load on the balance of young healthy subjects. Further studies are needed to determine if such a kind of evaluation can be used in clinics with patients.

## Conflict of interest

None.

## Authors' contribution

OVH and BB designed the protocol of the study, OVH did the experiments, BB performed the data analysis and statistics, OVH, AVM and DL interpreted the results. OVH, BJ and BB draft the first manuscript, DL, VF and SVSJ revised the manuscript. All the authors participated in the revision of the last version of the manuscript and approved it.

**Table 2**

Difference [95% CI] and *p*-value of group comparisons after Bonferroni corrections (* p < 0.05, ** p < 0.01, *** p < 0.001).

| Variable | Conditions | Control | Mouthpiece | Low | Mid |
|---|---|---|---|---|---|
| DOT | Mouthpiece | −91 [-356 ; 175] | | | |
| | Low | −99 [-363 ; 163] | −9 [- 270 ; 252] | | |
| | Mid | 126 [-133 ; 385] | **217 [40 ; 474] *** | **226 [28 ; 480] *** | |
| | High | **479 [222 ; 737] **** | **570 [315 ; 825] **** | **579 [327 ; 832] **** | **353 [105 ; 601] **** |
| Area | Mouthpiece | −437 [-2897 ; 2021] | | | |
| | Low | 11 [-2406 ; 2427] | 448 [-1945 ; 2841] | | |
| | Mid | **2724 [344 ; 5104] *** | **3161 [805 ; 5517] **** | **2713 [401 ; 5025] *** | |
| | High | **4528 [2147 ; 6908] **** | **4965 [2609 ; 7321] **** | **4517 [2205 ; 6829] **** | **1803 [469 ; 4077] *** |
| ML RoM | Mouthpiece | −3 [-16 ; 9] | | | |
| | Low | 1 [-11 ; 14] | 4 [-8 ; 17] | | |
| | Mid | **16 [3 ; 28] **** | **19 [6 ; 31] **** | **14 [2 ; 27] *** | |
| | High | **22 [10 ; 34] **** | **25 [13 ; 37] **** | **21 [9 ; 33] **** | 6 [- 6 ; 19] |
| AP RoM | Mouthpiece | −13 [-51 ; 25] | | | |
| | Low | −13 [-51 ; 26] | 1 [-37 ; 39] | | |
| | Mid | **26 [11 ; 63] *** | **40 [3 ; 76] *** | **39 [2 ; 76]** | |
| | High | **72 [34 ; 109] **** | **86 [49 ; 122] **** | **85 [48 ; 122] **** | **46 [10 ; 81] **** |
| ML SD | Mouthpiece | −0.3 [-2.4 ; 1.7] | | | |
| | Low | 0.3 [-1.7 ; 2.3] | 0.6 [-1.4 ; 2.6] | | |
| | Mid | **2.5 [0.4 ; 4.5] **** | **2.8 [0.8 ; 4.8] **** | **2.2 [0.2 ; 4.2] *** | |
| | High | **4.0 [2.0 ; 6.1] **** | **4.3 [2.4 ; 6.3] **** | **3.7 [1.7 ; 5.7] **** | **1.5 [0.4 ; 3.5] *** |
| AP SD | Mouthpiece | −2.2 [-9.4 ; 4.9] | | | |
| | Low | −3.1 [-10.2 ; 3.9] | −0.9 [-7.9 ; 6.1] | | |
| | Mid | 2.4 [-4.5 ; 9.4] | 4.7 [-2.2 ; 11.6] | **5.6 [1.3 ; 12.4] *** | |
| | High | **11.9 [5.0 ; 18.9] **** | **14.2 [7.4 ; 21.1] **** | **15.1 [8.3 ; 21.9] **** | **9.5 [2.9 ; 16.2] **** |
| ML Speed | Mouthpiece | 0 [-5 ; 5] | | | |
| | Low | 2 [-3 ; 7] | 3 [-2 ; 8] | | |
| | Mid | **7 [2 ; 12] **** | **8 [3 ; 12] **** | **5 [0; 10] *** | |
| | High | **12 [7 ; 17] **** | **12 [7 ; 17] **** | **10 [5 ; 15] ***** | **5 [1; 9] *** |
| AP Speed | Mouthpiece | −1 [-16 ; 14] | | | |
| | Low | 5 [-10 ; 20] | 6 [-8 ; 21] | | |
| | Mid | **21 [6 ; 36] *** | **22 [8 ; 37] **** | **16 [2 ; 30] *** | |
| | High | **38 [23 ; 52] **** | **39 [24 ; 53] **** | **33 [18 ; 47] **** | **17 [2 ; 31] *** |
| TMV | Mouthpiece | −1 [-19 ; 17] | | | |
| | Low | 6 [-11 ; 24] | 7 [- 10 ; 25] | | |
| | Mid | **25 [7 ; 42] **** | **26 [8 ; 43] **** | **18 [2 ; 35] *** | |
| | High | **46 [28 ; 64] **** | **47 [29 ; 64] **** | **40 [23 ; 56] **** | **21 [4 ; 38] **** |

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