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Wobble board balance assessment in subjects with chronic ankle instability

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ABSTRACT

Background: Wobble boards (WBs), commonly used to train postural control, have been recently equipped with accelerometers connected to a computer displaying real-time balance performances. However, little is known about their ability to detect balance deficits in subjects with unilateral chronic ankle instability (CAI).
Objective: To determine if computerized WBs can detect balance deficits in subjects with unilateral CAI.
Methods: Fifteen subjects with unilateral CAI and fifteen uninjured subjects performed one WB test and one Y Balance Test (YBT) during two separate randomized sessions. WB performance was assessed as the time (s) spent on the platform by keeping it flat at 0° during three 30-s trials for each limb. Normalized (%) reach distances values for anterior, posteromedial, posterolateral directions and composite were recorded for YBT.
Results: WB has been shown to be a reliable and accurate device for detecting balance deficits between and within subjects with unilateral CAI. The area under the curve for receiver operating characteristic was 0.80 (asymptotic significance 0.001), suggesting that WBs have the capability to accurately discriminate between injured and uninjured limbs.
Significance: Computerized WBs can fill the gap caused by limitations between subjective-based clinical assessment and laboratory-based testing, especially in field-based settings, where specificity, transportability and time constraints are crucial. The results of the present study suggest that WBs may facilitate the detection of balance impairments in subjects with unilateral CAI, without complexity in its use or data interpretation.

1. Introduction

Neuromuscular control is an active process designed to maintain postural stability during motor activities depending on afferent input from vestibular, visual, and somatosensory systems. These systems inform about body position, its relation to the base of support (BoS), and segment locations relative to each other. Subsequently, afferent information is processed by supraspinal areas and spinal neural networks that determine the required movements to maintain balance [1]. Multiple factors, such as physiological, biomechanical and previous injuries [2–4], can influence balance performance and movements executed by the neuromuscular system.

Injuries, especially ankle sprains, are the most recurrent in sports, military, and occupational settings and generally common in physically active people [5–7]. Although they are often considered innocuous injuries without permanent consequences, residual symptoms, such as repetitive giving way of the ankle during functional activities, and the development of chronic ankle instability (CAI) are associated to future ankle sprains, with an incidence between 31% and 40% [8].

The most frequently involved ligaments in ankle sprains (i.e., anterior talofibular and calcaneofibular) cause mechanical and functional instabilities that influence the recovery and the development of CAI [9]. Moreover, alterations in strength, mechanical stability, range of motion and changes in central nervous system processing and integration have been found in subjects with CAI, suggesting further contributions to postural control deficits (i.e., any dysfunction in the ability to maintain, achieve or restore a state of balance) after ankle sprains [1]. In particular, among the most common balance deficits reported after ankle sprains, bilateral neuromuscular control impairments, commonly described as the inability to maintain postural stability during single limb stance on a small BoS, have been found after unilateral ankle sprain, suggesting that central pathways are also

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affected [10]. Although healthy individuals can maintain an upright single limb stance with reduced afferent input without difficulties or with only small increase in postural sway, subjects with neuromuscular control deficiencies or CAI can have relevant problems in similar tasks [1].

Several assessment methods and variables have been used to understand and detect neuromuscular control deficits in subjects with CAI [11,12], including the maintenance of balance during still stance when performing functional movements that replicate similar "real" life scenarios, by means of instrumented (i.e., force plates) and non-instrumented (i.e., reaching tests) approaches [13]. Force plates are considered the gold standard for balance performance assessment due to their accuracy, validity and reliability [14,15]. However, costs and complexity do not permit large-scale assessments, consequently limiting their applicability. Conversely, non-instrumented methods, such as Y balance test (YBT), are inexpensive and easily applied, although adequate time and practice trails influence their applicability in field-based testing [16,17].

Therefore, inexpensive, easy, administrable and portable tools are needed to detect postural control impairments in CAI population. Among those, computerized wobble boards (WBs) have been recently equipped with accelerometers and connected to a computer to show real-time balance performance [18,19]. In particular, Fusco et al. [18] suggested that a computerized WB is a reliable tool to measure dynamic balance performance during single limb stance in healthy young subjects. However, to the best of our knowledge, no study demonstrated their efficacy in detecting neuromuscular control deficits in subjects with CAI. Therefore, the aim of this study was to determine the reliability, validity and accuracy of a computerized WB to detect postural control deficits in subjects with unilateral CAI, by hypothesizing that CAI would negatively affect balance performances.

2. Methods

2.1. Subjects

After being informed of the benefits and risks of the investigation, thirty subjects (with unilateral CAI = 15; uninjured = 15) provided written informed consent to participate in the study carried out in accordance with the Declaration of Helsinki for Human Research of 1964 (last modified in 2000).

Subjects were included in the CAI group [20] if they self-reported: at least one ankle sprain, but none within the past 6 weeks; multiple (more than 3) episodes of the ankle giving way within the past 12 months; no previous fracture or surgery of either ankle; no cerebral concussions, lower extremity injuries, visual and vestibular disorders for 3 months before testing; no ear infection, upper respiratory tract infection at the time of the study; no prior balance training. Subjects were recruited for the uninjured group if they self-reported: no previous injuries, fracture, or surgery of either ankle; no cerebral concussions, lower extremity injuries, vestibular and visual disorders for 3 months before testing; no ear infection, upper respiratory tract infection at the time of the study; no prior balance training. Subjects' characteristics are presented in Table 1.

Table 1
Means and standard deviations of the subjects' characteristics.

	CAI group (n = 15)	Uninjured group (n = 15)
Age (years)	23.6 ± 1.7	22.6 ± 1.3
Body mass (kg)	67.9 ± 13.9	59.9 ± 11.0
Height (cm)	169.1 ± 10.1	164.4 ± 7.8
Lower limbs length (cm)	78.9 ± 6.6	77.1 ± 6.5

CAI: Chronic ankle instability.

2.2. Study design and procedures

Subjects performed one WB test and one YBT during two randomized morning [21] sessions organized with 48-hour in between. To avoid fatigue, subjects were required to refrain from moderate-to-vigorous physical activity for at least 24-hour before the experimental sessions. Moreover, as fluid ingestion may influence the preservation of muscular function and sensory afferences regulating postural control, subjects were instructed to drink water ad libitum before and during the tests [22].

One week before measurements, testing procedures were explained and anthropometrics measured. Body height and body mass were measured by means of a scale with integrated stadiometer with a precision of 0.1 cm and 0.1 kg (Seca, model 709, Vogel & Halke, Hamburg, Germany). Leg length was measured from the anterior superior iliac spine to the most distal part of the medial malleolus by using a tape measure while the subject laid in supine position.

WB performance was assessed via computerized proprioceptive board (Balance Board WSP, GSJ Service, Rome, Italy; 40 cm diameter with a half plastic sphere of 6 cm height and 20 cm width; maximal tilt angle = 20°) equipped with a triaxial accelerometer (Phidget Spatial 0/0/3 Basic 1041, Phidgets Inc. 2016, Calgary, Canada) internally calibrated and able to measure ± 8 g (± 78 $m \cdot s^{-2}$) per axis and both dynamic acceleration (change in velocity) and static acceleration (gravity vector). Tilt angle data were transferred to a computer via USB cable at 200 Hz via proprietary software (GSJ Service, software WSP).

After 3-min familiarization followed by 1-min rest in sitting position, subjects stood barefoot in a single leg stance on the WB, finding a comfortable and central position with knee slightly bent and keeping the hands on the hips. Subjects were asked to focus on the motion marker (diameter = 6 mm) displayed on the monitor (1920 × 1080 resolution screen) placed at eye level 2-meter in front of them and to keep it inside the target zone (diameter = 6.5 cm) as long as possible. This set-up has been chosen as it could represent the optimal situation to assess balance performances without being affected by any sort of visual disturbances. The target zone was represented by a circle showing the 0° tilt angle measured by the triaxial accelerometer. The boundaries of the motion marker and target zone were standard for all the subjects during each trial. The test consisted of three 30-second trials per limb with a 1-min sitting rest in between. The starting limb was randomly chosen. As it has been suggested [23] that the more demanding the task the more sensitive it will be for the identification of neuromuscular dysfunctions, effects of training or fatigue impairments, the time (s) spent by the motion marker inside the target zone, which expresses the time the subject spent on the platform keeping it flat at 0°, was collected for further analysis. In particular, the time has been chosen because it is accessible, without further data processing and analysis, and easy to understand from health professionals.

To validate the WB test in subjects with unilateral CAI, the YBT was chosen as reference. The YBT has shown to be a reliable test of balance performance [16,17]. It is widely used in clinical practice and valid to detect impairments in subjects with CAI [4,12]. According to the protocol [16,17], subjects performed 6 practice trials in 3 different directions (anterior-A, postero-medial-PM and postero-lateral-PL), followed by 3 testing trials for each direction and limb. The order of the trials was randomly assigned and counterbalanced across subjects and limb. The average reach distances of the 3 testing trials in each direction per limb normalized to the subject's leg length was used for further analysis. Normalized composite reach distance (COMP) was also calculated for each limb [16,17].

2.3. Statistical analysis

Data were analyzed using STATA software version 14 (StataCorp LP, College Station, Texas).

Normal distribution was verified by the Shapiro-Wilk test and means and standard deviations (SD) were calculated for all variables. The mean of the 3 WB trials per limb, the 3 normalized reach distances of the YBT for each direction and limb, and the COMP value per limb were calculated and used as dependent variables.

Intraclass correlation coefficient (ICC) and standard error of measurement (SEM) were calculated to investigate the reliability of WB measures in subjects with unilateral CAI. An ICC (3,3) two-way mixed model estimated the correlation between average measurements on the same target. This model was used since it assesses only the reliability of the measurements by considering subjects as random effects and the measurement tool as a fixed effect. ICC values were interpreted as poor (0.00–0.39), fair (0.40-0.59), good (0.60–0.74), and excellent (0.75–1.00) [24]. SEM was derived from the following formula: $SEM = SD \ x \ \sqrt{1\text{-}ICC}$. SEM quantifies the measurement error by indicating the within-subject variability and allows to determine a likely range of the true score based on an observed score [24].

Repeated-measures analyses of variance (ANOVA) were carried out to examine potential differences for the WB and YBT performances. According to the literature [25], to side match the control group with the CAI group, one limb was assigned as "false injured" and one as "false uninjured". The between-subjects factor was group with 2 levels (CAI, control), while the within-subjects factor was limb with 2 levels (injured, uninjured). If significant interactions and main effects emerged, post hoc comparisons were performed by means of Fisher's Least Significant Difference. Cohen's effect sizes (ES) were determined by calculating the mean difference between groups (CAI, control) and limbs (injured, uninjured) and dividing it by the pooled reference SD. An ES 0.2 or less was considered trivial, from 0.3 to 0.6 small, less than 1.2 moderate, and greater than 1.2 large [26].

Pearson Product Moment correlation was performed to assess the strength of the relationships between YBT and WB test values for each standing limb in subjects with unilateral CAI. Correlation strength was defined as excellent (> 0.75), moderate (0.5-0.74), fair (0.25-0.49) or poor (< 0.24) [27].

Lastly, the accuracy of the WB measures in detecting injured limbs was calculated using the area under the curve (AUC) for receiver operating characteristic (ROC) curve. ROC curve illustrates the tradeoff between sensitivity and specificity throughout a measure's entire range of values. A traditional academic point scale was used to classify the accuracy of the AUC for discriminating between injured and uninjured limbs: fail (0.00-0.59), poor (0.60–0.69), fair (0.70–0.79), good (0.80–0.89), and excellent (0.90–1.00). ROC curve with perfect accuracy would run vertically from the origin (point 0.0) to 100% sensitivity (point 0.1) and then run horizontally to 100% specificity (point 1.1). Thus, the best cutoff score was determined as the point on the ROC curve with the shortest distance from point (0.1) [28].

The significance level was set a priori at $p < 0.05$ for all analyses.

Table 3
Pearson product moment correlation values between wobble board balance test and Y Balance Test performances for injured and uninjured limb in subjects with unilateral chronic ankle instability.

	Wobble Board Test			
	Injured Limb		*Uninjured Limb*	
Y Balance Test	**r**	***p***	**r**	***p***
Anterior	0.27	0.32	0.47	0.07
Postero-lateral	0.52	0.04*	0.07	0.79
Postero-medial	−0.17	0.53	−0.12	0.66
Composite	0.16	0.55	0.20	0.45

* denotes significant difference ($p < 0.05$).

3. Results

Means and SDs for WB, YBT reach directions and COMP values are shown in Table 2.

ICC values ranged from fair to excellent, whereas SEM were low, demonstrating good levels of error and low variability. Specifically, ICC values were 0.58 (injured), 0.69 (uninjured), and 0.84 (both limbs averaged). SEM values were 2.4 s (injured), 1.7 s (uninjured), and 0.9 s (both limbs averaged).

Significant group-by-side interaction was identified for WB performance ($F_{1,28} = 9.40$, $p = 0.005$, ES range = 0.42–1.55), the A reach direction ($F_{1,28} = 4.49$, $p = 0.04$, ES range = 0.37–0.75) and COMP ($F_{1,28} = 4.42$, $p = 0.04$, ES range = 0.45-0.59) of the YBT. A significant group main effect was found for the WB performance ($F_{1,28} = 7.28$, $p = 0.01$, $ES = 0.91$). Significant main effects between sides emerged for WB performance ($F_{1,28} = 14.69$, $p = 0.0007$, $ES = 0.43$), and the PL ($F_{1,28} = 4.97$, $p = 0.03$, $ES = 0.25$) and PM ($F_{1,28} = 5.91$, $p = 0.02$, $ES = 0.29$) reach directions of the YBT.

Pearson Product Moment correlation results between WB and YBT performance are shown in Table 3.

The WB ROC curve had an AUC of 0.80 (asymptotic significance 0.001) (Fig. 1). The best cutoff value was 18.5 s.

4. Discussion

The aim of this study was to determine the reliability, validity and accuracy of a computerized WB to detect postural control deficits in subjects with unilateral CAI. ICC, SEM, and ANOVA showed that WB can reliably and accurately detect balance impairments and discriminate between subjects with and without CAI. However, weak correlations between WB and YBT performance were found.

Although evidence supporting the use of WB in discriminating and detecting balance deficits is missing, the WB used in this study was able

Table 2
Means and standard deviations of wobble board performances, Y balance test's (YBT) normalized reach distances and composite values in subjects with unilateral chronic ankle instability (CAI) and uninjured groups for injured and uninjured limb.

	CAI group (n = 15)		Uninjured group (n = 15)	
TEST	Injured limb	Uninjured limb	Injured limb	Uninjured limb
Wobble Board (s)	16.2 ± 4.2	19.6 ± 4.3*	21.5 ± 4.3*#	21.8 ± 3.0*#
YBT Anterior (%)	84.0 ± 8.1	87.4 ± 5.7*	91.0 ± 10.6*#	90.5 ± 11.6*#
YBT Postero-lateral (%)	94.3 ± 8.1	99.1 ± 8.2*	99.5 ± 15.3*	101.0 ± 16.4*
YBT Postero-medial (%)	98.7 ± 11.0	105.4 ± 10.3*	105.0 ± 15.0*	106.0 ± 16.6*
YBT Composite (%)	97.8 ± 7.2	101.8 ± 6.2*	102.6 ± 13.5*	102.5 ± 14.0*

#significantly different from the uninjured limb of the CAI group ($p < 0.05$).
* significantly different from the injured limb of the CAI group ($p < 0.05$).

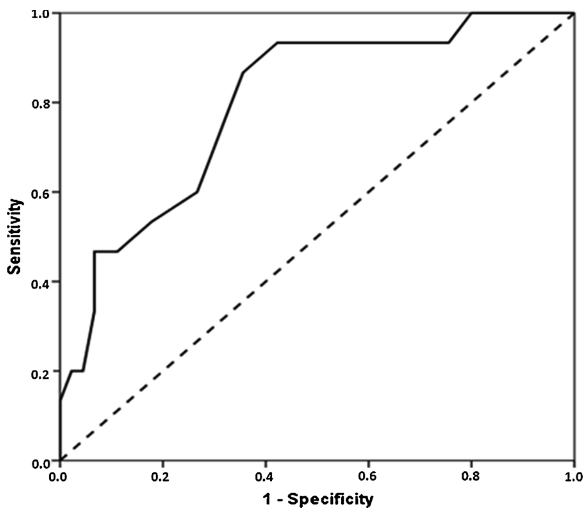

Fig. 1. Receiver operating characteristic (ROC) curve for the wobble board test (solid black) indicating sensitivity and 1– specificity tradeoff are shown relative to the reference line (dotted black), which indicates that a test performed no better than random.

to successfully detect balance impairments between and within subjects with unilateral CAI. The significant group-by-side effect found in WB performance supports the assumption that computerized WBs are valid to detect balance deficits in subjects with CAI. Regarding YBT, findings confirm its ability to detect balance impairments in subjects with CAI [4,12]. In particular, the injured limbs in the CAI group were associated with less reach distance performance than the contralateral healthy limb and both limbs of the control group for all reaching directions. Olmsted et al. [12] were the first demonstrating that subjects with CAI performed worse in their affected limbs compared with their unaffected limbs, as well as with the matched limbs of the control group, during a reaching test.

Interestingly, in the present study the CAI group showed lower WB and YBT (A direction) performances with respect to the control group, independently of limb. As unilateral ankle instability could affect the somatosensory system influencing stability during stance on either extremity [29], it could be assumed that the balance performance differences in limbs could reflect the progression of rehabilitation protocol after an acute ankle sprain via data from the uninjured limb when measurements on the injured limb are not possible. This would allow coaches and health professionals to better monitor the progression of neuromuscular retraining and provide valuable information about the timing of returning to sport participation by reducing the risk of ankle reinjure. As it is still not clear weather WB can track and monitor the effectiveness of neuromuscular retraining protocols over the timespan, future studies should investigate this area of practical application.

Computerized WBs may facilitate the detection of balance impairments, without complexity in its use or data interpretation as previous tests showed [4,11]. In fact, a single WB outcome describing balance performances and impairments, could avoid the considerable redundancy of other tests. On the other hand, strong correlations between WB and YBT are lacking. In fact, only 1 out of 8 correlation results was significant (i.e., between WB performance and PL direction of the YBT for the injured limb). Although the results of a previous study [25] showed that PL reach direction is one of the most representative for overall balance performance in limbs with and without CAI, the significant relationship found in this study is not enough to confirm validity based on YBT as reference. Consequently, the tests cannot be considered interchangeable for the assessment of balance impairments in subjects with unilateral CAI. However, when considering the similar results found between WB and YBT tests in discriminating balance deficits in subjects with unilateral CAI, both methods could be considered suitable and sensible to assess a complex ability as the dynamic balance and detect its impairments. Although they should not be considered exclusive for dynamic balance assessment, computerized WBs seem to have the potential to become essential devices for screening dynamic balance during large-scale evaluation, especially in field-based settings, where time constraints are crucial. In fact, their specificity, affordability, transportability, as well as easiness in data interpretation and settings features, are crucial key factors to make data collection accurate, precise and administrable for coaches, practitioners, and health scientists.

While previous studies [12,16] investigated the accuracy of the YBT for discriminating limbs differences in subjects with unilateral CAI, no researches determined the accuracy of computerized WBs for such purpose. The current ROC curve results suggest that WB measures have the capability to accurately discriminate between injured and uninjured limbs. However, future researches should establish cutoff scores for WB measures across a wide spectrum of different populations to maximize the future classification to predict who is more likely to develop balance impairments after an injury.

Despite the meaningful findings of this investigation, some limits need to be acknowledged. Firstly, WB performance was displayed to the subjects in real-time: as visual feedback can enhance neuromuscular control [30], it is possible that visual feedback could have affected (increased) WB performances. However, as the effects of additional feedbacks (i.e., audio, vibrotactile or multi-modal) on injured and uninjured limb performance is still unknown, it is not possible to establish their impact on performance. Secondly, the inclusion of subjects with mechanical instability in the CAI group has been carried out according to previous studies [12,25], assigning subjects with CAI to a sub-category of either mechanical or functional instability. Either way, subjects can self-report repetitive episodes of giving way of the ankle regardless of the presence or absence of pathologic laxity. As there is no evidence that WB and functional test performances differ in subjects with mechanical instability, those subjects were not excluded from the present study. Therefore, future studies should investigate the effect of visual feedback on WB performance in subjects with CAI and other pathological populations, the sensitivity of WBs to detect balance impairments in other injured populations (e.g. anterior cruciate ligament), and the ability of WB in tracking and monitoring the effectiveness of neuromuscular retraining protocols over time.

5. Conclusions

To the best of our knowledge, this is one of the few studies showing computerized WB as a reliable, accurate and practical tool to detect balance impairments in subjects with unilateral CAI. Furthermore, WBs can avoid the common redundancy of multiple tests usually used to detect postural control impairments.

Ethical approval

The local Institutional Review Board approved the present study in accordance with the declaration of Helsinki for human research of 1964 (last modified in 2000).

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Conflict of interest

The authors have no conflict of interest relevant to the context of this study.

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