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Original Research

Evaluation of functional ankle instability assessed by an instrumented wobble board

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ABSTRACT

Objectives: Ankle sprains often lead to a history of recurrent injuries and functional joint instability. This study evaluated a new method for assessing functional impairment in patients with chronic ankle instability.
Design: Case-control study for construct validation purpose.
Setting: The participants were tested during one-leg standing for 20 s on an instrumented wobble board and on a balance platform.
Participants: Twenty-five young people with previous ankle sprain and an instability score >11 in the "Identification of Functional Ankle Instability questionnaire" and an age-matched control group of 25 healthy individuals.
Main outcome measures: Wobble board variation of tilt angle measured by two accelerometers placed horizontally in the board.
Results: The variation in angular tilt of the wobble board in the medio-lateral direction (standard deviation of tilt angle) was higher in the group with perceived ankle instability than in the control group: 1.5 (0.7) versus 1.1 (0.3). ICC for intra-tester reliability: 0.87 and correlation with COP area measures from the stable balance platform: 0.64.
Conclusions: People with functional ankle instability display poorer postural stability in the medio-lateral direction when challenged on an unstable surface. The instrumented wobble board may serve as a relevant tool in the clinical evaluation of functional ankle stability.

1. Introduction

The ankle joint plays a central role for postural correction but is often exposed to injury (H Tropp & Odenrick, 1988). Lateral ankle sprains are among the most frequent sports injuries and typically occur when the rear foot undergoes excessive supination on an externally rotated lower leg (Hertel, 2002). In 40%–80% of such incidents, the individual will develop chronic ankle instability (CAI), which has been defined as the occurrence of repetitive bouts of lateral ankle instability, resulting in numerous ankle sprains (Gribble et al., 2014; Hertel, 2002). CAI may be the result of a mechanical instability, i.e. laxity of the joint after injury to the stabilizing passive structures like ligaments and capsule (Munn, Sullivan, & Schneiders, 2009). However, a purely mechanical instability may be unlikely, as impaired proprioception may be a direct consequence of tissue disarrangements during a first-time ankle sprain (Hertel, 2002). Damage to capsular and ligamentous structures may lead to alterations in the tissue arrangement around the joint, which will affect the sensory systems located in these tissues (Hans Tropp, 2002; Ross, Linens, Wright, & Arnold, 2011). An altered weighting of the somatosensory signal may disturb the sensory-motor interaction and impair motor control (Bullock-Saxton, 1995). The term functional ankle instability (FAI) may therefore be used to characterize persistent ankle instability (Delahunt et al., 2010; Snyder, Evans, & Neibert, 2014). FAI includes neuromuscular impairments like muscle strength, reaction times, and proprioceptive deficits (Hans Tropp, 2002; Levin et al., 2012). A recent review offering guidelines for the examination and

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treatment of ankle instability states that the role of the neuromuscular elements in subjective instability is controversial and needs further study (Martin, Davenport, Paulseth, Wukich, & Godges, 2013).

Postural control and balance dysfunction are commonly measured by the amount of postural sway, revealed as center of pressure (COP), when standing on a force plate. COP excursions in the form of trajectory variables are considered the "gold standard" for evaluation of postural control and balance (McKeon & Hertel, 2008; Ross et al., 2011). However, in people with CAI, functional impairments have not been detected consistently with these traditional outcome measures (Knapp, Lee, Chinn, Saliba, & Hertel, 2011; McKeon & Hertel, 2008; Sefton et al., 2009). The task of standing on a force plate with a stable supporting surface may not represent a specific challenge to the ankle stability control. The use of more complex tasks and other measures than postural sway, potentially more closely linked to FAI, have therefore been suggested (Hupperets, Verhagen, & van Mechelen, 2009; Martin et al., 2013). Studies on unilateral jump-landing tasks reveal dynamic postural stability deficits in individuals with CAI (Simpson, Stewart, Macias, Chander, & Knight, 2018), but the collection of such data requires laboratory equipment. In a clinical setting, simpler tests like the Star Excursion Balance test (Gribble, Hertel, & Plisky, 2012) or a standardized test on a wobble board may be more feasible for the assessment of CAI.

The strategies used to maintain balance on a wobble board have been shown to differ from the ones used when single-leg standing on a force platform (Silva, Oliveira, Mrachacz-Kersting, Laessoe, & Kersting, 2016). A wobble board provides an unstable supporting surface and may prove sensitive to smaller degrees of impairments. Equipped with integrated movement sensors to quantify the board movement, it may be useful as a mobile monitoring and training tool for clinical practice. Previous results indicate that such a tool may provide supplementary objective measure for the clinical identification of people with functional ankle instability (Larsen, Andersen, Hansen, & Laessoe, 2018).

The aim of this study was therefore to validate a test on an instrumented wobble board for the assessment of single-leg balance. In this construct validation it was hypothesized that a group of people with previous ankle sprain and self-reported ankle instability (i.e. people with mildly functionally unstable ankles) would have a less stable wobble board control than healthy controls.

2. Methods

2.1. Participants

The study was designed as a case-control study. A convenience sample of 25 people with functional ankle instability was recruited for the case group through public announcement. Inclusion criteria were: age 18–35 years; one or more episodes of lateral ankle sprain; experience of instability within the previous six months; perceived instability score above 11 in the Identification of Functional Ankle Instability questionnaire (IdFAI) (Simon, Donahue, & Docherty, 2012). The control group was an age- and gender-matched group of 25 healthy people with an IdFAI score not above 11. Apart from the ankle instability in the FAI group, none of the participants had any musculoskeletal or neurological impairment. Exclusion criteria in both groups were previous lower extremity fracture, pain, edema, or movement restrictions within the past six weeks (Gribble et al., 2014). It has previously been demonstrated that wobble board training improves postural control (Oliveira, Silva, Farina, & Kersting, 2013). The participants in both groups were therefore excluded if they had been exercising on a wobble-board within the previous two weeks. We recorded age, gender, height, weight, dominant leg, and weekly hours of strenuous physical activity (i.e. activity at a level where one is out of breath).

Informed consent was obtained from all participants in accordance with the Declaration of Helsinki. The research ethics committee of Northern Denmark approved the study protocol (N-20160079).

2.2. Outcome measures

2.2.1. Instrumented wobble board

We used a commercially available instrumented wobble board, SensBalance Mini Board (Sensamove, Netherland), (Fig. 1). This tool is a wooden wobble board incorporating two accelerometers (inclinometers) placed horizontally in the anterior-posterior plane (AP) and the medio-lateral plane (ML), respectively. Any tilt in the direction of a sensor is detected as an acceleration signal due to the influence of the Earth's gravity. In this way, the accelerometers reflect the tilt movements of the board at a sampling frequency of 22 Hz, which is the standard feature of the product. The product package provides continuous visual feedback from a monitor, but this feature was not utilized in this study. The maximum tilt of the board was 15°.

A standard software user interface presents figures for the performance on the wobble board by a 0–100% score. However, these averaged figures are based on the averaged tilt of the board, which may be misguiding as a very stable position at five degrees tilt may present with a low score. Furthermore, the averaged figures are not representative for the ongoing corrections representing the postural stability. The raw data representing the wobble board angular tilt in AP and ML direction for all samples was

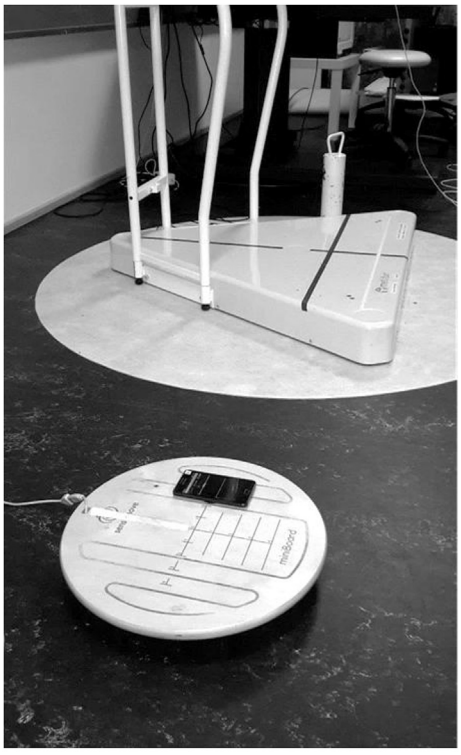

Fig. 1. The photo shows the commercially available wobbleboard with accelerometers incorporated in the wooden plate. A smartphone is placed on the top to indicate the future perspectives for instrumentation. In the background, the triangular balance plate for measuring COP.

therefore exported from the SensBalance software to MS Excel for further analysis.

In the present study, the new procedure for analyzing the accelerometer data simply evaluates variation in wobble board inclination (Larsen et al., 2018). Standard deviation of the tilt positions during the 20 s of testing was calculated for both directions (AP and ML). This variance measures represented the main outcome measures for the stability performance. A larger variation in the tilt angle was regarded as a sign of poorer stability. Also, the averaged displacement and the angular velocity were calculated to provide more traditional measures.

2.2.2. Balance platform

A triangular balance platform with a force sensor in each corner (Good Balance, Metitur Inc., Finland) was used to evaluate COP excursions, as a "gold standard" for balance evaluation (Fig. 1). COP trajectories were recorded at 50 Hz, and the standard software derived averaged values for selected parameters (Era et al., 2006). The COP velocity was evaluated in the AP and ML direction. The velocity moment, i.e. the area covered by a COP position vector per time (unit: mm^2/s), described the area of the COP trajectory. These measures have been validated for balance evaluation with larger values indicating poorer balance performance (Era et al., 2006).

2.2.3. Questionnaire

The participants' perceived ankle instability was characterized by the "Identification of Functional Ankle Instability questionnaire" (IdFAI) (Simon et al., 2012). Functional ankle instability is here described as the foot's tendency to 'give way'. This is defined as 'the regular occurrence of uncontrolled and unpredictable episodes of excessive inversion of the rear foot (usually experienced during initial contact during walking or running), which do not result in an acute lateral ankle sprain' (Gribble et al., 2014). The questionnaire has 10 items, which are ranked on the experienced severity of the impairment. Good reliability (ICC>0.97) of the questionnaire has been established in other studies (Gurav, Ganu, & Panhale, 2014).

2.3. Procedure

In both balance tests, the participants were instructed to stand on one leg for 20 s. They stood barefooted with their hands placed on their hips (akimbo) and they were looking at a mark placed at eye height on the wall 1.5 m away. The FAI group was tested standing on their unstable ankle, and the control group was tested on a leg of their own choice. The participants were allowed one trial before recording began in order to get familiar with the task. Marks on the wobble board at midline and at the back of the heel were used to standardize the foot position. The testing was performed twice on both instruments; and in each trial, the participants had 3 s to find their balance before the recording began. There was no distracting noise or conversation during testing. No attempts were made to blind the participants or the tester. The sequence of the two balance tests was randomized, and there was a pause of at least 2 min between the trials.

2.4. Data analysis

The FAI group and the control group were compared with respect to age, Body Mass Index (BMI), gender, use of dominant leg, and level of physical activity. Independent t-tests and Chi^2 tests were used to evaluate the matching of the groups.

As the main stability measure the standard deviation of the tilt was calculated to express the variation of the wobbleboard position in ML and AP directions. For each measure the data from the two trials in each test were averaged. Data were not normally distributed, and Mann Whitney's *U* test was used for comparison between the two groups. *P*-values < 0.05 were considered statistically significant.

As the wobble board variation measures have not previously been reported, the test-retest reliability was evaluated with respect to the common results from the two groups using Spearman's correlation and the Wilcoxon test. After log transformation of the data, a two-ways mixed effect model was used to calculate intra-class correlation coefficients (ICC). The ICCs were interpreted according to Landis and Koch: 0.0–0.4, unacceptable; 0.4–0.6, moderate; 0.6–0.8, substantial, and 0.8–1.0, almost perfect agreement (Landis & Koch, 1977).

Furthermore, the correlations between the self-reported IdFAI and the stability and balance measures were evaluated using Spearman's correlation coefficients with respect to all participants' scores. The statistical software package SPSS ver. 25 was used for the analyses.

3. Results

Apart from the scores on the IdFAI questionnaire, the control group matched the FAI group (Table 1).

The wobble board tilt angle was typically less stable for individuals in the FAI group. An example of raw data from an individual in each group is shown in Fig. 2. The averaged variation in wobble board tilt was higher in the FAI group for both the ML and the AP direction. However, these differences were statistically significant only in the ML direction (Table 1).

Comparison of the FAI group with the healthy control group revealed statistically significant differences also in the angular velocity of the wobble board and in the balance platform measures with higher COP velocities and COP area for the FAI group (Table 1).

Test-retest reliability of the wobble board instability scores showed no significant differences in group performance (Table 2). The ICCs between the two tests were "almost perfect" (0.87) in the ML and "substantial" (0.70) in the AP direction.

The measures from the wobble board test and the balance platform correlated significantly with correlation coefficients lower

Table 1
Performance in one-leg standing for a group with unilateral functional ankle instability (FAI) (n = 25) and an aged-matched healthy control group (n = 25).

	FAI group	Control group	Difference (%)
Participant characteristics			
Age	25.0 (4.1)	24.5 (2.1)	
BMI	24.8 (4.0)	23.9 (2.4)	
Gender (Female)	14	13	
Activity level[a]	6.3 (3.2)	4.8 (3.1)	
Test leg (Dominant)	15	20	
IdFAI-score	20.4 (6.4) **	3.6 (3.1)	
Performance scores			
Wobble board			
Instability ML	1.5 (0.7) **	1.1 (0.3)	46.2
Instability AP	2.1 (0.8)	1.8 (0.7)	18.8
Displacement ML (deg)	0.2 (2.7)	0.9 (1.2)	
Displacement AP (deg)	0.2 (1.3)	0.6 (1.4)	
Velocity ML (deg/s)	8.7 (5.2) *	5.9 (2.8)	
Velocity AP (deg/s)	6.7 (2.8)	5.4 (2.2)	
Balance platform			
COP velocity ML (mm/s)	23.8 (5.8) *	19.8 (5.1)	20.3
COP velocity AP (mm/s)	21.0 (6.6) **	16.7 (4.8)	25.8
COP area (mm^2/s)	101.8 (49.3) **	71.2 (25.9)	42.9

Mean (SD). Instability measures are standard deviation of angular tilt. Medio-lateral (ML), Antero-posterior (AP).
*p < 0.05, **p < 0.01.
[a] Weekly hours of strenuous physical activity.

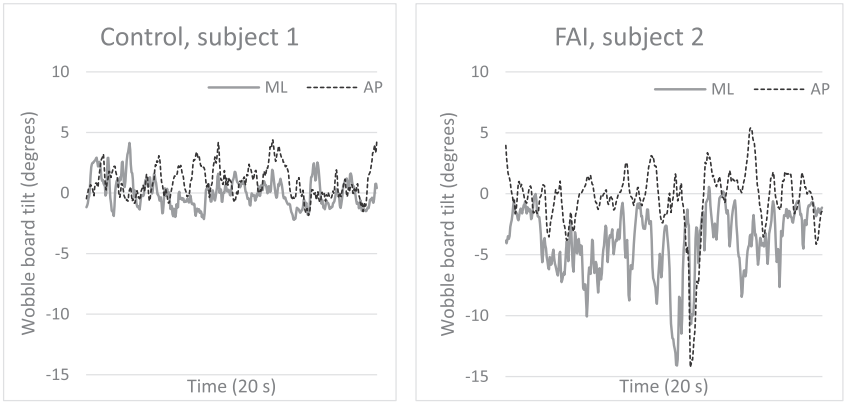

Fig. 2. Illustrates the wobble board angular tilt during the 20 s of testing for two different participants. The thick lines indicate medio-lateral direction and the dashed lines indicate antero-posterior direction.

Table 2
Wobble board test-retest reliability evaluation (n = 50).

	Test	Retest	Diff. %	Correlation	ICC
ML direction	1.34 (0.66)	1.26 (0.63)	−6.1	0.73	0.87
AP direction	1.93 (0.93)	1.92 (0.89)	−0.6	0.60	0.70

Instability measures (standard deviation of angular tilt) presented with group means (SD), test-retest difference (%), correlation coefficients and intra-class correlation coefficients (ICC) from log-transformed data.

than 0.61 (Table 3). The correlations with the IdFAI scores were not high (<0.41), and the correlation was not significant with respect to wobble board AP direction.

4. Discussion

The group with FAI displayed more tilt variation in the ML direction than the age- and gender-matched healthy control group when tested standing on one leg on an instrumented wobble board. Similar differences were seen in COP velocities and COP area when the participants were tested on a balance platform with a stable surface.

4.1. Balance platform

COP measures are considered the gold standard in balance evaluation. Alternative ways of analyzing the COP trajectory may enhance the validity of this outcome measure, as variation in COP measures allowed Linens et al. to discriminate between a CAI and a control group (Linens, Ross, Arnold, Gayle, & Pidcoe, 2014). A meta-analysis concluded that signs of balance deficits appear to exist regardless of whether balance is assessed with static or dynamic tests (Arnold, De La Motte, Linens, & Ross, 2009). The results from the present study supports the relevance of using the balance platform since differences were revealed between the groups with respect to COP velocity and COP area. It may be noted that more individuals in the control group used their dominant test leg. Leg dominance is, however, meant not to influence the balance (Rein, Fabian, Zwipp, Mittag-Bonsch, & Weindel, 2010).

The more vigorous COP adjustments of the FAI group may be the result of a different motor control strategy. If the ankle sprain has led to altered mechanical characteristics of the joint capsule and ligaments this may provide different stimuli for the joint mechanoreceptors. An altered weighting of the somatosensory signal may disturb the sensory-motor interaction and impair motor control (Bullock-Saxton, 1995). A skilled individual with an intact sensory-motor interaction system will be able to make early and well-coordinated adjustments and will not need as fast and large movement corrections as a person with an impaired mechano-sensory system (Fu & Hui-Chan, 2005). A motor strategy to overcome this impairment may comprise co-contractions of the muscles stabilizing the ankle. This compensatory strategy has been called “freezing the degrees of freedom” (Bernstein, 1967). With this strategy, the movements become stiff and less smooth than movements of a well-coordinated movement strategy, and this will be revealed as higher COP velocities. However, no unequivocal interpretation of these COP outcome measures as a sign of ankle instability can be done, as other aspects of postural control may have influenced performance (Shumway-Cook & Woollacott, 2012). Prospective studies that evaluate improvement in these parameters after training are warranted.

4.2. Wobble board

The use of other measures than COP and postural sway has been suggested for the detection of functional impairments/ankle stability deficits (Hupperets et al., 2009). Standing on a wobble board represents a challenging task that involves movements of the ankle joint. This kind of stability demand is closely linked to the ankle joint's functional stability and this may reveal aspects of the

Table 3
Correlation of wobble board and balance platform outcome measures and Identification of Functional Ankle Instability questionnaire (IdFAI) scores (n = 50).

	Wobble board AP	COP velocity ML	COP velocity AP	COP area	IdFAI
Wobble board ML	0.81*	0.61*	0.69*	0.63*	0.34*
Wobble board AP		0,54*	0.61*	0.51*	0.22
COP velocity ML			0.86*	0.82*	0.34*
COP velocity AP				0.83*	0.41*
COP area					0.41*

Spearman's correlation coefficients. *P < 0.01.

performance not captured with the stable balance platform. Performance on the wobble board may quite simply be reported as the amount of time a subject can keep the balance in double- or single-leg standing on the board (Gioftsidou P.;Pafis, G.;Beneka, A.;Godolias, G.;Maganaris, C. N., 2006). An instrumentation of a wobble board with accelerometers seems to be another simple, feasible way to collect objective data, but the evaluation of these data may still be challenging. In recent years, different types of instrumented wobble boards have become commercially available (Williams & Bentman, 2014), and several studies have reported postural stability indexes based on various types of software algorithms (Clark & Burden, 2005; Fitzgerald, Trakarnratanakul, Smyth, & Caulfield, 2010).

We suggest that the variation in tilt position of the wobble board may be used as a relevant measure. It has been observed that reduced sensory capacity, as imposed by closed eyes, yields larger deviations in the tilt of the wobble board (Williams & Bentman, 2014). This suggests that large deviations reflect reduced postural capacity. In the present study, the increased tilt variation in the FAI group may therefore be seen as a sign of poorer performance. This interpretation is supported by the observation of correlations between the instability measures and the larger COP velocity measures on the balance board (Table 3). The findings most likely indicate that the FAI group was more challenged when doing this task, especially in the ML direction. As ankle sprain most often affects the lateral ligaments (Hertel, 2002), the tilt variation in ML direction seems to be the most relevant plane to assess.

The study design does not allow causality to be established, and only few studies have yet explored how wobble board measures may be interpreted (Silva et al., 2016). In the present study the reliability was satisfying, but a learning effect was seen in the ML direction. A testing procedure with more trials before the test may be warranted in future studies.

In a wobble board exercise program, a simple score of the wobble board stability may be motivating as a performance feedback for the patient and improve the training adherence (Ogaya, Ikezoe, Soda, & Ichihashi, 2011). However, the testing procedure needs to be standardized before it potentially can be introduced as a clinical assessment tool. The intertester reliability as well as relevant cut-off values need to be established. Also, the criterion validation of the test in comparison with more established dynamic and functional tests such as Star excursion balance test, hop tests, etc. needs to be evaluated. Although the task of maintaining postural control while standing on a wobble board mimics a functional task, it remains a proxy measure for the subject's ankle stability. A combination of different test tools and questionnaires may therefore be recommended for performance assessment of an individual with ankle instability (Linens et al., 2014).

The ongoing development of new technologies may provide new possibilities with respect to the instrumentation of a wobble board. One cheap option may be suggested here. A smartphone may be attached to the upper surface of the wobble board and follow its movements. In this way the inertial sensors (accelerometers) in the smartphone will record the tilt of the wobbleboard. This data may then be used in an app for further processing. For online feedback the results may be transmitted from the smartphone to a PC and displayed on a monitor. With this feature any wobble board may be instrumented and this could be an inexpensive tool to provide the patient with feedback of the stability performance.

5. Conclusion

In the present study, the participants were challenged in one-leg stance on a wobble board and on a stable balance platform. Compared to a healthy control group, participants with FAI displayed increased instability on the wobble board with respect to tilt variation in the ML direction. Similar differences were seen on the balance platform with respect to COP velocity and area. The higher adjustment activity is most likely a consequence of the functional ankle instability, but the study design allows no unequivocal conclusion in this respect. The instrumented wobble board may serve as a relevant tool in combination with other tests in the clinical evaluation of functional ankle stability.

Conflicts of interest

None.

Funding

None.

Ethical approval

Informed consent was obtained from all participants in accordance with the Declaration of Helsinki.

The research ethics committee of Northern Denmark approved the study protocol.

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