

## Assessment of postural stability in stable and unstable conditions

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*Purpose:* The aim of the study was to determine whether it is possible to assess static balance on an unstable surface using center of pressure velocities obtained with a force platform when standing on a wobble board. *Methods:* The center of pressure velocities were recorded with a force platform within three days (four trials per day) in thirty young adults in three conditions: standing on a rigid surface, compliant surface, and on a wobble board. Reliability of mean velocities of the center of pressure was examined using intraclass correlation coefficients. Relationships between the three conditions were assessed with Pearson correlation coefficients. *Results:* Intra-session reliability was excellent for standing on a rigid surface and on a compliant surface and good for standing on a wobble board. Inter-session reliability was good for all parameters in all conditions, except for poor reliability in the anterior-posterior direction in standing on a wobble board. All correlations between the same parameter in different conditions were statistically significant ( $P < 0.05$ ), except for velocity of the center of pressure in the anterior-posterior direction between stance on a rigid surface and stance on a wobble board. *Conclusions:* Centre of pressure velocity parameters obtained with a force plate when standing on a wobble board can provide valuable information about postural stability in unstable conditions.

*Key words:* balance, biomechanics, force plate, reliability, wobble board

### 1. Introduction

Balance can be defined as the ability to maintain the body's center of mass (COM) within its base of support with minimal movement [26]. It is a dynamic complex process, which is influenced by sensory information from somatosensory, visual and vestibular systems and their integration within the central nervous system [18].

The assessment of postural stability is essential for identification of basic predictors of performance, injury prevention, and the efficacy of rehabilitation techniques [14], [15]. It is necessary to establish suitable methods of assessment of postural stability which would enable evaluation of the risk of falling [23].

There are two basic types of the assessment of postural stability: (1) qualitative observation of the person's

physical activities, and (2) quantitative methods utilizing measuring equipment [7]. Balance performance is most often quantified by parameters derived from the centre of pressure (COP) data obtained with a force platform. COP data, especially indicators of lateral stability, may be used for prediction of falls.

The falls usually occur in dynamic situations, therefore, the tests of the stability under dynamic conditions are important for the postural stability assessment [12]. In the dynamic conditions the central nervous system must control not only the position of the COP but also its relative velocity during the sway [19]. There are significant differences between static measures of sway and dynamic assessment of postural control [11]. Therefore, when selecting the conditions for the measurement of postural stability (static versus dynamic) it is necessary to take into account the age, the health and the physical fitness of participants.

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To assess dynamic balance, ability tests such as functional reach, limits of stability, balance board test etc. have been developed [17]. Balance board tests require keeping a stable posture on an unstable platform (a wobble board, a foam pad, a trampoline, etc.) [24]. A wobble board is a tool used for reducing sports-related injuries among healthy adolescents [5], for balance training of dynamic postural stability [6], for rehabilitation in patients after ankle injuries [25], etc.

It appears there is a relative paucity of studies investigating both static and dynamic measures of postural stability in a healthy population [22]. Therefore, the objective of the present study was to investigate the possibility of using a force platform for the assessment of COP velocity when standing on a wobble board in a healthy population. Firstly, the differences between measuring conditions were assessed. Secondly, reliability of COP mean velocity was assessed and compared in three different bipedal stance conditions: (1) standing on a rigid surface, (2) standing on a compliant surface (a foam pad), and (3) standing on an unstable surface (a wobble board). Lastly, balance between the three conditions was correlated.

## 2. Methods

### 2.1. Participants

Thirty young recreationally active adults (17 women, 13 men; mean age  $22 \pm 1$  years; weight  $68.5 \pm 12.0$  kg; height  $172.2 \pm 9.72$  cm) without any musculoskeletal or neurological deficiencies participated in the study. Each participant became familiar with the measurement procedures and signed written informed consent before data collection started. The study protocol was approved by the institutional ethics committee.

### 2.2. Equipment and measurement

Force data were recorded with force platform AMTI OR6-5 (Advanced Mechanical Technology, Inc., Watertown, MA, USA; sampling frequency 200 Hz) embedded within the floor.

The participants underwent four trials in each of three different conditions in each of three measuring days. First two days were consecutive and the third measuring day was 14 days after the first. The measurement of each participant was performed approxi-

mately at the same hour each day to ensure similar conditions for all measurements.

Postural balance in the barefoot quiet stance was evaluated under three conditions: standing on a wobble board (ClassicR25V10, VSB – Technical University of Ostrava, Ostrava, Czech Republic) (WBS), standing on a rigid surface (RSS), and standing on a compliant surface (foam pad Airex Balance Pad, Airex AG, Sins, Switzerland) (CSS). The wobble board (WB) – diameter 40 cm, height 10 cm, maximal tilt angle  $30^\circ$  (Fig. 1) was designed as a telemetric rehabilitation device with a 3D accelerometer, 3D gyroscope and 3D magnetometer recording the tilt and rotation. The foam pad and the WB were placed on the center of the force plate. Before the first trial of the first measuring day, a comfortable feet position on the WB was established for each participant. This position was noted using the grid on the surface of the WB and remained the same during all the trials in all three conditions. The participants were asked to stand as still as possible with eyes open and to look at a mark ( $10 \times 10$  cm) placed at eye level on the wall 1.5 meters in front of them. At the beginning of each trial some stabilization time (10–20 s for WBS and 5 s for the CSS and RSS) was given to the participants and then the 60-s recording was started. The participants had a rest period of at least 2 minutes between the trials.



Fig. 1. Wobble board ClassicR25V10

### 2.3. Data analysis

The data obtained from force plate were filtered by the 4th order low-pass bidirectional Butterworth filter with the cut-off frequency of 10 Hz. A custom MATLAB (v2015b, Mathworks, Inc., Natick, MA, USA) script was used to compute mean velocities in the medial-lateral ( $V_x$ ) and anterior-posterior ( $V_y$ ) directions and the mean total velocity ( $V$ ) of the COP translation.

## 2.4. Statistics

Kolmogorov–Smirnov test was used to assess the normality of data distribution. The conditions and measuring days were compared using two-way repeated measures analysis of variance using the Bonferroni post-hoc test. For reliability assessment, intraclass correlation coefficients type ICC (2,1) were calculated based on the two-way analysis of variance. Intra-session reliability was computed from four trials recorded per day for each measuring day separately. Inter-session reliability was assessed using mean values computed by averaging values of the four trials per day between the individual measuring days. The interpretation of ICC was as follows: ICC > 0.75 representing excellent, 0.40–0.75 fair to good, and <0.40 poor reliability. Relationships between the three conditions were assessed by Pearson correlation coefficient, with its value interpreted as follows: >0.90 very high, 0.70–0.90 high, 0.50–0.69 moderate, 0.30–0.49 low, and <0.30 negligible [9]. The statistical significance level threshold for all the tests was set to 0.05.

## 3. Results

### 3.1. Comparison of the conditions and measuring days

The analysis of variance showed significant effect of conditions ( $P < 0.05$ ), day of the measurement

( $P < 0.05$ ) and combined effect ( $P < 0.05$ ) for all of the parameters. The post-hoc analysis showed no differences between measuring days in RSS for all of the parameters. There was also no difference between the second and the third measuring day for all the parameters in CSS and WBS. For  $V_y$  and  $V$ , no difference was found between the first and the second measuring day. All the other combinations showed significantly different results ( $P < 0.05$ ). The apparent trend for all the parameters was to decrease with increasing experience of the participant.

### 3.2. Reliability

COP mean velocities as well ICCs are presented in Table 1. All three velocities obtained for RSS displayed excellent intra-session reliability. The size of the ICCs for  $V_x$  and  $V$  for CSS was similar to RSS while  $V_y$  had good reliability in all three measurements. As expected, reliability for WBS was lower but still reached good reliability levels, the ICCs for all three velocities were increasing with increasing participants' experience.

Inter-session reliability was good both for RSS and CSS. Likewise, reliability for WBS was good for  $V_x$  and  $V$  although with the ICCs lower than in the other two conditions, however,  $V_y$  displayed poor reliability.

### 3.3. Correlations

Correlation coefficients between the different standing conditions are presented in Table 2. In all three

Table 1. COP mean velocities (in mm/s) and intra- and inter-session reliability

	1st measurement		2nd measurement		3rd measurement		Inter-session ICC
	Mean ± SD	ICC	Mean ± SD	ICC	Mean ± SD	ICC	
Stance on a rigid surface							
$V_x$	4.34 ± 1.44	0.82	3.93 ± 1.44	0.88	3.67 ± 1.18	0.88	0.72
$V_y$	5.47 ± 1.32	0.85	5.43 ± 1.33	0.85	5.34 ± 1.12	0.79	0.73
$V$	7.79 ± 2.01	0.87	7.46 ± 2.03	0.89	7.20 ± 1.67	0.86	0.73
Stance on a compliant surface							
$V_x$	9.59 ± 2.39	0.83	8.37 ± 2.23	0.89	7.92 ± 2.10	0.89	0.76
$V_y$	10.14 ± 1.74	0.69	9.47 ± 1.74	0.78	9.15 ± 1.22	0.72	0.65
$V$	15.56 ± 2.91	0.77	14.09 ± 2.78	0.85	13.48 ± 2.46	0.88	0.72
Stance on a wobble board							
$V_x$	23.64 ± 3.92	0.57	21.26 ± 3.01	0.57	20.71 ± 2.97	0.60	0.55
$V_y$	25.16 ± 4.52	0.57	20.46 ± 3.02	0.68	19.36 ± 3.27	0.75	0.34
$V$	38.54 ± 6.25	0.59	32.92 ± 4.35	0.64	31.69 ± 4.44	0.69	0.41

Note. SD = standard deviation; ICC = intraclass correlation coefficient;  $V_x$  = COP mean velocity in the medial-lateral direction;  $V_y$  = COP mean velocity in the anterior-posterior direction;  $V$  = total COP mean velocity.

measuring days, the correlation was highest between RSS and CSS, followed by the correlation between CSS and WBS, the lowest correlation was observed between RSS and WBS.

In the first measurement, the correlation between RSS and CSS was high for  $V_y$  and  $V$  and moderate for  $V_x$ . The correlation between CSS and WBS was moderate for all three velocities. The correlation between RSS and WBS was low, but except for  $V_x$  the correlations were still statistically significant ( $P < 0.05$ ).

In the second measurement, the correlation was high between RSS and CSS for all three velocities. The correlation between CSS and WBS was moderate, with minimal differences between the correlation coefficients. The correlation between RSS and WBS was low, the correlation for  $V_x$  was not statistically significant.

In the third measurement (which followed two weeks after the first one), the correlation between RSS and CSS was high for  $V_y$  and  $V$  and moderate for  $V_x$ . The correlation between CSS and WBS was moderate for all three velocities, with the correlation coefficients for  $V_y$  and  $V$  being greater than in the first two measurements. The correlation between RSS and WBS was low, with the sizes of correlations coefficients comparable to the second measurement. The correlation for  $V_x$  was not statistically significant.

Table 2. Pearson correlation coefficients between the different standing conditions

	RSS vs. CSS	RSS vs. WBS	CSS vs. WBS
1st measurement			
$V_x$	0.67	0.35	0.59
$V_y$	0.83	0.39	0.54
$V$	0.81	0.37	0.58
2nd measurement			
$V_x$	0.80	0.36	0.51
$V_y$	0.76	0.49	0.54
$V$	0.83	0.41	0.53
3rd measurement			
$V_x$	0.69	0.36	0.56
$V_y$	0.76	0.47	0.70
$V$	0.73	0.41	0.63

*Note.* RSS = stance on a rigid surface; CSS = stance on a compliant surface; WBS = stance on a wobble board.  $V_x$  = COP mean velocity in the medial-lateral direction;  $V_y$  = COP mean velocity in the anterior-posterior direction;  $V$  = total COP mean velocity.

## 4. Discussion

The intra-session reliability in our study was computed from four trials recorded during the same day. Duration of the trials was 60 seconds. Lafond et al. [13] suggested that to increase the stationarity of the signal the COP should be recorded for at least 60–120 s. However, it was necessary to take into account difficulty of standing on the WB and therefore we chose the duration of 60 s, also with regard to Pinsault, Vuillerme [20] who reported that 30 seconds was sufficient to ensure reliability of velocities of the COP displacements. From the parameters characterizing the COP movement we decided to use the COP mean velocity, which had been most often reported to be the most reliable COP variable [16]. Our results showed excellent intra-session reliability for all three velocities when standing on a rigid surface. Similar results were obtained for standing on a compliant surface (a foam pad), except for  $V_y$  where the reliability was found to be good. Specific differences in motor control patterns may reflect various biomechanical constraints associated with sagittal and frontal planes of movement. Postural control mechanisms in the medial-lateral ( $V_x$ ) and in the anterior-posterior ( $V_y$ ) direction differ. Whereas balance in the anterior-posterior direction is maintained by ankle control, in the medial-lateral direction the hip (abductor/adductor) control is dominant [27]. The reason of larger variability of movement in the anterior-posterior direction caused by balance perturbation are anatomical constraints of the joints on the lower extremities. Limited possibilities of movement regulation in the medial-lateral direction are associated with an increased risk of falling [8]. Our results are in accordance with other research studies. Lafond et al. [13] investigated the effect of stance duration on the size of ICC and reported that the ICC increased along with increasing stance duration of standing reached 0.87–0.94 for the velocity in the medial-lateral direction and 0.73–0.83 for the velocity in the anterior-posterior direction. Rugelj et al. [21] compared reliability of the COP parameters in younger and older populations. They found that in the group of older people, mean velocity had the highest test–retest reliability for a rigid (ICC = 0.91) as well as a compliant (ICC = 0.92) surface, in the group of younger people reliability was lower (ICC = 0.69 and 0.74, respectively). Stemplewski et al. [23] found excellent intra-session reliability (ICC = 0.76) for the mean velocity during quiet stance on a rigid surface with eyes open.

In our study a good reliability for all three COP velocities during stance on the WB (ICC 0.57–0.75) was found. A comparison between the results of our study to previous literature is somewhat limiting as there are only a few studies that have captured COP velocity parameters in dynamic measurement of postural stability. For the assessment under dynamic conditions, the reliability of variables computed from the professional balance system (Biodex, SMART Balance Master etc.) were primarily reported. Hinman [10] evaluated the reliability for two trials performed on the same day on the Biodex Balance System. She reported excellent reliability of the stability index for static test with eyes open.

When comparing these results with the results in our study, it is necessary to account for the difference in measuring conditions and observed parameters. The Biodex Balance System enables setting different levels of difficulty by adjusting the range of tilt (with a maximum of 20°) while the WB used in present study could freely tilt up to 30°.

Dimensions of the WB used in our study (diameter 40 cm, height 10 cm, maximal tilt angle 30°) are similar to those of commercially available wobble boards. The dimensions were sufficient for young healthy adults participating in our study, who could stand on the WB for required time only with a short familiarization. In the case of testing balance abilities with wobble boards in people with possibly impaired balance it would be necessary to use a wobble board with a larger diameter and a lower height.

The inter-session reliability in the present study was found to be good for all measured velocities in all three conditions, apart from  $V_y$  for WBS, which had poor reliability. The ICCs for inter-session reliability were lower than for intra-session reliability, which is in agreement with studies in which the within-day reliability was superior to between-day reliability [2]. Stemplewski et al. [23] reported for intra- and inter-session reliability for the mean velocity during quiet stance on a rigid surface with eyes open values similar to those obtained in our study, with the inter-session reliability (ICC = 0.76) lower than the intra-session variability (ICC = 0.96). De Kegel et al. [4] assessed the test–retest reliability (two different days in the same week) of COP parameters in children with and without balance difficulties. They found that the most reliable parameter with all ICCs higher than 0.72 was the COP mean velocity.

Standing on a wobble board has similar characteristics to those of the standing on a tiltboard. The inter-session reliability of the tiltboard test was assessed by Broadstone et al. [3] who reported ICC of 0.54 for

both right and left tilt. Atwater et al. [1] reported for one-leg balance on a tiltboard ICCs of 0.45 in both open and closed eyes conditions.

When assessing the relationships between different stance conditions we found that the correlation between RSS and CSS was high for  $V_y$  and  $V_z$ , moderate for  $V_x$ . The correlation between CSS and WBS was moderate for all three velocities, the correlation between RSS and WBS was low. All correlations except for  $V_x$  between RSS and WBS were statistically significant. Unfortunately, we did not find any studies investigating the relationship between balance during stance on a rigid surface and on a wobble board, thus there are little data available to compare with those of the present study.

Sell [22] studied relationships between static (a single leg standing task) and dynamic (a single leg landing task) postural stability in healthy, physically active adults. He did not find any significant correlations between the results of static and dynamic tests. He concluded that the dynamic measures are more appropriate for healthy, athletic populations as well as for studies examining risk of ankle and knee injury.

Results of the present study are in agreement with previously published findings. We found strong correlation between standing on a rigid and a compliant surface, the correlation became weaker with decreased surface stability (stance on the WB). The results of the present study confirm that static balance on a stable and an unstable surface is regulated by different mechanisms. In the case of static balance testing, the amount of muscular effort necessary to maintain a stable position is minimal. During dynamic postural tasks muscle activation increases and so do the demands on the postural control system [22].

Assessment of standing balance utilizing standing on a wobble board placed on a force platform provides reliable information about the COP velocity. We found low correlation between COP velocities in quiet standing on a rigid surface and on a wobble board. Assessment of standing balance with a wobble board can provide valuable information about the level of postural stability in more challenging conditions which are similar to those of fall-risk situations.

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