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Test–Retest Reliability of the FIBOD System for Postural Stability Assessment

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A B S T R A C T

Accurate balance assessment is essential for rehabilitation and fall-risk evaluation. Traditional observation-based tools such as the Balance Error Scoring System (BESS) and Berg Balance Scale (BBS) are widely used but are limited by subjectivity and observer bias. The FIBOD is a novel sensor-based wobble board system that provides objective and quantitative assessment of postural stability using integrated inertial measurement unit (IMU) sensors**.** This study aimed to evaluate the within-session test–retest reliability of the FIBOD system and to determine whether a simplified single-trial protocol can provide results comparable to repeated measurements. A cross-sectional study was conducted with 171 healthy adults (mean age = 36.5 ± 13.4 years) who performed two consecutive FIBOD balance assessments. The Overall Stability Index (OSI) values from both trials (T1, T2) were analysed using the Shapiro–Wilk test for normality, Bland–Altman analysis for agreement, and the Intraclass Correlation Coefficient (ICC (2,1)) for reliability. Post-hoc power analysis was performed to confirm statistical adequacy. The first trial exhibited an approximately normal distribution ($p = 0.065$), whereas the second showed a significant deviation ($p = 0.001$). A small mean bias of +0.12 OSI units and narrow 95% limits of agreement (–1.30 to +1.54) indicated good agreement between trials. Reliability analysis demonstrated good within-session consistency (ICC (2,1) = 0.88; 95% CI: 0.83–0.92). Post-hoc power analysis ($\alpha = 0.05$, $d = 0.40$) yielded a statistical power of 0.999. The FIBOD system demonstrated strong reliability and agreement between consecutive trials. These findings suggest the potential feasibility of a single-trial protocol as a time-efficient and clinically practical approach for balance assessment.

INTRODUCTION

Balance is fundamental to postural control in daily life activities such as standing, walking, and exercising [1]. Research has shown that balance training enhances motor function, improves stability, and reduces the risk of falls [2,3,4]. The center of pressure (COP) is widely regarded as the gold standard for assessing postural stability [5]. Motion capture systems and wearable accelerometers have also been employed for quantitative postural stability evaluation [1,3]. In clinical practice, low-cost tools such as the Romberg test, Timed Up and Go (TUG), and the Berg Balance Scale (BBS) are commonly used [3]. The BBS, in particular, has been applied across neurological populations, including stroke survivors, individuals with Parkinson's disease, and older adults [4]. However, these assessments depend heavily on expert observation, are time-intensive, and may lack sensitivity to subtle balance deficits [3,5]. In response, sensor-based balance assessments using inertial measurement units (IMUs) have gained traction as objective and quantitative alternatives [5,6]. Wearable sensors can capture parameters such as sway amplitude, velocity, and frequency in both the anterior–posterior and mediolateral axes, providing detailed biomechanical data with minimal observer bias [5]. A systematic review of IMU-based balance studies in healthy adults reported moderate to good reliability (both inter- and intra-session) and moderate concurrent validity compared with force-plate systems [5]. Recent evidence suggests that a single sensor placed near the body's center of mass (e.g., the lumbar region) may provide reliability comparable to multi-sensor

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configurations under many conditions [7]. For instance, Abdollah et al. demonstrated that standing balance parameters derived from a single sternum- or head-mounted accelerometer achieved intraclass correlation coefficients (ICC) ≥ 0.90 across various testing conditions [7]. Moreover, in clinical populations such as post-stroke individuals, single-sensor IMU-based balance assessments have also shown promising reliability [8]. Yet, clinical adoption remains limited due to equipment costs [3] and the relatively small number of validation studies against established assessment tools.

Despite the promise of sensor-based systems, test–retest consistency remains a critical concern, particularly when repeated trials may introduce learning or fatigue effects. In many clinical or field contexts, only a single measurement may be feasible due to time constraints or participant fatigue. Therefore, determining whether a single trial can provide comparable results without compromising measurement quality is both scientifically and practically important. Bland–Altman analysis is widely recognized as a robust method for evaluating agreement between repeated measurements by quantifying systematic bias and limits of agreement [5], and when combined with reliability metrics, it provides a comprehensive assessment of measurement consistency.

Although IMU-based systems have demonstrated good reliability in previous studies, most approaches were focused on wearable sensors or laboratory-based equipment. Most previous research has focused on establishing reliability under repeated measurements, there is limited evidence regarding whether a single-trial assessment is sufficient to produce reliable and clinically meaningful results [7,8]. Evidence remains limited for wobble board–based IMU systems designed for practical clinical use, such as the FIBOD balance assessment system investigated in this study. In addition, existing research primarily focuses on reliability across repeated trials, with limited investigation into the minimum number of trials required to obtain stable measurements. This represents an important gap, as it remains unclear whether repeated trials are necessary or whether a single-trial protocol could provide comparable results. Addressing this issue is clinically relevant, as shorter assessments may reduce fatigue, improve patient compliance, and enhance efficiency in real-world settings.

Therefore, the primary objective of this study was not merely to establish the reliability of an IMU-based balance assessment system, but to determine whether a simplified single-trial protocol could provide reliability comparable to repeated measurements. While previous IMU-based balance studies have primarily focused on improving sensor configurations or evaluating repeated-trial reliability, limited evidence has specifically investigated whether repeated measurements are necessary to obtain reliable balance outcomes [5,7,8]. The proposed FIBOD system addresses this gap by evaluating the feasibility of a rapid single-trial assessment using a portable wobble board equipped with an integrated IMU [9,10]. Demonstrating comparable reliability from a single trial could substantially reduce assessment time while maintaining acceptable measurement consistency, thereby improving the practicality of balance assessment in routine clinical practice [9,10].

METHODS

Experimental Protocol

Each participant underwent two consecutive balance assessments using the sensor-based FIBOD wobble board system. All participants provided written informed consent prior to participation. To minimize potential order effects such as fatigue or learning bias, the sequence of rest intervals between the first (T1) and second (T2) trials was standardized for all subjects. Each participant was instructed to maintain balance on the board for the prescribed duration under identical environmental and setup conditions. The data from both trials were recorded as the Overall Stability Index (OSI). Statistical analyses, including the Shapiro–Wilk normality test and Bland–Altman analysis were performed to evaluate the test–retest agreement and reliability. A power analysis performed after the data have been collected and analyzed to confirm that the sample size was sufficient to detect meaningful differences, using a significance level of 0.05.

Participants

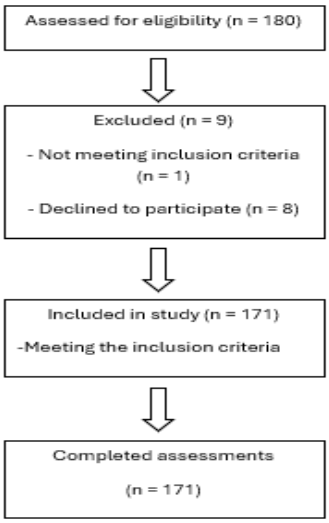

Figure 1. Flowchart detailing the recruitment, inclusion, and exclusion process.

A total of 180 individuals were initially assessed for eligibility. Of these, 9 participants were excluded, including 1 who did not meet the inclusion criteria and 8 who declined to participate. Consequently, 171 healthy adults were included in the study, and all participants completed the assessments. The participant recruitment and selection process is illustrated in Figure 1. Participants were recruited through convenience sampling from the local community via word-of-mouth and poster advertisements. The final sample comprised 105 males (61.4%) and 66 females (38.6%), with a mean age of 36.5 ± [13.4] years. These baseline characteristics were recorded as they may influence postural control and balance performance. All participants provided written informed consent prior to participation.

Prior to enrolment, all participants underwent both subjective and objective evaluations conducted by two trained examiners following a standardized operating procedure (SOP). Screening was performed to ensure compliance with predefined inclusion and exclusion criteria. Eligible participants were aged between 18

to 65, able to stand independently, walk without assistance, and follow verbal instructions. Participants were excluded if they presented with neurological disorders, orthopaedic or musculoskeletal injuries, vestibular or cerebellar dysfunction, uncontrolled diabetes mellitus, unstable angina, visual or auditory impairments, dementia, pregnancy, or any other medical condition that could affect postural stability. Although sex and age were recorded, anthropometric variables such as height and body weight were not consistently available for all participants and were therefore not included in the final analysis. This may limit the interpretation of factors influencing postural control outcomes.

Ethical Considerations and Consent to Participate

This study received ethical approval from the Ministry of Health Malaysia's Medical Research and Ethics Committee (NMRR-ID-23-01539-UOJ). All procedures were performed in accordance with the Declaration of Helsinki and national regulatory guidelines. Written informed consent was obtained from every participant before data collection.

Equipment

The balance assessment was conducted using the FIBOD sensor-based wobble board, a device equipped with an inertial measurement unit (IMU) comprising accelerometers and gyroscopes to quantify postural stability with high precision, as shown in Figure 2. The FIBOD is a sensor-based electronic wobble board developed for objective balance assessment and interactive balance training [10,11]. It consists of a circular standing platform with a diameter of approximately 0.4 m (15.5 inches), weighs 1.3 kg, supports a maximum user weight of 200 kg, and permits multidirectional tilting within a range of −20° to +20° in both the anterior–posterior (AP) and medial–lateral (ML) directions, enabling the detection of postural sway during standing balance tasks [10].

The IMU continuously measures linear acceleration and angular velocity during standing balance tasks. These raw sensor signals are integrated to estimate platform orientation in terms of pitch, roll, and yaw, which represent movement in three-dimensional space. As postural sway during standing balance primarily occurs in the AP and ML directions, pitch and roll were the principal parameters analysed in this study [5,10,11]. The processed IMU data were transmitted wirelessly via Bluetooth to the FIBOD software platform, where an embedded processing algorithm automatically calculated three quantitative indices of postural stability: the Overall Stability Index (OSI), Medio-Lateral Stability Index (MLSI), and Antero-Posterior Stability Index (APSI) [10,11].

The FIBOD samples orientation data at a frequency of 20 Hz, providing continuous monitoring of postural sway during assessment [11]. The sensor has a measurement resolution of 0.01°, an accuracy of ±0.04%, and a repeatability of ±0.06%, allowing detection of subtle changes in platform inclination [10]. During testing, the software provided real-time visual feedback, including balance targets, timers, and on-screen indicators to assist participants in maintaining steady posture. Upon completion of each trial, the calculated stability indices were displayed immediately, as illustrated in Figure 3 Each participant completed two identical trials separated by a standardized rest period to minimize fatigue and potential carryover effects [12]. The system was automatically recalibrated before each trial to ensure measurement accuracy and consistency.

Figure 2. The balance assessment was conducted using the FIBOD sensor-based wobble board.

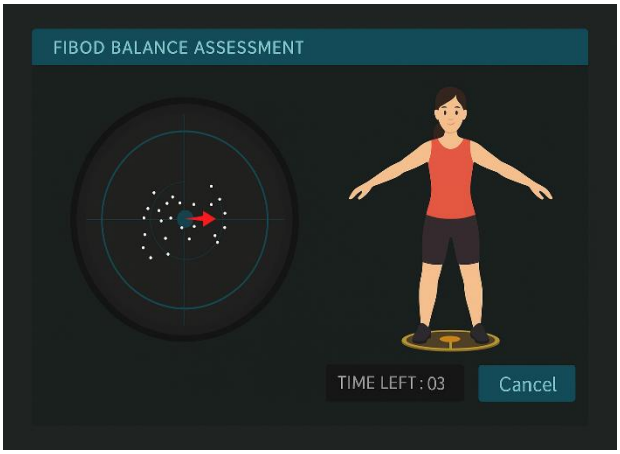

Figure 3. Stability scores in the result.

Procedure

During the experiment, all participants performed two consecutive balance assessments using the FIBOD sensor-based wobble board system. Each session was conducted individually in a controlled setting to minimize external disturbances and ensure consistent testing conditions. The wobble board was positioned approximately 110 cm from the display screen, which provided real-time visual feedback throughout the assessment [11]. Participants were instructed to stand barefoot on the board with their feet shoulder-width apart and hands resting comfortably by their sides. To introduce a controlled level of instability, the board was placed on a circular foam base. All assessments were conducted by two trained physiotherapists with 2 years 11 months and 1 year 4 months of clinical experience, respectively. To ensure consistency and minimize inter-rater variability, each participant was assessed by the same examiner across both trials. Prior to data collection, both examiners underwent standardized training to ensure uniformity in testing procedures.

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Following familiarization, participants completed two formal test trials in T1 and T2 under identical conditions. In each trial, they were required to maintain balance for 10 seconds while focusing on the visual display. The 10-second duration was selected based on prior studies indicating that short-duration balance assessments (5–15 seconds) are sufficient to capture postural sway characteristics while minimizing fatigue and maintaining participant focus [7]. Shorter durations are particularly relevant in clinical settings where efficiency and patient tolerance are critical. The FIBOD software displayed a moving cursor within a target circle, visually representing real-time sway as the system continuously recorded motion data. A standardized two-minute rest period was provided between trials to prevent fatigue or carryover effects, and the system was automatically recalibrated before each trial to maintain measurement accuracy [12].

During both assessments, the inertial measurement unit (IMU) sensors captured multidirectional accelerations and angular velocities. These raw motion signals were processed by the onboard algorithm to calculate three key quantitative indices: the Overall Stability Index (OSI), the Medio-Lateral Stability Index (MLSI), and the Antero-Posterior Stability Index (APSI). The FIBOD system generates three primary indices of postural stability: the Overall Stability Index (OSI), Medio-Lateral Stability Index (MLSI), and Antero-Posterior Stability Index (APSI). The OSI represents the overall variance of platform displacement in all directions and serves as a composite measure of postural stability. The MLSI reflects sway in the frontal (medio-lateral) plane, while the APSI quantifies sway in the sagittal (antero-posterior) plane.

These indices are derived from real-time motion data captured by the inertial measurement unit (IMU) sensors during the balance task. For all indices, higher values indicate greater postural instability, whereas lower values represent better balance control and stability. Together, these parameters provided a detailed representation of each participant's postural stability and control strategy during the balance task. In this study, the indices reflect dynamic postural control, as participants actively maintained balance on an unstable wobble board surface.

DATA ANALYSIS

All data were analyzed using IBM SPSS Statistics (version 29.0; IBM Corp., Armonk, NY). The Overall Stability Index (OSI) values obtained from the first (T1) and second (T2) FIBOD trials were included in all statistical analyses. The Shapiro–Wilk test was applied to evaluate the normality of OSI distributions for each trial, as it provides greater sensitivity for moderate sample sizes [13]. Results indicated that T1_OSI values were approximately normally distributed ($W = 0.99$, $p = 0.065$), whereas T2_OSI values deviated significantly from normality ($W = 0.97$, $p = 0.001$). Therefore, both parametric and non-parametric analyses were performed to ensure robust statistical interpretation.

To determine the test–retest agreement between the two trials, Bland–Altman analysis was performed to evaluate the mean bias and the 95% limits of agreement (LoA) between repeated measurements. The intraclass correlation coefficient [ICC (2,1)] was calculated using a two-way random-effects model with absolute agreement to assess test–retest reliability [14].

In addition, the Standard Error of Measurement (SEM) and Minimal Detectable Change at the 95% confidence level (MDC95) were calculated using the OSI values obtained from first (T1) and second (T2) FIBOD trials to quantify measurement error and determine the minimum change required to reflect a true difference beyond measurement variability.
The Standard Error of Measurement (SEM) was calculated using the formula:

$$SEM = SD \times \sqrt{(1 - ICC)} \quad (1)$$

where SD represents the pooled standard deviation of the repeated measurements and ICC represents the intraclass correlation coefficient.

The Minimal Detectable Change at the 95% confidence level (MDC95) was subsequently calculated using the formula:

$$MDC_{95} = SEM \times 1.96 \times \sqrt{2} \quad (2)$$

After data collection, a post-hoc power analysis was performed to verify that the sample size ($n = 171$) was sufficient to detect meaningful differences between trials. Based on an observed effect size of Cohen's $d = 0.40$ and a significance level of $\alpha = 0.05$, the analysis achieved a statistical power of 0.999 (99.9 %), confirming that the study possessed more than adequate power to support the reliability findings.

In addition to OSI, the same reliability and agreement procedures were applied to the Medio-Lateral Stability Index (MLSI) and Antero-Posterior Stability Index (APSI). Bland–Altman analyses were performed to evaluate agreement between repeated trials, and descriptive statistical comparisons were conducted to assess the consistency of repeated MLSI and APSI measurements [13].

RESULTS

The Overall Stability Index (OSI) values obtained from the first (T1) and second (T2) FIBOD trials were included in all statistical analyses. To determine the suitability of parametric testing, the normality of OSI distributions was assessed using the Shapiro–Wilk test, which is considered a sensitive and reliable method for evaluating normality in moderate sample sizes. The results indicated that T1_OSI values were approximately normally distributed ($W = 0.99$, $p = 0.065$), whereas T2_OSI values showed a statistically significant deviation from normality ($W = 0.97$, $p = 0.001$).

Although the Kolmogorov–Smirnov test did not reject normality for either dataset, the Shapiro–Wilk test was prioritized due to its higher sensitivity in detecting subtle deviations in distributions with sample sizes below 2,000 [13]. Based on these findings, T2_OSI data were considered non-normally distributed for subsequent analyses. To ensure robustness of the results, both parametric and non-parametric statistical approaches were performed in parallel to verify consistency across analytical methods.

Table 1 summarizes the Bland–Altman agreement analysis for the Overall Stability Index (OSI). The mean bias between repeated trials was small (+0.12 OSI units), indicating minimal systematic difference between T1 and T2 measurements. The 95% limits of agreement ranged from −1.30 to +1.54 OSI units, demonstrating the extent of variability between repeated measurements. Overall, the findings suggest acceptable agreement and consistent test–retest performance of the FIBOD system.

Table 2 summarizes the measurement error and reliability indices for OSI across repeated trials. The mean OSI values were 6.63 ± 0.78 for T1 and 6.51 ± 0.86 for T2, with a mean difference (bias) of +0.12 OSI units. The intraclass correlation coefficient (ICC (2,1)) was 0.88 (95% CI: 0.83–0.92). The standard error of measurement (SEM) was 0.22 OSI units, and the minimal detectable change at the 95% confidence level (MDC_{95}) was 0.61 OSI units.

A Bland–Altman analysis was conducted to evaluate test–retest agreement between the two FIBOD trials, as illustrated in Figure 4. The distribution of differences between T1 and T2 measurements is presented graphically, showing the spread of individual differences across the measurement range.
A post-hoc power analysis was performed using G*Power software to evaluate the adequacy of the sample size for detecting differences between repeated trials. Based on an observed effect size of Cohen's d = 0.40 and a significance level of α = 0.05, the calculated statistical power was 0.999 (99.9%), indicating that the sample size (n = 171) was sufficient to detect small to moderate effects.

As shown in Tables 3 and 4, the Bland–Altman analysis for both MLSI and APSI demonstrated small mean biases, with values of +0.08 and +0.28, respectively, indicating that T1 measurements were slightly higher than T2. The descriptive statistics further showed comparable mean values between trials for both indices, supporting the consistency of repeated measurements. The 95% limits of agreement for MLSI (−1.20 to +1.35) and APSI (−1.18 to +1.74) demonstrated acceptable consistency between repeated measurements. The width of the limits of agreement was slightly wider for APSI, suggesting greater variability in anteroposterior postural control compared with mediolateral stability. Collectively, these findings support acceptable test–retest reliability of the FIBOD system for both mediolateral and anteroposterior stability measurements.

Table 1. Bland–Altman Agreement Analysis for Overall Stability Index (OSI)

Parameter	Value	Interpretation
Mean bias (T1 − T2)	+0.12	Small positive bias; T1 slightly higher than T2
95% limits of agreement (LoA)	−1.30 to +1.54	The 95% limits of agreement ranged from −1.30 to +1.54 OSI units, indicating the extent of variation between repeated measurements
Width of LoA	2.84	Moderate measurement variability
Overall interpretation	Acceptable agreement between trials	Consistent test–retest performance

Footnote: OSI = Overall Stability Index; LoA = Limits of Agreement; T1 = first trial; T2 = second trial.

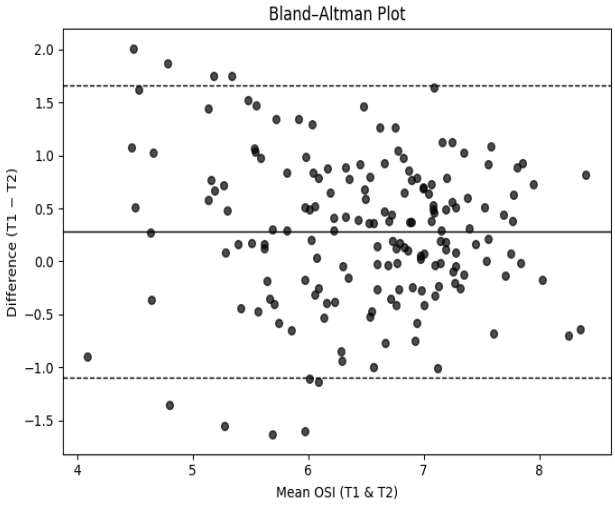

Fig. 4 Bland–Altman plot illustrating agreement between Test 1 (T1) and Test 2 (T2) Overall Stability Index (OSI) measurements. The horizontal axis represents the mean of T1 and T2 OSI values, while the vertical axis represents the difference between T1 and T2 measurements (T1 − T2). In the Bland–Altman plot, the vertical axis represents the difference between T1 and T2 OSI values, while the horizontal axis represents the mean of the two measurements.

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Table 2 Measurement Error and Reliability Indices for OSI

Parameter	Value	Interpretation
Mean OSI (T1)	6.63 ± 0.78	Baseline postural stability
Mean OSI (T2)	6.51 ± 0.86	Repeated measurement
Mean Difference (Bias)	+0.12	Small systematic difference
SD of Differences	0.72	Variability between trials
ICC (2,1)	0.88 (0.83–0.92)	Good reliability
SEM (OSI)	0.22	Low measurement error
MDC (OSI)	0.61	Threshold for true change

Footnote: OSI = Overall Stability Index; ICC = Intraclass Correlation Coefficient; SEM = Standard Error of Measurement; MDC_{95} = Minimal Detectable Change at the 95% confidence level; SD = Standard Deviation.

Table 3 Statistic of Bland-Altman (MLSI and APSI)

Statistics	MLSI	APSI	Interpretation
Bias (T1–T2)	+0.08	+0.28	Small bias — T1 slightly higher
LoA (95%)	−1.20 to +1.35	−1.18 to +1.74	Narrow range — good agreement
Width of LoA	2.55	2.92	Comparable variability
Conclusion	FIBOD consistent	FIBOD consistent	Both confirm good reliability

Footnote: MLSI = Medio-Lateral Stability Index; APSI = Antero-Posterior Stability Index; LoA = Limits of Agreement; T1 = first trial; T2 = second trial.

Table 4 Descriptive Statistics for OSI, MLSI and APSI

Variable	T1 (Mean ± SD)	T2 (Mean ± SD)
OSI	6.63 ± 0.78	6.51 ± 0.86
MLSI	3.96 ± 0.92	3.89 ± 0.88
APSI	5.40 ± 1.01	5.23 ± 1.06

Footnote: OSI = Overall Stability Index; MLSI = Medio-Lateral Stability Index; APSI = Antero-Posterior Stability Index; SD = Standard Deviation; T1 = first trial; T2 = second trial.

DISCUSSION

This study aimed to determine whether a single trial of the FIBOD sensor-based balance assessment system is sufficient to yield reliable results comparable to two consecutive trials. Based on data from 171 participants, the findings demonstrated a good within-session test–retest agreement and reliability between the first (T1) and second (T2) FIBOD trials. The observed mean difference (+0.12 OSI units) indicates a small systematic difference between repeated measurements. The 95% limits of agreement (–1.30 to +1.54 OSI units) suggest that most repeated measurements fall within a relatively narrow range of variation.

The observed bias toward slightly higher T1 values may be associated with minor adaptation or fatigue effects during repeated testing. Participants may have been more responsive during the initial trial, whereas small variations in the second trial could reflect short-term physiological or attentional factors. Nevertheless, the magnitude of this difference was minimal, and overall agreement remained consistent across trials.

These findings are consistent with previous studies reporting good reliability of inertial measurement unit (IMU)-based systems for assessing postural stability in both healthy and clinical populations [10,15,16]. Previous studies have reported intraclass correlation coefficient (ICC) values ranging from approximately 0.80 to above 0.95 for wearable IMU-based balance assessment systems under controlled laboratory conditions [5,7,8]. For example, Abdollah et al. reported ICC values exceeding 0.90 using a single wearable accelerometer positioned at the sternum or head [7], whereas Noamani et al. demonstrated the validity of wearable IMU sensors for assessing standing balance [5], and Felius et al. reported good reliability of IMU-based balance assessment in individuals undergoing stroke rehabilitation [8]. The ICC value obtained in the present study (0.88) falls within this reported range, indicating that the FIBOD system provides reliability comparable to existing IMU-based technologies despite employing a different measurement approach based on an instrumented wobble board rather than body-mounted sensors.

Unlike wearable IMU systems that require sensor attachment and placement calibration, FIBOD integrates the IMU directly into the wobble board, reducing setup complexity and improving ease of use during routine clinical assessment [9,10]. Furthermore, the present study extends previous work by demonstrating that a simplified single-trial protocol may provide measurement reliability comparable to repeated trials, an aspect that has received limited investigation in previous IMU-based balance assessment studies [5,7,8].

In addition to OSI, the analysis of directional stability indices further supports the reliability of the FIBOD system. Bland–Altman analysis for both MLSI and APSI demonstrated small mean biases and relatively narrow limits of agreement, indicating good agreement between repeated trials. Slightly greater variability was observed in APSI compared to MLSI, which may reflect the increased challenge of maintaining stability in the anteroposterior direction. These findings are consistent with known characteristics of postural control, where anteroposterior sway tends to exhibit greater variability than mediolateral sway. Overall, the consistent results across OSI, MLSI, and APSI strengthen the evidence for the reliability of the FIBOD system in assessing multidirectional postural stability.

However, some studies have reported reduced reliability under more challenging conditions or longer test durations, suggesting

that test protocol characteristics play a critical role in measurement stability [17, 18]. In contrast to studies employing multiple trials or extended durations, the present findings suggest that a short-duration, two-trial protocol can produce stable measurements under controlled conditions. This may indicate the potential for protocol simplification, although further validation is required in more diverse and clinically relevant settings.

In the present study, two consecutive trials were intentionally selected to provide a practical and clinically relevant estimate of within-session reliability. While increasing the number of repetitions may improve the precision of measurement error estimation, the primary objective of this study was to evaluate whether a simplified single-trial protocol could be justified based on the agreement between repeated measurements. From a clinical perspective, balance assessments are often performed within a limited time frame, and excessive repetitions may introduce fatigue, reduce concentration, and affect performance, particularly in populations with reduced endurance [17,19]. Therefore, the use of two trials represents a balance between methodological rigor and clinical feasibility. Nevertheless, future studies incorporating a greater number of repetitions are recommended to further refine the estimation of measurement error and repeatability.

The additional analysis of measurement error further supports the reliability of the FIBOD system. The standard error of measurement (SEM = 0.22 OSI units) was small relative to the overall OSI values, indicating that measurement error represents only a small proportion of total variability. The minimal detectable change at the 95% confidence level (MDC_{95} = 0.61 OSI units) provides a threshold for identifying true changes beyond measurement variability. These findings suggest that the variability observed between repeated trials may reflect a combination of measurement error and natural inter-individual variability in postural control [20].

From a practical perspective, the findings suggest that a single-trial protocol may provide comparable results to repeated measurements under the conditions tested. This may offer advantages in reducing assessment time and minimizing participant fatigue, particularly in clinical or field settings. However, this interpretation should be made with caution, as the clinical significance of the observed differences was not directly evaluated.

The large sample size (n = 171) strengthens the stability of the findings. The post-hoc power analysis (power = 0.999) confirms that the study had sufficient sensitivity to detect small to moderate differences between trials. Furthermore, the use of multiple complementary analytical approaches, including normality testing, Bland–Altman analysis, intraclass correlation coefficient (ICC), and measurement error indices, provides a comprehensive evaluation of reliability and agreement. In addition, the descriptive statistics presented in Table 4 showed comparable mean values between T1 and T2 for OSI, MLSI, and APSI, indicating consistent central tendency across repeated measurements and further supporting the stability of the FIBOD system.

Several limitations should be acknowledged. First, the findings should be interpreted with caution, as the study involved only healthy adults under controlled static conditions. Therefore, the applicability of a single-trial protocol to clinical populations, such as individuals with neurological or balance impairments, remains to be established. Second, the present study evaluated within-session reliability only, as repeated measurements were obtained during a single testing session. Therefore, the inter-session reliability and long-term stability of the FIBOD system remain unknown. Future studies should investigate the reproducibility of measurements across different testing sessions and examiners. Third, postural stability may be influenced by anthropometric and demographic factors, which were not explored through subgroup analyses in this study. Fourth, the use of only two trials provides a basic estimation of reliability, and additional repetitions may offer a more robust evaluation of measurement variability. Furthermore, although MLSI and APSI were included in the analysis, further investigation is required to explore their sensitivity and clinical applicability in different populations and under more challenging balance conditions. Finally, concurrent validity against established reference systems, such as laboratory force plates or other validated balance assessment systems, was beyond the scope of the present study. Future studies should evaluate the agreement between the FIBOD system and these established methods to further support its clinical applicability.

The findings indicate that the FIBOD sensor-based wobble board system provides reliable and consistent measurements of postural stability under controlled conditions. The results also support the potential use of a simplified single-trial protocol for rapid assessment. However, further studies are warranted to validate its applicability in clinical populations and to evaluate its performance under more challenging and dynamic balance conditions.

CONCLUSIONS

The findings indicate that a single FIBOD trial demonstrates comparable agreement and reliability relative to repeated trials in healthy adults. Using data from 171 participants, the results showed that the FIBOD system produced consistent and repeatable measurements of postural stability. The small mean bias of +0.12 OSI units and narrow 95% limits of agreement (–1.30 to +1.54 OSI) suggest minimal variation between trials. The intraclass correlation coefficient [ICC (2,1) = 0.88, 95% CI 0.83–0.92] further supports good test–retest reliability, indicating that most variability reflects true differences among individuals rather than measurement error. The post-hoc power analysis ($\alpha = 0.05$, d = 0.40) demonstrated high statistical power (0.999), reinforcing the robustness of the findings.

Taking together, these results suggest that a single-trial FIBOD assessment may provide measurements comparable to repeated trials under controlled conditions. This has potential practical advantages, including reduced testing time and minimized participant fatigue. However, these findings should be interpreted with caution, as the study was conducted in healthy adults under static conditions and did not include validation against an external reference standard. Therefore, while a single-trial protocol may be a feasible approach for efficient balance assessment, further research is required to validate its applicability in clinical

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populations and more challenging testing conditions. Future studies should also investigate its performance relative to established gold-standard measures to determine its suitability for broader clinical implementation.

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DECLARATIONS

The authors declare no competing interests.

CONSENT FOR PUBLICATION

Not applicable. No individual person's data (such as images, videos, or identifiable information) is included in this manuscript.

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NOMENCLATURE

IMUs	Inertial Measurement Units
OSI	Overall Stability Index
MLSI	Medio-Lateral Stability Index
APSI	Antero-Posterior Stability
ICC	Intraclass Correlation Coefficient

SEM	Standard Error of Measurement
MDC_{95}	Minimal Detectable Change at the 95% confidence level
SD	Standard Deviation.
LoA	Limits of Agreement
T1	First trial
T2	Second trial.
(1)	Equation 1
(2)	Equation 2
√	Square root

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