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Research article

Reliability of Dynamic Balance Test with A Mobile Application of Physics Toolbox Suite

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Abstract
Although mobile applications are used as an alternative to expensive and difficult to access systems used to evaluate dynamic balance, existing applications have some shortcomings. This study aimed to evaluate the reliability of the Physics Toolbox Suite mobile application, which can obtain objective data for dynamic balance measurements in healthy adults, shorten the duration of measurements, and minimize the number of measurement equipment. The dynamic balance of 22 university students (9 male, 13 female, aged 20.3 (± 1.13 years)) was evaluated using the Physics Toolbox Suite mobile application in three test sessions with a 1-week interval. Anterior-posterior stability index (APSI), medial-lateral stability index (MLS), and overall stability index (OSI) of dynamic balance were calculated. Interclass Correlation Coefficients (ICC), Minimal Detectable Change (MDC), Standard Error of Measurement (SEM), and Coefficient of Variation for SEM (CV_{SEM}) were evaluated as indicators of intra- and inter-rater reliability. The mean APSI, MLSI, and OSI scores (Standard deviation) were 2.59 (0.69), 2.21 (0.68), and 3.58 (0.94), respectively. In the evaluation made with the Physics Toolbox Suite mobile application, APSI scores had good intra-rater (ICC(3,1) = 0.67) and inter-rater reliability (ICC(3,1) = 0.73), MLSI scores had high intra-rater (ICC(3,1) = 0.90) with good inter-rater reliability (ICC(3,1) = 0.71), and OSI scores had high intra- rater (ICC(3,1) = 0.87) with good inter-rater reliability (ICC(3,1) = 0.73). The Physics Toolbox Suite Mobile Application can be used as a reliable objective tool to assess dynamic balance among healthcare professionals and athletes.

Key words: Balance test, dynamic balance, smartphone application, reliability.

Introduction

Balance refers to the ability to maintain the body posture in the desired position despite changing situations during static and dynamic movements to maintain the center of gravity within the limits of the support surface (Rugelj, 2010). The ability to maintain balance is an essential component of motor skills, which range from maintaining a simple posture to performing complex voluntary movements (Rogers et al., 2005). As it is known, lack of balance is closely related to sports injuries and fall risk (Hrysomallis, 2007; Cuevas-Trisan, 2017). Improving balance in both young and older individuals has been shown to help prevent injuries and improve functional performance (Patterson et al., 2014).

Balance is usually examined clinically in terms of static and dynamic balance (Roth et al., 2006). Static balance is the maintenance of a general posture or body parts at a certain position without the need for an external force while the contact surface with the ground is fixed (Horak and Shupert, 1994). Unlike static balance, dynamic balance is the state of being able to maintain the body's center of gravity, which changes under the influence of external forces, within the limits of the support surface when the body's contact surface with the ground is variable (Pfile et al., 2016). Dynamic balance measurements are recommended instead of static balance to better evaluate instability and proprioceptive disorders (Cachupe et al., 2001).

The Biodex Balance System (BDS) is one of the most frequently used system in clinical practice and scientific studies, with accepted validity and reliability in dynamic balance measurement (Hinman, 2000; Glave et al., 2016). Although the BDS system is used in clinics and has high reliability, it is expensive and difficult for patients and athletes to access. Due to their cost-effectiveness and accessibility, the use of mobile applications that objectively assess postural movement using triaxial accelerometers, such as the FDA (U.S. Food and Drug Administration) approved Sway App, is increasing (Eldesoky et al., 2017). However, a different scoring system from the BDS system was used in the Sway application, and the scores were close to the upper limit and caused a ceiling effect in measurements (Amick et al., 2015). In addition, in current applications, holding the phone with the application installed may increase measurement error depending on the participant.

To evaluate the risk of injury and progress in rehabilitation, highly reliable mobile applications that eliminate the shortcomings of existing mobile applications and enable more objective and accurate measurements are required. This study aimed to evaluate the reliability of the Physics Toolbox Suite mobile application, which is a cost-effective and accessible system that can provide objective data for dynamic balance measurements for health professionals and athletes.

Methods

Participants
A total of 22 university students (9 males, 13 females, age = 20.3 ± 1.13, body mass index = 21.42 ± 4.6) who were studying in the program of orthopedic prosthesis and orthosis education at Eskisehir Osmangazi University

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voluntarily participated in the study. The study was conducted during the 2022 - 2023 academic year. The inclusion criteria for the study were no history of chronic disease, no history of lower extremity injury, or surgery, and being a young adult aged 18 - 30 years. Individuals with a history of drug use, metabolic diseases such as diabetes and hypertension, and cognitive and psychiatric diseases affecting balance, gait, and motor control were not included in the study.

As a result of the power analysis conducted with the PASS program (PASS 2008 8.0.2, NCSS, LLC, USA), taking into account the study conducted by Schmitz and Arnold, the total number of samples was calculated as 15 with a margin of error of 0.05 and 100% power (Schmitz and Arnold, 1998). Ethics committee approval was received from Eskisehir Osmangazi University Non-Interventional Clinical Research Ethics Committee (2023-236). The participants provided informed consent in accordance with the spirit of the Declaration of Helsinki.

Data collection tools

Physics Toolbox Sensor Suite Mobile Application

The Physics Toolbox Sensor Suite Mobile Application (2021, Vieyra Software, Washington, USA) is offered free of charge to Android and iOS users and is used in many areas, such as activity recognition and engineering (Alexander, 2015; Saha et al., 2020). This tool uses internal smartphone sensors to collect, display, record, and export.csv files. The Physics Toolbox Sensor Suite includes a g-force meter, linear accelerometer, gyroscope, barometer, proximater, thermometer, and magnetometer (Alexander, 2015). This application was preferred because it is free for users and the recorded data can be exported as a csv file. An Android-based smartphone was chosen because the iOS version of this application has limited capabilities compared to its Android counterpart (Vieyra Software, 2024). Measurements were made along the x and y axes using the inclinometer program of the Physics Toolbox Sensor Suite. Prior to each measurement, the device was calibrated on a flat surface.

Data analysis

Statistical Packages for the Social Sciences (SPSS) version 21.0 (Chicago, Illinois) was used for statistical analysis. The Kolmogorov-Smirnov test was applied to test the normality of the distribution of measured balance scores. The statistical significance level was determined as $p < 0.05$. For reliability, test-retest analysis intra-class correlation coefficient (ICC) were determined between the first- second and the first- third assessments (confidence interval (CI) was 95%). ICC values were interpreted as follows: >0.75, high reliability; 0.40 - 0.75, medium reliability; <0.40, poor reliability (Amick et al., 2015). Minimal Detectable Change (MDC), Standard Error of Measurement (SEM), and Coefficient of Variation for SEM (CV_{SEM}) were used because they provide important information in evaluating reliability when used together with the ICC. MDC refers to the smallest difference that is not due to measurement errors ($MDC = SEM \times 1.96 \times \sqrt{2}$). The SEM was used as an indicator of agreement between measurements (Beckerman et al., 2001; Weir, 2005; Ulupınar, 2022) ($SEM = \text{Standard Deviation} \times \sqrt{1-r}$). CV_{SEM}, which is used to calculate the coefficient of variation for the SEM value, was also evaluated ($CV_{SEM} = SEM / Mean \times 100$) (Amick et al., 2015; Ulupınar, 2022). Microsoft Excel Program (Microsoft Office Professional Plus 2013, Microsoft Corporation, Washington, USA.) was used to calculate the anterior-posterior stability index (APSI), medial-lateral stability index (MLSI), and overall stability index (OSI) scores (Figure 1) with the MDC, SEM, and CV_{SEM} values.

$$APSI = \sqrt{\frac{\Sigma(0-Y)^2}{\text{number of samples}}}$$

$$MLS = \sqrt{\frac{\Sigma(0-X)^2}{\text{number of samples}}}$$

$$OSI = \sqrt{\frac{\Sigma(0-X)^2 + \Sigma(0-Y)^2}{\text{number of samples}}}$$

Figure 1. Formulas of the anterior-posterior stability index (APSI), medial-lateral stability index (MLSI), and overall stability index (OSI).

Measuring procedure

A BOSU (Both Sides Utilized Balance Trainer) balance ball (USR BS581, 2022) with a diameter of 58 cm (centimeters) and height of 28 cm was used with an internal pressure of 1 psi (Pounds Per Square Inch). It was placed between parallel bars with its oval surface on the floor and its flat surface above. A Galaxy Note 10 Lite (Samsung, 2021, South Korea) mobile phone with the Physics Toolbox Suite mobile application was fixed to the upper flat surface of the stability ball using double-sided tape. The areas where participants stepped were marked with tape to ensure that they always stepped on the same area. Due to the unstable surface of the stability ball, measurements could only be performed on two legs. Participants were informed again about the test procedure. The participant was allowed to take a starting position on the balance platform, standing on two legs without shoes, with their arms slightly open at the sides (Figure 2). To eliminate the risk of participants falling, measurements were made between parallel bars, and a researcher supported the participant while walking on the balance ball. When the participant was ready for measurement, the measurement was started and recorded for 30 seconds. Data were recorded using the Physics Toolbox Suite mobile application. A practice session was held 1 week before the measurements to increase the participants' compliance and reduce the learning effect. Measurements were repeated 3 times with 1-week intervals, and data were recorded (Amick et al., 2015; Kuznetsov et al., 2018). In measuring an individual's balance objectively, by measuring the degree of inclination in the anterior-posterior and medial-lateral axes; MLSI, APSI, and OSI were calculated.

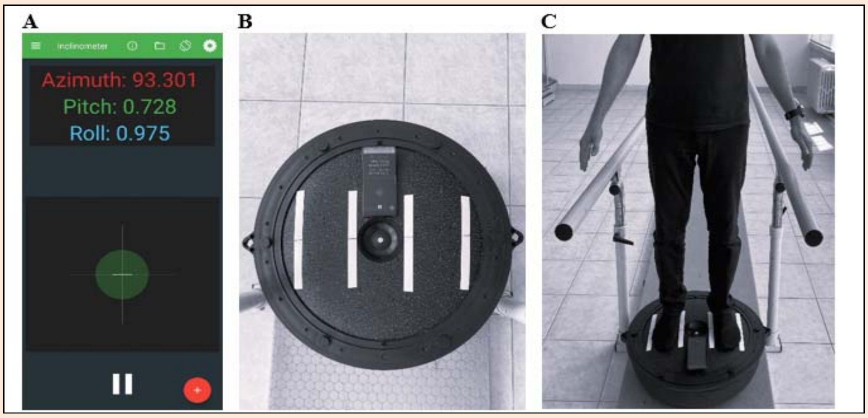

Figure 2. **Application interface and assessment procedure. A) Screenshot image of the Physics Toolbox Sensor Suite Mobile Application. B) Placement of the phone on the BOSU ball. C) Position of the participants on the BOSU ball.**

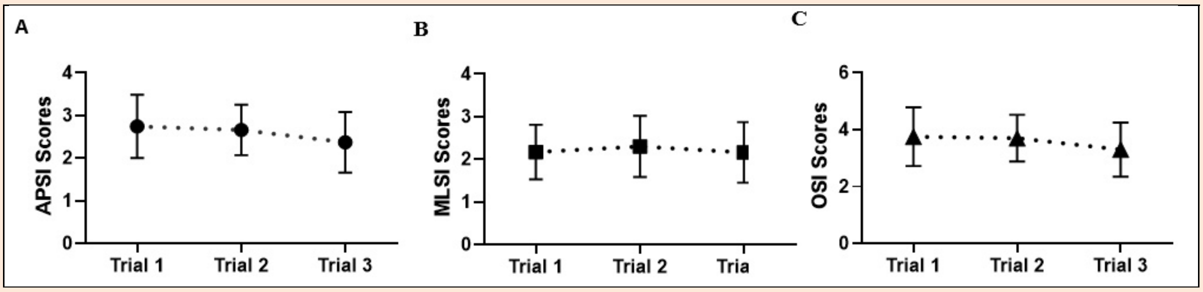

Figure 3. **Mean APSI, MLSI, OSI scores and Standard deviations. A) APSI= Anterior-posterior stability index. B) MLSI= Medial-lateral stability index. C) OSI = Overall stability index.**

Table 2. **Intra-rater and Inter-rater reliability scores.**

A. Intra-rater reliability of the Physics Toolbox Suite Mobile application			
	APSI (Trials 1-2)	**MLSI (Trials 1-2)**	**OSI (Trials 1-2)**
ICC	0,67	0,90	0,87
SEM	0,38	0,20	0,32
MDC	1,05	0,58	0,90
CV_{SEM}	14,08	9,34	8,79
B. Inter-rater reliability of the Physics Toolbox Suite Mobile application			
	APSI (Trials 1-3)	**MLSI (Trials 1-3)**	**OSI (Trials 1-3)**
ICC	0,73	0,71	0,73
SEM	0,37	0,36	0,50
MDC	1,03	1,0	1,40
CV_{SEM}	14,62	16,67	14,38

APSI = Anterior-posterior stability index, MLSI= Medial-lateral stability index, OSI= Overall stability index. ICC = Interclass correlation coefficients. MDC = Minimal Detectable Change. SEM = Standard Error of Measurement. CVSEM = Coefficient of Variation for SEM.

Table 1. **Subject demographic information**

Parameter	**Female (SD) n = 9**	**Male (SD) n = 13**	**All (SD) n = 22**
Age (years)	20.0 (1.2)	20.7 (1.0)	20.3 (1.1)
Weight (kg)	57.1 (14.4)	62.6 (11.4)	59.9(12.9)
Height (cm)	160,33 (5,09)	174 (4,52)	167,16 (8,44)
BMI (kg/m^2)	22,27 (5,89)	20,57 (3,04)	21,42 (4,63)

SD= Standard deviation; BMI= Body mass index

Results

Demographics

Demographic information about the 22 participants in the study is presented in Table 1. It was observed that all measured balance scores were distributed normally. Figure 3 illustrates the mean OSI, APSI, and MLSI scores from the three assessments conducted at one-week intervals.

The APSI score evaluations conducted using the Physics Toolbox Suite mobile application demonstrated good intra-rater and inter-rater reliability. For MLSI scores, high intra-rater reliability and good inter-rater reliability were observed. Similarly, OSI scores exhibited high intra-rater reliability and good inter-rater reliability. The smallest SEM value was recorded for MLSI intra-rater reliability (0.20), while the highest was found in OSI (0.50). Table 2 presents the intra-rater and inter-rater results for ICC, SEM, MDC, and CV_{SEM} values.

Discussion

This study demonstrated that the Physics Toolbox Suite mobile application is a reliable measurement tool for assessing the dynamic balance of healthy adults. The application showed good to high intra- and inter-rater reliability for APSI, MLSI, and OSI scores.

Assessment of balance can be an important part of the rehabilitation protocol for an athletic injury, such as knee or ankle (Arnold and Schmitz, 1998). Measurement of dynamic balance can be used to assess the risk of injury, determine the severity of injury and monitor progress in rehabilitation protocols (Mattacola et al., 1995). In assessing dynamic balance, measurement tools that are reliable, cost effective, and do not suffer the limitations of existing mobile applications are required. The reliability of the Physics Toolbox Suite mobile application, which is similar to the working mechanism and scoring system of the BBS system and does not include the shortcomings of existing mobile applications, was evaluated in this study.

Reliability indicates the degree of consistency between repetitions of a measurement or test (Weir, 2005; Ulupınar, 2022). The ICC is the most frequently preferred reliability indicator in research because it provides comprehensive information about the correlation of measurements (Hopkins, 2000; Ulupınar, 2022). For the first time in the literature, Pincivero (1995) conducted a dynamic balance reliability study with 20 university students on BBS. When OSI measurements were evaluated for the dominant and non-dominant legs at level 2 resistance (resistance levels 1: least stable, 8: most stable), both ICC scores were 0.60 (Pincivero, 1995). Following Pincivero (1995), Schmitz and Arnold (1998) evaluated the reliability of dynamic balance measurement with BBS using 30 seconds measurements with 19 people on dominant leg. They reported an inter-rater ICC value for OSI of 0.43 and 0.80 for intra-rater. In the study conducted with the Physics Toolbox, the OSI score ICC values were 0.73 for inter-rater and 0.87 for intra-rater. Although the platform used in this study moved in all directions without resistance restrictions, the ICC values were higher than those in the other two studies. The reason for this difference may be that the measurements made with the Physics Toolbox were made on two legs instead of a single leg due to the platform's very mobile nature. The OSI score values show high intra-rater and good inter-rater reliability, indicating that the Physics Toolbox application is reliable in OSI evaluation.

The APSI score provides detailed information for evaluating anterior and posterior changes in dynamic balance. Reliability measurements for APSI scores performed using the Physics Toolbox application showed good intra-rater (ICC(3,1) = 0.67) and inter-rater (ICC(3,1) = 0.73) reliability. In their evaluation with BBS, Schmitz and Arnold reported an APSI score of 0.68 for inter-rater and 0.80 for intra-rater (Schmitz and Arnold, 1998). The different testing protocols may explain the partially different reliability values. According to these results, it seems that the Physics Toolbox application is a reliable method for evaluating anterior-posterior dynamic balance.

Another component of dynamic balance evaluation is medial-lateral assessment. Schmitz and Arnold, in their reliability evaluation of MLSI scores on the dominant leg, reported an inter-rater ICC of 0.42 and an intra-rater ICC of 0.40 (Schmitz and Arnold, 1998). Even if the measurement was made on the dominant leg, measurement on the other leg may have caused the ICC to be reported as low. In the evaluation conducted using the Physics Toolbox, high intra-rater reliability (ICC(3,1) = 0.90) and good inter-measurer reliability (ICC(3,1) = 0.71) were found in MLSI scores. The possible reason why MLSI scores show higher reliability than APSI scores is that the ankle is more anatomically stable in the medial and lateral aspects and has a lower joint range of motion.

Although many studies have evaluated static balance with mobile applications, dynamic balance evaluation has been examined in a limited number of studies. In one important application study evaluating static balance, high reliability was reported for the Gait & Balance application for postural stability in the anterior-posterior axis (ICC(0.78)) and for the medial-lateral axis (ICC(0.84)) (Rashid et al., 2021). In the static balance assessment performed using the FDA approved Sway application, good reliability was reported in intersession (0.6 - 0.76) and intrasession (0.47 - 0.78) measurements (Amick et al., 2015). When considering the few studies that evaluated dynamic balance, Kuznetsov et al. evaluated the dynamic balance of participants on one leg and reported the ICC reliability value of the AccWalker smartphone application as 0.59 (Kuznetsov et al., 2018). In the study using the AccWalker application, the phone was fixed to the thigh during the measurement. In measurements performed with Sway, the phone was fixed on the body, similar to the AccWalker study (Amick et al., 2015; Eldesoky et al., 2017). High reliability values cannot be achieved in reliability studies on smartphone applications because of the negative impact of placing the phones on the body. However, it has been shown that there is no significant difference between smartphone applications and classical and reliable systems such as the BSS in dynamic balance measurement (Eldesoky et al., 2017). In their study, Eldesoky et al. (2017) evaluated the dynamic balance (at level 8) using the Sway application and the Biodex balance system simultaneously. They reported that there was no significant difference between Sway and BBS OSI scores in the measurement of dynamic balance (Eldesoky et al., 2017). Unlike previous mobile applications, in this study, which was carried out with the Physics Toolbox application, the phone was not placed on the body, and measurements were carried out by fixing it on a platform similar to the BBS platform. Fixing the phone on the platform may reduce measurement errors caused by the patient and may contribute to the higher reliability of this study compared with previous studies.

Although ICC provides detailed information about the correlation of measurements, it is recommended to support it with calculations such as SEM, MDC and CV_{SEM}, because of ICC results are affected by the number and homogeneity of subjects.

The SEM value provides important information about the number of possible measurement errors, and it is stated that evaluations with lower SEM values are more reliable (Chiu et al., 2016; Ulupınar, 2022). Schmitz and Arnold reported interrater SEM values between 0.65 and 0.90 and interrater values of 0.61 and 0.71 in their dynamic balance measurements on one leg using BBS (Schmitz and Arnold, 1998). In a similar study conducted with BBS, Akhbari et al. (2015) found inter-session SEM values in the range of 3 - 5. Parraca et al. (2011), who evaluated the dynamic balance of physically active individuals, calculated the SEM value for the OSI score as 0.19. The difference between these results in the literature may be explained by using different difficulty levels in dynamic balance measurements with BBS. In their study using the Sway application, which is considered reliable, Amick et al. (2015) reported SEM values between 0.47 and 0.76 and CV% values as 5.95% - 10.47%. In the dynamic balance evaluation performed using the Physics Toolbox application, intra-rater SEM values were found to be in the range of 0.20- 0.38 and inter-rater values were found to be 0.36 - 0.50. CV_{SEM}, which shows the ratio of the possible error amount to the average was evaluated and was found to be between 8.79% and 16.67%. According to these SEM results, the sensitivity of measurements obtained using the Physics Toolbox application was considered to be good.

The smallest difference indicating the change between measurements that was not caused by measurement errors was calculated using MDC (Wilkerson and Nitz, 1994; Chiu et al., 2016). In the dynamic balance measurement by Akhbari et al. (2015) using BBS, MDC values were determined between 0.1 and 0.8. When the dynamic balance measurement was performed using the Sway application, which uses a scoring system different from the BBS system, MDC values were reported to be between 14.95 and 20.96 (Amick et al., 2015). In the evaluation performed with the Physics Toolbox application using the BBS scoring system, MDC values were found to be in the range of 0.58 - 1.40. As expected in the evaluations conducted using the Physics Toolbox, the intra-rater MDC values were measured at a better level than the inter-rater values. The reason that the evaluation made with the Physics Toolbox application found results that were partially higher than those made with BBS may be due to Akhbari et al. (2015) using a medium level of stability difficulty level in their evaluation.

As a limitation of this study, measurements could only be made on two legs instead of one leg due to the placement of the mobile phone on a very mobile platform. Another limitation of the study is that only healthy young adult participants were included, and no reliability evaluation was performed for individuals with balance impairment. Future development and balance testing is needed to optimize the design of the app for use in patients with balance disorders and other comorbidities (eg, diabetes mellitus, neurologic disease).

The findings of this study indicate that the Physics Toolbox Suite mobile application is a reliable and accessible tool for assessing dynamic balance in healthy adults, exhibiting high intra- and inter-rater reliability. This application offers a practical solution by addressing the limitations of existing mobile applications and providing an affordable, accessible alternative to costly and complex systems such as BBS.

Conclusion

The Physics Toolbox Suite mobile application demonstrated good to high intra- and inter-rater reliability for APSI, MLSI, and OSI scores in measuring dynamic balance in healthy adults. This mobile application can provide a reliable, cost-effective, and accessible measurement opportunity for healthcare professionals and athletes in dynamic balance measurements by obtaining objective data, shortening measurement times, and minimizing the number of measurement equipment. Comparing the Physics Toolbox Suite mobile application with other dynamic balance measurement devices used in clinical settings and evaluating its reliability in different rehabilitation groups may contribute to the literature.

Acknowledgments

The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The datasets generated during and/or analyzed during the current study are not publicly available but are available from the corresponding author who organized the study.

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Key points

- Dynamic balance assessment is a commonly used in injury prevention and sports rehabilitation.
- Mobile applications are used as an alternative to costly systems in dynamic balance assessment, but there is a need for applications that provide more objective and reliable measurements.
- The Physics Toolbox Suite mobile application is a reliable measurement method for assessing dynamic balance.

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