Reliability and minimal detectable change of smartphone accelerometry for single-leg stability assessment in young adults

Fiabilidad y cambio mínimo detectable de la acelerometría de smartphone para la evaluación de la estabilidad unipodal en adultos jóvenes

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Abstract

Introduction: Limited research exists on smartphone accelerometry for assessing single-leg standing balance during dual-task activities. This gap necessitates establishing reliability and minimal detectable change (MDC) benchmarks.

Objective: This study aims to investigate the test–retest reliability and MDC of smartphone-based accelerometry during single-leg standing under various neck postures and surface conditions.

Methodology: Thirty healthy young adults (18–25 years) performed single-leg standing tests while texting. Center of Mass (CoM) acceleration was recorded using an iPhone 11 at the sacral level (S2) across four conditions. Measurements were repeated after a 7-day interval to calculate Intraclass Correlation Coefficients (ICC$_{3,1}$) and MDC at 95% confidence (MDC$_{95}$).

Results: The device demonstrated good-to-excellent reliability across all conditions. The highest reliability was observed in the neutral neck/hard surface condition (ICC$_{3,1}$ = 0.91–0.94), with low measurement error (MDC$_{95}$ = 1.23–2.70 cm/s^2). Conversely, the flexed neck/soft surface condition showed slightly lower reliability (ICC$_{3,1}$ = 0.87–0.90) and higher variability, requiring larger changes for significance (MDC$_{95}$ = 2.94–9.58 cm/s^2). Specifically, MDC$_{95}$ for Total Acceleration increased from 2.71 cm/s^2 in stable conditions to 9.90 cm/s^2 in unstable conditions.

Conclusion: Smartphone accelerometry is a reliable tool for evaluating postural stability in young adults. The established MDC values provide critical references, highlighting that challenging tasks (e.g., soft surfaces) require larger threshold values to detect real clinical changes in balance performance.

Keywords

Smartphone-based; accelerometry; postural stability; balance; reliability; minimal detectable change.

Resumen

Introducción: Existe una investigación limitada sobre la acelerometría basada en teléfonos inteligentes (smartphone-based accelerometry) para evaluar la estabilidad postural unipodal durante actividades de doble tarea. Esta brecha hace necesario establecer la fiabilidad y el cambio mínimo detectable (MDC).

Objetivo: Este estudio investigó la fiabilidad test-retest y el MDC de la acelerometría por smartphone durante la bipedestación unipodal bajo diversas posturas del cuello y condiciones de superficie.

Metodología: Treinta adultos jóvenes sanos (18–25 años) realizaron pruebas de bipedestación unipodal mientras enviaban mensajes de texto. La aceleración del centro de masa (CoM) se registró utilizando un iPhone 11 a nivel del sacro (S2) en cuatro condiciones. Las mediciones se repitieron tras un intervalo de 7 días para calcular los coeficientes de correlación intraclase (ICC$_{3,1}$) y el MDC con un 95% de confianza (MDC$_{95}$).

Resultados: El dispositivo demostró una fiabilidad de buena a excelente en todas las condiciones. La mayor fiabilidad se observó en la condición de cuello neutro/superficie dura (ICC$_{3,1}$ = 0.91–0.94), con un error de medición bajo (MDC$_{95}$ = 1.23–2.70 cm/s^2). Por el contrario, la condición de cuello flexionado/superficie blanda mostró una fiabilidad ligeramente menor (ICC$_{3,1}$ = 0.87–0.90) y una mayor variabilidad, requiriendo cambios mayores para la significancia (MDC$_{95}$ = 2.94–9.58 cm/s^2). Específicamente, el MDC$_{95}$ para la Aceleración Total aumentó de 2.71 cm/s^2 en condiciones estables a 9.90 cm/s^2 en condiciones inestables.

Conclusión: La acelerometría por smartphone es una herramienta fiable para evaluar la estabilidad postural en adultos jóvenes. Los valores de MDC establecidos proporcionan referencias críticas, destacando que las tareas desafiantes (por ejemplo, superficies blandas) requieren valores umbral más grandes para detectar cambios clínicos reales en el rendimiento del equilibrio.

Palabras clave

Basado en smartphone; acelerometría; estabilidad postural; equilibrio; fiabilidad; cambio mínimo detectable.

Introduction

Postural stability is a fundamental component of overall health and physical well-being in healthy young adults (Onofrei & Amaricai, 2022). Although this population is generally considered to have robust balance control, maintaining optimal stability is a complex motor skill that relies on the precise integration of sensory information from the visual, vestibular, and somatosensory systems. This physiological mechanism is influenced by multiple intrinsic and extrinsic factors, including physical activity levels (Onofrei & Amaricai, 2022), the integrity of sensory systems (Onofrei & Amaricai, 2022), and individual lifestyle behaviors. However, recent epidemiological trends suggest that the stability of young adults is increasingly compromised. Sedentary lifestyles, characterized by reduced physical activity, have been identified as a significant factor contributing to diminished balance capabilities (Angyán et al., 2007). Furthermore, the ubiquity of mobile technology has introduced a novel environmental constraint: the dual-task condition of using a smartphone while standing or walking (Lanzarin et al., 2015; Onofrei et al., 2020).

The interaction between smartphone use and postural control is of particular concern. Engaging in dual-task activities, such as texting, demands divided attention and significant cognitive resources, which can interfere with the automaticity of postural control (Nurwulan et al., 2015). This cognitive-motor interference often results in performance decrements in both tasks—slower gait speed, increased sway, or reduced texting accuracy. The literature emphasizes that such disruptions in postural stability are not merely trivial inconveniences; they are precursors to a higher risk of losing balance (Mohd Safee & Abu Osman, 2023). Consequently, maintaining optimal postural stability is vital not only for athletic performance but also for preventing injuries and accidents in daily life activities (Gandawidura & Ikeda, 2024; Van Humbeeck et al., 2023).

Given these emerging risks, the clinical evaluation of posture under challenging, ecologically valid conditions is essential. The single-leg standing test is a widely recognized and standardized measure of postural stability (Beelen et al., 2021). Biomechanically, this test imposes significantly greater demands on the musculoskeletal and nervous systems compared to quiet bipedal standing (Ameer et al., 2024; Tivadar & Kotnik, 2024). By reducing the base of support to a single foot, the body must generate rapid and precise muscular adjustments around the ankle and hip joints to maintain the center of mass (CoM) within the stability limits. This task becomes exponentially more challenging when combined with smartphone use. Texting typically induces a flexed neck posture, which alters the head's position relative to gravity. This biomechanical shift changes the body's mass distribution and can disrupt vestibular inputs, thereby challenging the central nervous system's ability to maintain equilibrium (Ezzat et al., 2025). Incorporating these neck position changes and dual-task constraints into balance assessments simulates real-world conditions, revealing potential deficits in postural stability that standard tests might miss. Understanding these specific deficits is crucial for developing targeted interventions to enhance balance and prevent musculoskeletal injuries among habitual smartphone users.

To objectively assess these postural dynamics, various methodological approaches are available (Panjan & Sarabon, 2010). Traditional laboratory-grade methods, such as the Star Excursion Balance Test (SEBT) (Gribble et al., 2012) and force plate analysis (Quijoux et al., 2021), are often considered the gold standard. Force plates, in particular, provide precise quantitative data on the displacement of the center of pressure (CoP). However, these instruments are expensive, non-portable, and restricted to laboratory settings, limiting their utility in large-scale screenings or field-based clinical practice. In response to these limitations, accelerometer-based assessments have emerged as a reliable, objective, and non-invasive alternative (Alqahtani et al., 2020). Tri-axial accelerometers placed near the body's CoM (e.g., at the sacrum) can accurately measure trunk sway and effectively differentiate between static orientations and dynamic motions (Yoong et al., 2019), offering a promising approach for evaluating postural stability in diverse settings (Boubaker et al., 2025; Neville et al., 2015).

Currently, the integration of micro-electromechanical systems (MEMS) into smartphones has democratized access to this technology. Smartphone-based accelerometry has been demonstrated to be a useful and valid tool for assessing balance (Onofrei et al., 2020). Recent studies suggest that specific applications, such as the Gait&Balance (G&B) App, can accurately measure gait and balance parameters in young adults (Olsen et al., 2023). Furthermore, the smartphone has been validated to measure postural stability and differentiate fall risk in older adults, demonstrating its versatility across different age groups (Pinho et al., 2019). These findings emphasize the convenience, cost-effectiveness, and scalability of smartphone-based accelerometry for assessing balance in both clinical and community settings.

Nevertheless, despite the growing popularity of this technology, a significant gap remains in the literature. The utilization of smartphone-based accelerometry for assessing postural stability specifically during a *single-leg standing test* combined with *dual-task texting* and *varied surface conditions* (e.g., foam vs. hard surface) is underexplored. Most importantly, for any measurement tool to be clinically useful, its psychometric properties must be established. Consequently, there is a paucity of research investigating the between-day reliability and the Minimal Detectable Change (MDC) associated with this specific measurement protocol. The MDC is a critical statistical parameter that defines the smallest amount of change in a score that reflects a true difference in performance, rather than measurement error. Without established MDC values, clinicians and researchers cannot confidently interpret whether changes in balance performance following an intervention are genuine or merely artifacts of biological variability or instrument noise.

Therefore, exploring the potential of smartphone-based accelerometry as a robust alternative method for assessing postural stability under these complex conditions is both intriguing and necessary. This study aims to investigate the test-retest reliability and minimal detectable change of smartphone-based accelerometry measurements during the assessment of single-leg standing balance under various neck postures and surface conditions while performing diverse tasks. By establishing these normative reliability metrics, this research seeks to validate a portable, accessible protocol that can improve how postural stability is monitored in the modern, technology-driven era.

Method

Study Design

This cross-sectional study with a repeated measures design to evaluate test-retest reliability. The study was approved by the Human Research Ethics Committee of the University of Phayao, Thailand (Approval Code No.: HREC-UP-HSST 1.2/112/68) and was conducted in accordance with the ethical principles of the Declaration of Helsinki. This investigation employed a repeated measures concordance design to evaluate the test–retest reliability of accelerometry measurements conducted via smartphones during the assessment of single standing balance under diverse conditions. The performance of participants was assessed on two separate days, introducing a seven-day interval between the initial measurement and the subsequent one (Hilden et al., 2023). This deliberate temporal gap was implemented to mitigate the potential influence of overlap and learning effects between the two tests, ensuring a robust evaluation of the reliability of smartphone-based accelerometry measurements. The assessments were carried out in diverse conditions and while individuals engaged in various tasks, including utilizing a smartphone in a flexed neck position on both hard and soft surfaces (FN/HS and FN/SS), as well as using a smartphone in a neutral neck position on similar surfaces (NN/HS and NN/SS) among healthy early adults. Data collection took place in the Physical Therapy Laboratory, Faculty of Allied Health Sciences, University of Phayao, Thailand. Prior to the initiation of the study, informed consent was obtained from all participants who voluntarily engaged in this investigation, aligning with the ethical considerations of the Declaration of Helsinki.

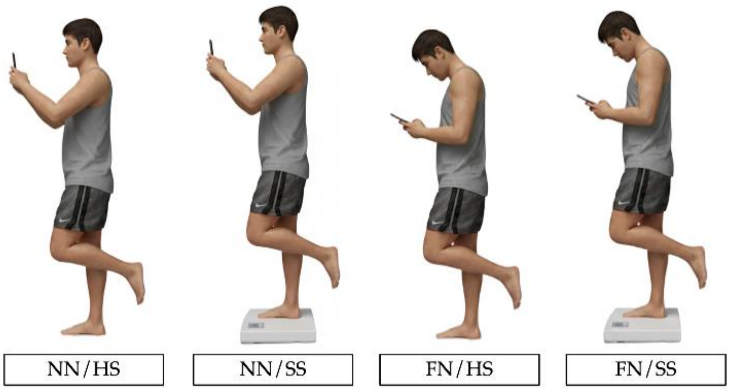
Participants

To determine the required sample size for our study, we have provided the specific parameters used in our G*Power calculation to justify the sample size (Minimum acceptable ICC = 0.60, Expected ICC = 0.85, $\alpha = 0.05$, and Power $\beta = 0.90$) (Sevillano-Castaño et al., 2023), confirming that N=30 provides sufficient statistical power. The study employed a non-probabilistic convenience sampling approach to recruit a sample of healthy young adults who were regular users of smartphones. All participants willingly consented to take part in the research and were required to possess the ability to comprehend and complete the assessments. A cohort comprising thirty healthy young adults, with an even distribution of genders and ages ranging from 18 to 25 years, was assembled through promotional activities at the University of Phayao, Thailand. These individuals, all right-handed, boasted a minimum of one year of smartphone usage experience, typically engaging with their devices for at least four hours daily. Notably, none of the participants reported any recent history of trauma or musculoskeletal symptoms in the neck and upper extremities within the past week. Moreover, participants affirmed the absence of neurological or musculoskeletal issues and attested to not having undergone any balance-specific training in the preceding six months. Additionally, it was established that the right leg served as the dominant limb for all participants, as determined by their preferred leg for kicking a ball (Tapanya et al., 2023), aligning with their dominant hand (i.e., the writing hand).

Procedure

Prior to engaging in the study, all participants furnished written consent. A random allocation procedure was employed before the experiment's initiation, assigning each participant to one of four distinctive conditions. The allocation process utilized straightforward randomization techniques to counteract potential systematic biases originating from the sequence of the experimental conditions (Suresh, 2011). All participants underwent all four conditions in a single day, followed by retesting over seven separate days. Tailored to individual smartphone usage patterns, participants' postures, shoulder angles, smartphone height, and distance were adjusted excluding neck angle, which was modified in both flexed and neutral neck postures (Tapanya et al., 2021). In the neutral neck condition, the researcher (WT) precisely adjusted the cervical posture to uphold a 0° neck flexion angle using a goniometer, aligning the shoulder angle accordingly. Conversely, in the flexed neck condition, the researcher (WT) modified the cervical posture to maintain a 45° neck flexion angle with the goniometer, simultaneously adjusting the shoulder angle, as depicted in Fig. 1. Participants were allotted three minutes for acclimatization to the measurement process, adopting a method adapted from Xie et al. (2016) (Xie et al., 2016). During each test condition, participants were instructed to execute a single-leg standing test on their dominant leg while concurrently texting the English alphabet (A-Z) on their smartphone screen using both thumbs. Both hands securely held the device throughout the test. Each session endured for 1 minute, with a two-minute rest interval separating the two trial sessions. The single-leg standing test began with participants initially positioned with both feet on the ground. Following that, the researcher directed participants to transfer their weight to their dominant leg while maintaining possession of the smartphone with both hands, and the non-dominant knee flexed at a 90-degree angle (Tapanya et al., 2023). For single-leg standing test on soft surface condition, the AIREX® balance - pad foam (Legal Notice, Airex AG, Inc.), with dimensions of 0.50 x 0.41 mater was used.

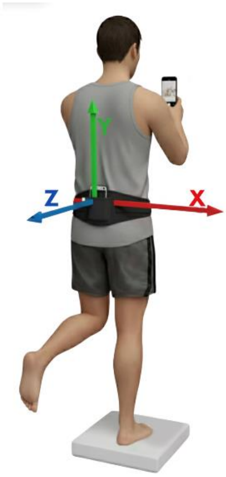
Figure 1. Smartphone texting task while single leg standing in difference conditions



Smartphone-Based Accelerometry

Acceleration measurements in three directions were acquired using an Apple iPhone 11. The Physics Toolbox Sensor Suite app (version 2022.09.11) on the Apple iOS platform was employed to gather and export acceleration data, sampled at a rate of 200 Hz from the smartphone's accelerometer. Placed vertically on the sacral region (S2) near the body's Center of Mass (CoM), the smartphone was secured in a waist-mounted pouch (Hou et al., 2018) as shown in Fig. 2. Raw acceleration signals underwent Fourier analysis using MATLAB™ (MathWorks Inc., Natick, MA,USA), revealing a frequency range of 15 to 20 Hz (Borzì et al., 2020). Subsequently, a 20 Hz low-pass Butterworth filter was applied to refine the acceleration signals within this frequency range (Borzì et al., 2020). For the examination of acceleration-based variables, the middle 30 seconds of individual acceleration signals, including anteroposterior (AP), mediolateral (ML), and vertical (VT) accelerations, were chosen to eliminate any movements associated with adjusting to the test condition.

Figure 2. Acceleration measurements with smartphone positioned at S2 vertically for body CoM tracking



Data analysis

The SPSS statistical software (Statistical Package for Social Sciences 28, SPSS Inc., Chicago, IL USA) was employed for the statistical analysis, and the results were expressed in terms of mean, standard deviation, and a 95% confidence interval. A Shapiro–Wilk test was used to test the normal distribution of the considered variables prior to the analysis. All of testing variables had a normal distribution. To assess the test-retest (between day) reliability of smartphone-based accelerometry measurements during the evaluation of single standing balance under various conditions with a 7-day interval, the $ICC_{3,1}$ was utilized. Reliability levels were categorized as excellent (ICC ≥ 0.90), good (0.90 > ICC ≥ 0.70), fair (0.70 > ICC ≥ 0.40), and poor (ICC < 0.40) based on predefined benchmarks (Landis & Koch, 1977). The precision of reliability outcomes was gauged using the Standard Error of Measurement (SEM), calculated using the formula $(SD \times \sqrt{[1 - ICC]})$. Additionally, the Minimum Detectable Change (MDC) was determined as $SEM \times \sqrt{2} \times 1.96$ for a 95% confidence level and $SEM \times \sqrt{2} \times 1.65$ for a 90% confidence level. Furthermore, the agreement between measurements was assessed using Bland-Altman graphs. All statistical tests were interpreted with a significance level set at 5% ($p < 0.05$)

Results

A total of 30 participants (15 men and 15 women) completed the study without reporting any adverse effects. Detailed demographic and anthropometric data, including age, weight, height, BMI, years of smartphone use, and daily usage duration, are provided in Table 1.

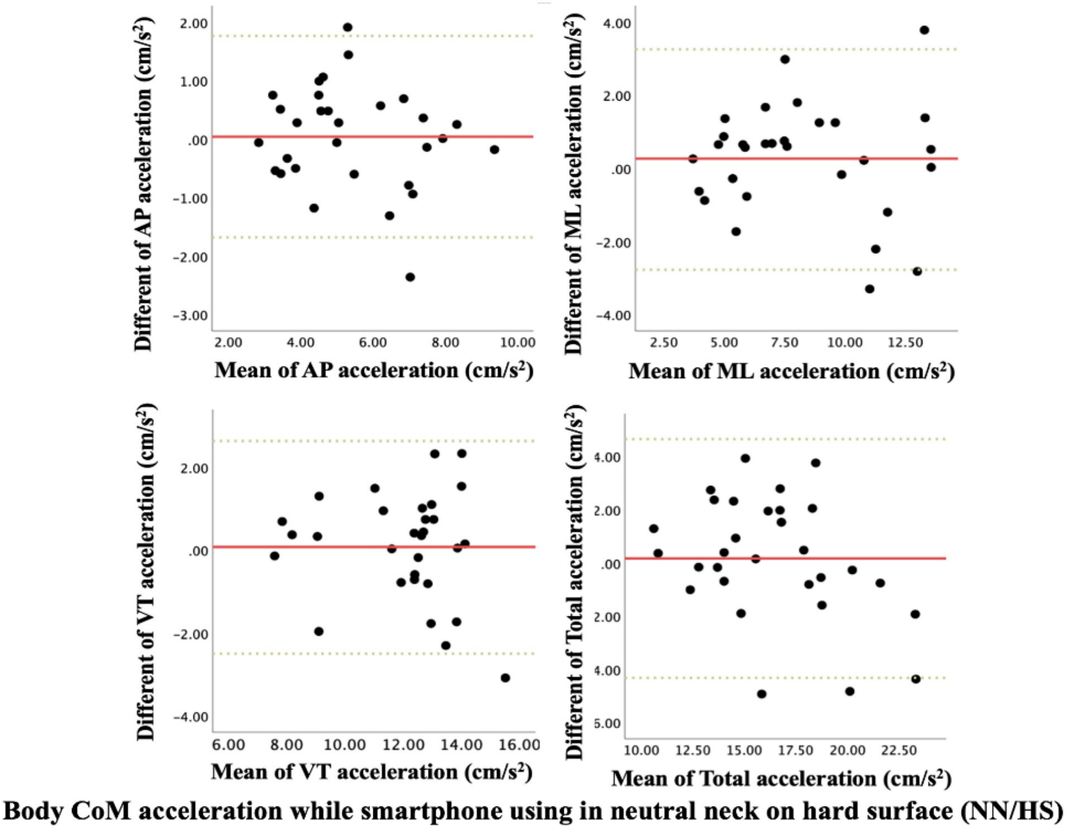
Table 1. Subject demographic data and anthropometric characteristics variables ($n = 30$).

Variables (n=30)	Mean±SD
Gender, (males/females)	15/15
Age (years)	20.91 ± 1.66
Body weight (kg)	59.02 ± 9.38
Height (cm)	172.92 ± 11.11
Body mass index; BMI (kg/m^2)	19.67 ± 1.93
Total experience time of smartphone use (years)	7.34 ± 1.50
Daily duration of smartphone use (hours)	6.04 ± 1.19

Test-Retest Reliability

No statistically significant differences were found in the acceleration variables related to the body CoM between the initial and seventh days of assessment in all circumstances and directions ($p > 0.05$). The evaluation of body CoM acceleration under conditions involving a smartphone in a neutral neck position on a hard surface (NN/HS) showcased excellent test–retest reliability ($ICC_{3,1} = 0.91$ to 0.94), accompanied by a small SEM ranging from 0.44 to 0.98 cm/s^2. Transitioning to a soft surface (NN/SS) yielded slightly diminished reliability, still considered good ($ICC_{3,1} = 0.89$ to 0.91), with SEM values ranging from 0.87 to 3.57 cm/s^2. Similarly, in flexed neck positions on both hard (FN/HS) and soft surfaces (FN/SS), a consistent trend emerged. FN/HS exhibited excellent reliability ($ICC_{3,1} = 0.91$ to 0.92) with SEM between 0.50 to 1.59 cm/s^2, while FN/SS demonstrated good reliability ($ICC_{3,1} = 0.87$ to 0.90) with SEM ranging from 1.06 to 3.45 cm/s^2 as present in table 2. The Bland–Altman plots graph presented in the study illuminate distinct patterns of discrepancies in acceleration across all conditions and directions were shown in Fig. 3.

Figure 3A. Bland-Altman plot Test-Retest Reliability of Smartphone-Based Accelerometry Measurements in each testing condition and direction. Abbreviations: AP, anteroposterior; ML, mediolateral; VT, vertical; Come, center of mass; NN/HS, neutral neck posture on hard surface; NN/SS, neutral neck posture on soft surface; FN/HS, flexed neck posture on hard surface; FN/SS, flexed neck posture on soft surface.



Body CoM acceleration while smartphone using in neutral neck on hard surface (NN/HS)

Figure 3B. Bland-Altman plot Test-Retest Reliability of Smartphone-Based Accelerometry Measurements in each testing condition and direction. Abbreviations: AP, anteroposterior; ML, mediolateral; VT, vertical; Come, center of mass; NN/HS, neutral neck posture on hard surface; NN/SS, neutral neck posture on soft surface; FN/HS, flexed neck posture on hard surface; FN/SS, flexed neck posture on soft surface.

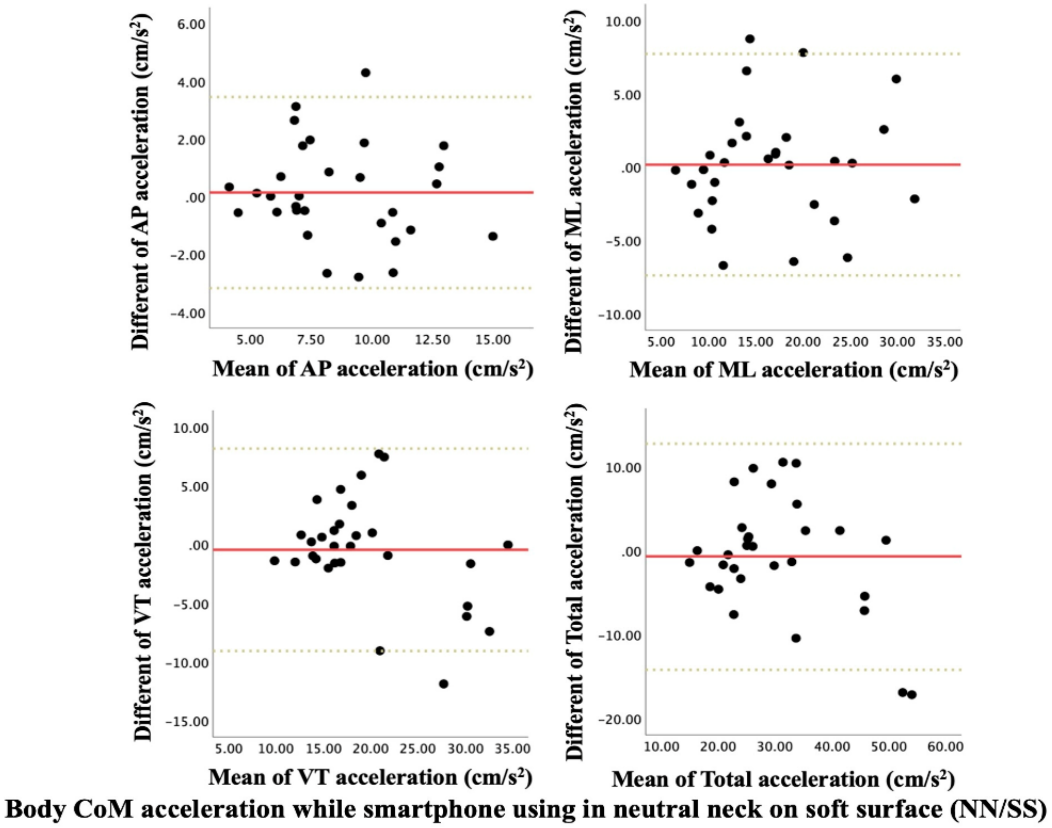


Figure 3C. Bland-Altman plot Test-Retest Reliability of Smartphone-Based Accelerometry Measurements in each testing condition and direction. Abbreviations: AP, anteroposterior; ML, mediolateral; VT, vertical; Come, center of mass; NN/HS, neutral neck posture on hard surface; NN/SS, neutral neck posture on soft surface; FN/HS, flexed neck posture on hard surface; FN/SS, flexed neck posture on soft surface.

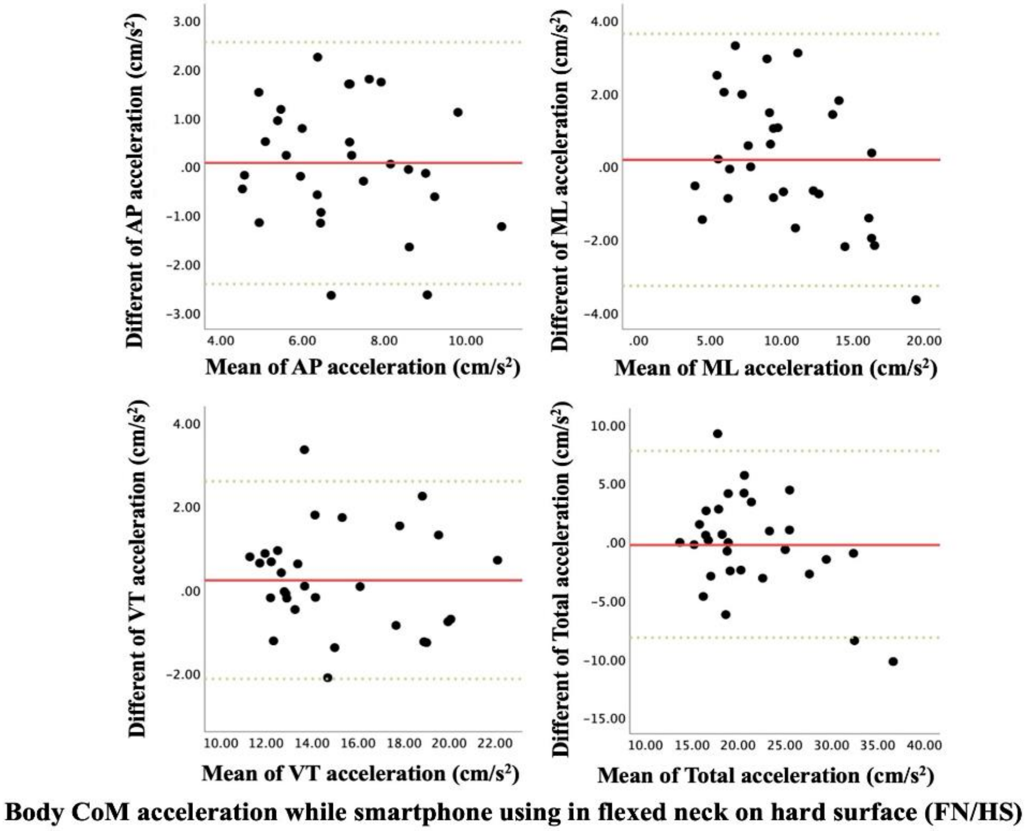


Figure 3D. Bland-Altman plot Test-Retest Reliability of Smartphone-Based Accelerometry Measurements in each testing condition and direction. Abbreviations: AP, anteroposterior; ML, mediolateral; VT, vertical; Come, center of mass; NN/HS, neutral neck posture on hard surface; NN/SS, neutral neck posture on soft surface; FN/HS, flexed neck posture on hard surface; FN/SS, flexed neck posture on soft surface.

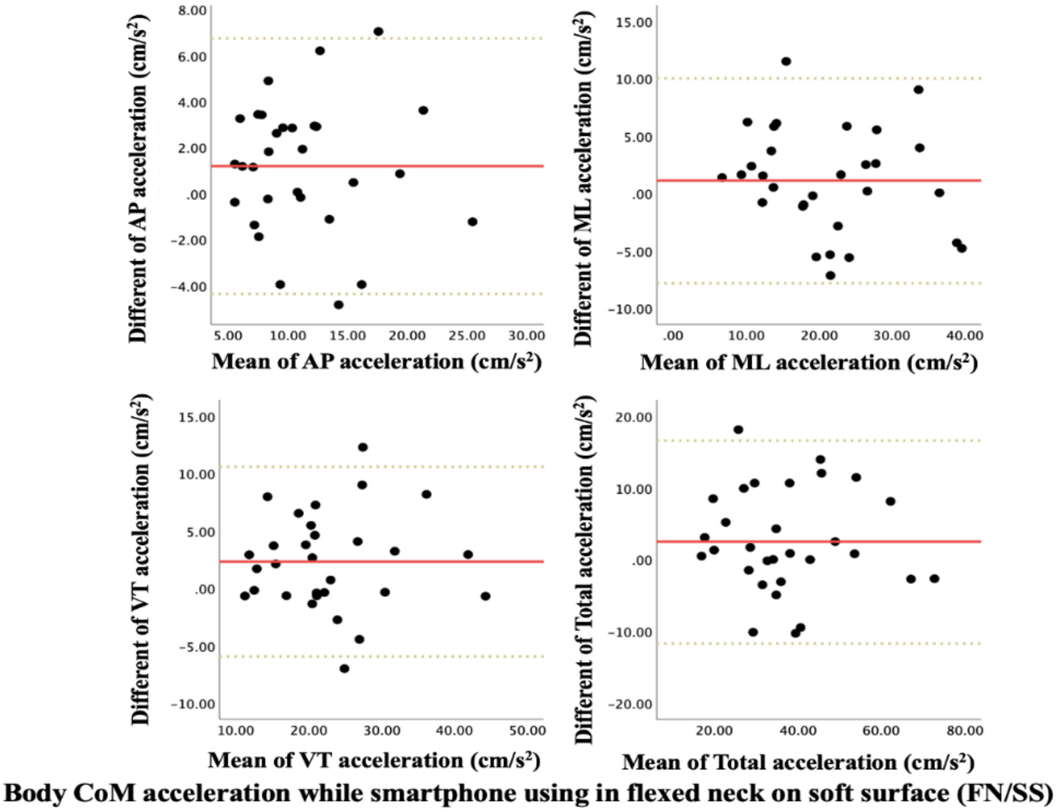


Table 2. Test – retest reliability of body CoM acceleration while smartphone using in each direction and tesks (n = 30).

Variables	Day 1	Day 2	Paired differences		Test – retest reliability			
			Mean differences	p-value (95% CI)	ICC$_{3,1}$	SEM	MDC$_{90}$	MDC$_{95}$
Body CoM acceleration while smartphone using in neutral neck on hard surface (NN/HS)								
AP acceleration (cm/s^2)	5.44 ± 1.71	5.40 ± 1.86	0.04 ± 0.88	0.807 (-0.29 to 0.37)	0.938** (0.87 to 0.97)	0.444	1.037	1.232
ML acceleration (cm/s^2)	8.34 ± 3.25	8.07 ± 3.35	0.26 ± 1.53	0.353 (-0.31 to 0.84)	0.943** (0.88 to 0.97)	0.788	1.838	2.184
VT acceleration (cm/s^2)	12.06 ± 2.00	11.81 ± 1.95	0.24 ± 0.92	0.160 (-0.10 to 0.59)	0.940** (0.88 to 0.97)	0.484	1.129	1.341
Total acceleration (cm/s^2)	16.59 ± 3.03	16.12 ± 3.71	0.47± 1.86	0.177 (-0.22 to 1.16)	0.916** (0.83 to 0.96)	0.977	2.279	2.707
Body CoM acceleration while smartphone using in neutral neck on soft surface (NN/SS)								
AP acceleration (cm/s^2)	8.70 ± 2.75	8.57 ± 2.94	0.14 ± 1.69	0.655 (-0.49 to 0.77)	0.906** (0.80 to 0.96)	0.872	2.035	2.418
ML acceleration (cm/s^2)	16.60 ± 6.98	16.44 ± 6.60	0.16 ± 3.85	0.819 (-1.28 to 1.60)	0.915** (0.82 to 0.96)	1.980	4.619	5.487
VT acceleration (cm/s^2)	19.11 ± 5.91	19.33 ± 6.78	-0.21 ± 3.65	0.749 (-1.58 to 1.15)	0.913** (0.82 to 0.96)	1.872	4.367	5.188
Total acceleration (cm/s^2)	29.84 ± 9.89	30.52 ± 12.37	-0.68 ± 6.90	0.593 (-3.26 to 1.90)	0.897** (0.79 to 0.95)	3.572	8.335	9.901
Body CoM acceleration while smartphone using in flexed neck on hard surface (FN/HS)								
AP acceleration (cm/s^2)	6.99 ± 1.68	7.00 ± 1.82	-0.01 ± 0.98	0.956 (-0.38 to 0.36)	0.918** (0.83 to 0.96)	0.501	1.169	1.389
ML acceleration (cm/s^2)	10.91 ± 3.14	10.41 ± 3.76	0.50 ± 1.77	0.135 (-0.16 to 1.16)	0.927** (0.85 to 0.97)	0.932	2.175	2.584
VT acceleration (cm/s^2)	15.39 ± 2.39	15.10 ± 3.04	0.29 ± 1.57	0.324 (-0.30 to 0.87)	0.910** (0.81 to 0.96)	0.815	1.901	2.258
Total acceleration (cm/s^2)	21.22 ± 5.16	21.47 ± 5.81	-0.25 ± 3.10	0.658 (-1.41 to 0.91)	0.916** (0.82 to 0.96)	1.590	3.709	4.406
Body CoM acceleration while smartphone using in flexed neck on hard surface (FN/SS)								

AP acceleration (cm/s^2)	11.31 ± 2.95	11.28 ± 2.91	0.04 ± 2.02	0.910 (-0.71 to 0.80)	0.869** (0.72 to 0.94)	1.060	2.475	2.940
ML acceleration (cm/s^2)	21.91 ± 8.93	21.78 ± 10.92	0.12 ± 5.98	0.913 (-2.11 to 2.36)	0.904** (0.80 to 0.95)	3.075	7.176	8.524
VT acceleration (cm/s^2)	25.35 ± 9.82	24.25 ± 9.18	1.10 ± 5.55	0.286 (-0.97 to 3.17)	0.906** (0.81 to 0.96)	2.913	6.797	8.073
Total acceleration (cm/s^2)	35.98 ± 10.75	34.47 ± 10.57	1.52 ± 6.52	0.213 (-0.92 to 3.95)	0.895** (0.78 to 0.95)	3.454	8.060	9.575

Note: “**” indicates a significant difference between conditions at p-value < 0.01. Abbreviations: ICC, intraclass correlation coefficient; SEM, standard error of measurement; MDC, minimum detectable change; AP, anteroposterior; ML, mediolateral; VT, vertical; CoM, center of mass; NN/HS, neutral neck posture on hard surface; NN/SS, neutral neck posture on soft surface; FN/HS, flexed neck posture on hard surface; FN/SS, flexed neck posture on soft surface

Minimum Detectable Change (MDC)

Among individuals utilizing smartphones with a NN/HS, notable alterations in body CoM acceleration across AP, ML, VT, and total directions were deemed significant, requiring a difference (MDC95) of 1.23 cm/s^2 (23%), 2.18 cm/s^2 (27%), 1.34 cm/s^2 (11%), and 2.70 cm/s^2 (17%), respectively. Conversely, those on a soft surface (NN/SS) exhibited higher MDC values, indicating that substantial changes in acceleration demanded larger differences: 2.42 cm/s^2 (28%), 5.49 cm/s^2 (33%), 5.19 cm/s^2 (27%), and 9.90 cm/s^2 (33%) in AP, ML, VT, and total directions, as detailed in table 2.

For individuals employing smartphones in a FN/HS, significant alterations in Body CoM acceleration in AP, ML, VT, and total directions necessitated a difference (MDC$_{95}$) of 1.39 cm/s^2 (20%), 2.58 cm/s^2 (24%), 2.26 cm/s^2 (15%), and 4.41 cm/s^2 (21%), respectively. Similarly, individuals using smartphones in a FN/SS encountered substantial changes in Body CoM acceleration, demanding a difference (MDC$_{95}$) of 2.94 cm/s^2 (26%), 8.52 cm/s^2 (39%), 8.07 cm/s^2 (33%), and 9.58 cm/s^2 (27%) in AP, ML, VT, and total directions, as outlined in table 2.

Discussion

The primary objective of this study was to investigate the test-retest reliability and establish the Minimal Detectable Change (MDC) of smartphone-based accelerometry for assessing single-leg standing balance under challenging, ecologically valid conditions. By introducing dual-task constraints (texting) and biomechanical alterations (neck flexion and surface instability), this research aimed to bridge the gap between laboratory-based balance assessments and real-world functional scenarios. The principal finding of this investigation is that the smartphone accelerometer, positioned at the sacrum (approximate Center of Mass, CoM), demonstrates good-to-excellent reliability across all testing conditions. However, our analysis reveals a critical nuance: reliability is not uniform but is inversely proportional to the complexity of the postural task. Specifically, as sensory information becomes conflicted (soft surface) and biomechanical alignment is altered (flexed neck), the variability of the measurement increases, necessitating higher MDC thresholds to detect true clinical changes. These findings have profound implications for the development of safe, accessible, and accurate assessment protocols in rehabilitation settings.

The reliability of postural stability measurements is intrinsically linked to the central nervous system's (CNS) ability to integrate sensory inputs. Our results indicated that the Neutral Neck/Hard Surface (NN/HS) condition yielded the highest reliability (ICC3,1 = 0.91–0.94) and the lowest measurement error. This can be attributed to the availability of redundant and congruent sensory information. On a hard surface, somatosensory feedback from the plantar mechanoreceptors is reliable, allowing the CNS to effectively regulate the Center of Pressure (CoP) relative to the CoM. In contrast, the Soft Surface (SS) conditions consistently demonstrated lower reliability and higher variability. This aligns with the "Sensory Reweighting Hypothesis," which suggests that when one sensory channel is disrupted (in this case, proprioception due to the foam pad), the CNS must up-weight reliance on other senses, such as vision and the vestibular system (Mademli et al., 2021). However, in our study design, the visual system was engaged in a secondary task (texting), and in the Flexed Neck (FN) conditions, vestibular orientation was altered. This created a "sensory conflict" scenario, forcing the neuromotor system to adopt a more exploratory postural strategy, resulting in greater sway variability. This explains why the discrepancy ranges in our Bland-Altman plots were significantly wider for the FN/SS conditions compared to NN/HS.

It is not merely that the task was "harder," but that the consistency of the motor output was compromised by the conflicting sensory demands.

A distinguishing feature of this study is the comprehensive examination of neck posture effects on balance measurement reliability. The transition from a neutral neck to a flexed neck position (approx. 45 degrees) resulted in a notable decrease in reliability, particularly in the vertical and mediolateral axes. Biomechanically, the head represents a significant proportion of total body mass. Flexing the neck moves the head's center of mass anteriorly, creating a flexion moment that must be counteracted by increased activity in the posterior chain muscles (e.g., erector spinae, gastrocnemius). This shift alters the body's overall equilibrium and may introduce mechanical noise into the accelerometer signal located at the sacrum. Furthermore, the flexed neck position alters the orientation of the otoliths and semicircular canals within the vestibular system. When the head is inclined downwards during visual fixation on the smartphone display, the CNS must re-calibrate the vestibular reference frame to distinguish between head tilt and whole-body sway. Our findings suggest that this re-calibration process introduces variability into the postural control loop. While previous studies have validated smartphone accelerometry for static balance (Rodrigues et al., 2022) and anticipatory adjustments (Onuma et al., 2023), our data extends this knowledge by demonstrating that "text neck" is a distinct biomechanical constraint that significantly impacts the precision of stability assessments. Clinicians must be aware that a patient's inability to maintain a consistent neck posture during testing could result in data artifacts that mimic instability, underlining the need for strict protocol standardization.

The reliability metrics obtained in this study corroborate and expand upon previous research. Consistent with findings which reported high reliability for static balance tasks in healthy individuals and Parkinson's patients respectively (Muñoz-Albarrán et al., 2025; Rodrigues et al., 2022; Thelen et al., 2022), our study confirms that consumer-grade MEMS accelerometers are sufficiently sensitive for clinical use. Similarly, the work that demonstrated the utility of smartphones in assessing core and seated stability in pathological populations (Frechette et al., 2020; Prat-Luri et al., 2023). Our results support these conclusions, showing comparable ICC values to research-grade equipment. However, this study sets itself apart from prior research endeavors in a significant manner. While previous studies focused largely on single-task, static conditions, our investigation highlights the robustness of smartphone accelerometry under dual-task interference. The fact that ICC values remained above 0.87 even in the most challenging condition (FN/SS) suggests that the device captures the "dual-task cost" on stability effectively. This is crucial because the risk of falls often manifests during complex, divided-attention tasks rather than during quiet standing. By validating the tool under these diverse conditions, we provide evidence that smartphone accelerometry can serve as a proxy for expensive force platform analysis in evaluating functional, real-world balance deficits (Roeing et al., 2017).

Perhaps the most critical contribution of this study is the establishment of condition-specific MDC values. In clinical practice, distinguishing between a "real" improvement and natural physiological variability is a constant challenge. Our analysis reveals that a "one-size-fits-all" cutoff for improvement is inappropriate. For a standard single-leg stance on a hard surface, a relatively small change in total acceleration (approx. 2.70 cm/s^2) indicates a real difference. This high sensitivity makes the smartphone an excellent tool for detecting subtle deficits in early-stage rehabilitation or in healthy athletic populations. Conversely, for the soft surface/flexed neck condition, the MDC threshold nearly quadruples (approx. 9.90 cm/s^2). This dramatic increase highlights the "noise" inherent in difficult tasks. If a clinician were to use the hard-surface MDC value to evaluate a patient performing a soft-surface task, they might falsely conclude that the patient has deteriorated or improved when they have not. These specific MDC values help understand CoM acceleration changes during smartphone use with different neck postures and surfaces. They provide a statistical safety net for decision-making. For instance, in a rehabilitation program aimed at improving proprioception (e.g., for ankle instability), a therapist using our protocol can now confidently state that a reduction in sway acceleration greater than 9.90 cm/s^2 on a foam pad represents a successful intervention effect, surpassing the threshold of measurement error. This granular level of detail enhances the interpretability of CoM acceleration changes for clinicians and researchers evaluating postural alterations during smartphone tasks.

The study highlights the benefits of using smartphone-based accelerometry for assessing postural stability, emphasizing its convenience and accessibility. In many low-resource settings or tele-rehabilitation contexts, specialized equipment like 3D motion analysis systems and force plates are unavailable due to cost and space constraints (Grouios et al., 2023; Roeing et al., 2017). The ubiquity of smartphones allows for the democratization of advanced balance assessment. This supports the use of smartphones for stability assessments in line with the healthcare trend of utilizing everyday technologies.

Moreover, the sensitivity of the CoM acceleration to subtle changes in variables—such as the slight instability introduced by neck flexion—makes smartphones a valuable substitute for costly methods (Grouios et al., 2023; Roeing et al., 2017). This sensitivity allows for a thorough understanding of postural dynamics, making smartphone accelerometry a practical and insightful choice. The validation supports integrating these tools into routine assessments, potentially transforming how balance assessments are conducted. For example, patients could potentially perform self-assessments at home using their own devices, with data transmitted remotely to clinicians. This capability is particularly relevant for monitoring chronic conditions such as Multiple Sclerosis [39] or fall risk in the elderly (Roeing et al., 2017), where frequent, longitudinal monitoring is superior to sporadic in-clinic visits. This study affirms the reliability and practicality of using smartphone-based accelerometry for postural stability assessments, emphasizing their accessibility, cost-effectiveness, and sensitivity to nuanced changes. We have demonstrated that while the device is highly reliable, the context of the assessment matters significantly. The interaction between neck posture, surface stability, and dual-tasking creates a gradient of difficulty that is reflected in the measurement metrics. By providing specific MDC values for each of these conditions, this research empowers healthcare professionals to effectively use technology for enhanced balance assessment and rehabilitation outcomes (Frechette et al., 2020; Fukaya et al., 2023; Wang et al., 2019). Understanding significant changes in body CoM acceleration helps clinicians make informed decisions on intervention efficacy for balance promotion (Fukaya et al., 2023; Wang et al., 2019), ultimately impacting patient care by enabling a more precise and patient-centered rehabilitation approach.

While the current study offers valuable insights into the reliability of instrumented balance assessment, it is crucial to recognize its limitations to contextualize the findings appropriately. Firstly, the absence of control over the time of day during testing introduces variability in participants' alertness and fatigue levels. Circadian rhythms and daily fatigue accumulation can influence neuromuscular performance, potentially undermining result reliability. Future protocols should standardize testing times to mitigate this confounder. Moreover, the exclusive focus on young, healthy adults hampers the generalizability of findings to other age groups or individuals with underlying health conditions. While establishing normative data in a healthy population is a necessary first step, the MDC values derived here may not be directly applicable to older adults or those with vestibular pathology, who typically exhibit higher baseline variability. Furthermore, the lack of sufficient data on the speed and precision of texting in the context of evaluations limits the thorough examination of the correlation between texting habits and stability of posture. We did not quantify the "cognitive cost" (e.g., texting errors per minute), which would have provided a more multidimensional view of the dual-task interference.

Future studies should aim to improve upon the limitations of our current research by implementing controlled testing protocols that include diverse participant demographics, such as geriatric populations or post-stroke patients. Integrating measures of texting proficiency and cognitive load would also be beneficial. This approach would enhance our understanding of postural dynamics during smartphone use and enable more accurate generalizations across different populations. Additionally, further research could explore the integration of gyroscope data (rotational velocity) alongside accelerometry to provide a complete 6-degree-of-freedom analysis of trunk sway during these tasks.

Conclusions

In conclusion, the present study indicates the reliability and reproducibility of smartphone-based accelerometry measurements in assessing postural stability during single standing balance under various conditions and while performing diverse tasks. Additionally, the study establishes the MDC, facilitating the identification of real changes in the results of intervention protocols aimed at improving balance. These findings underscore the utility of smartphone-based accelerometry as a valuable tool for evaluating postural stability and monitoring the effectiveness of balance improvement interventions.

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Conflicts of Interest

All authors declare that they have no conflict of interest.

References

Alqahtani, B. A., Sparto, P. J., Whitney, S. L., Greenspan, S. L., Perera, S., & Brach, J. S. (2020). Psychometric properties of instrumented postural sway measures recorded in community settings in independent living older adults. *BMC Geriatr*, *20*(1), 82. https://doi.org/10.1186/s12877-020-1489-0

Ameer, M., Al Abbad, A., Khan, A., Alanazi, F., Alsakhri, A., Abdullhadi, G., Albilasi, M., Alrashed, M., & Ali, S. (2024). The Impact of Acute Whole-Body Vibration and Anthropometric Data on Single-Leg Standing Balance in Sedentary Females. *International Journal of Human Movement and Sports Sciences*, *12*, 438-447. https://doi.org/10.13189/saj.2024.120218

Angyán, L., Téczely, T., & Angyán, Z. (2007). Factors affecting postural stability of healthy young adults. *Acta physiologica Hungarica*, *94*, 289-299. https://doi.org/10.1556/APhysiol.94.2007.4.1

Beelen, P. E., Okhuijsen, R., Prins, M. R., Huurnink, A., Hordijk, T., Kruiswijk, C., Goedhart, E. A., van der Wurff, P., Nolte, P. A., van Dieën, J. H., & Kingma, I. (2021). Reliability of a novel dynamic test of postural stability in high-level soccer players. *Heliyon*, *7*(4), e06647. https://doi.org/https://doi.org/10.1016/j.heliyon.2021.e06647

Borzì, L., Olmo, G., Artusi, C. A., Fabbri, M., Rizzone, M. G., Romagnolo, A., Zibetti, M., & Lopiano, L. (2020). A new index to assess turning quality and postural stability in patients with Parkinson's disease. *Biomedical Signal Processing and Control*, *62*, 102059. https://doi.org/https://doi.org/10.1016/j.bspc.2020.102059

Boubaker, B., Amara, S., & Mkaouer, B. (2025). Postural balance and mental rotation in U-12 gymnasts: comparison with handball players and video gamers. *Retos*, *70*, 769-787. https://doi.org/10.47197/retos.v70.114116

Ezzat, A., Elsayed, M., Atia, D., Tawfick, A., Shalaby, R., & Morsi, H. (2025). Investigating forward head posture and its influence on postural alignment among desk-based employeesInvestigación de la postura adelantada de la cabeza y su influencia en la alineación postural en empleados que trabajan en oficinasInvestigação da postura adelantada da cabeça e sua influência no alinhamento postural em colaboradores que trabalham em escritórios. *Retos*, *73*, 1529-1545. https://doi.org/10.47197/retos.v73.117904

Frechette, M. L., Abou, L., Rice, L. A., & Sosnoff, J. J. (2020). The Validity, Reliability, and Sensitivity of a Smartphone-Based Seated Postural Control Assessment in Wheelchair Users: A Pilot Study [Original Research]. *Frontiers in Sports and Active Living*, *2*. https://doi.org/10.3389/fspor.2020.540930

Fukaya, T., Mutsuzaki, H., & Mori, K. (2023). Sway and Acceleration Changes of the Center of Mass during Walking Stance Phase before and after Total Knee Arthroplasty. *Geriatrics*, *8*(1), 2. https://www.mdpi.com/2308-3417/8/1/2

Gandawidura, R. G., & Ikeda, Y. (2024). Correlation analysis of balance and postural stability as a risk for falls in individuals with visual impairment. *British Journal of Visual Impairment*. https://doi.org/10.1177/02646196241226836

Gribble, P. A., Hertel, J., & Plisky, P. (2012). Using the Star Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury: a literature and systematic review. *J Athl Train*, *47*(3), 339-357. https://doi.org/10.4085/1062-6050-47.3.08

Grouios, G., Ziagkas, E., Loukovitis, A., Chatzinikolaou, K., & Koidou, E. (2023). Accelerometers in Our Pocket: Does Smartphone Accelerometer Technology Provide Accurate Data? *Sensors*, *23*(1), 192. https://www.mdpi.com/1424-8220/23/1/192

Hilden, P., Schwartz, J. E., Pascual, C., Diaz, K. M., & Goldsmith, J. (2023). How many days are needed? Measurement reliability of wearable device data to assess physical activity. *PloS one*, *18*(2), e0282162. https://doi.org/10.1371/journal.pone.0282162

Hou, Y. R., Chiu, Y. L., Chiang, S. L., Chen, H. Y., & Sung, W. H. (2018). Feasibility of a smartphone-based balance assessment system for subjects with chronic stroke. *Comput Methods Programs Biomed*, *161*, 191-195. https://doi.org/10.1016/j.cmpb.2018.04.027

Landis, J. R., & Koch, G. G. (1977). The Measurement of Observer Agreement for Categorical Data. *Biometrics*, *33*(1), 159-174. https://doi.org/10.2307/2529310

Lanzarin, M., Parizzoto, P., De, T., Libardoni, C., Sinhorim, L., Morgana, G., Tavares, G., Gilmar, M., & Santos, G. (2015). The influence of dual-tasking on postural control in young adults. *22*, 61-68.

Mademli, L., Mavridi, D., Bohm, S., Patikas, D. A., Santuz, A., & Arampatzis, A. (2021). Standing on unstable surface challenges postural control of tracking tasks and modulates neuromuscular adjustments specific to task complexity. *Scientific Reports*, *11*(1), 6122. https://doi.org/10.1038/s41598-021-84899-y

Mohd Safee, M. K., & Abu Osman, N. A. (2023). Relationship between postural stability and fall risk in young adult after lower limb muscle fatigue. *Healthcare in Low-resource Settings*, *11*. https://doi.org/10.4081/hls.2023.11182

Muñoz-Albarrán, P., Castro-Perez, J., S. Mancilla, C., Martinez, D., Quiroz-Sandoval, G., Cheuquel-Jara, O., & Saez Duran, H. (2025). Dual task training in older adults with Parkinson's Disease: a systematic review. *Retos*, *70*, 546-560. https://doi.org/10.47197/retos.v70.114975

Neville, C., Ludlow, C., & Rieger, B. (2015). Measuring postural stability with an inertial sensor: validity and sensitivity. *Med Devices (Auckl)*, *8*, 447-455. https://doi.org/10.2147/mder.S91719

Nurwulan, N., Jiang, B., & Iridiastadi, H. (2015). Posture and Texting: Effect on Balance in Young Adults. *PloS one*, *10*, e0134230. https://doi.org/10.1371/journal.pone.0134230

Olsen, S., Rashid, U., Allerby, C., Brown, E., Leyser, M., McDonnell, G., Alder, G., Barbado, D., Shaikh, N., Lord, S., Niazi, I. K., & Taylor, D. (2023). Smartphone-based gait and balance accelerometry is sensitive to age and correlates with clinical and kinematic data. *Gait Posture*, *100*, 57-64. https://doi.org/10.1016/j.gaitpost.2022.11.014

Onofrei, R. R., & Amaricai, E. (2022). Postural Balance in Relation with Vision and Physical Activity in Healthy Young Adults. *International Journal of Environmental Research and Public Health*, *19*(9), 5021. https://www.mdpi.com/1660-4601/19/9/5021

Onofrei, R. R., Amaricai, E., Suciu, O., David, V. L., Rata, A. L., & Hogea, E. (2020). Smartphone Use and Postural Balance in Healthy Young Adults. *Int J Environ Res Public Health*, *17*(9). https://doi.org/10.3390/ijerph17093307

Onuma, R., Hoshi, F., Tozawa, R., Soutome, Y., Sakai, T., & Jinno, T. (2023). Reliability and validity of quantitative evaluation of anticipatory postural adjustments using smartphones. *Journal of Physical Therapy Science*, *35*(7), 553-558. https://doi.org/10.1589/jpts.35.553

Panjan, A., & Sarabon, N. (2010). Review of Methods for the Evaluation of Human Body Balance. *Sport Science Review*, *XIX*. https://doi.org/10.2478/v10237-011-0036-5

Pinho, A. S., Salazar, A. P., Hennig, E. M., Spessato, B. C., Domingo, A., & Pagnussat, A. S. (2019). Can We Rely on Mobile Devices and Other Gadgets to Assess the Postural Balance of Healthy Individuals? A Systematic Review. *Sensors*, *19*(13), 2972. https://www.mdpi.com/1424-8220/19/13/2972

Prat-Luri, A., Moreno-Navarro, P., Carpena, C., Manca, A., Deriu, F., Barbado, D., & Vera-Garcia, F. J. (2023). Smartphone accelerometry for quantifying core stability and developing exercise training progressions in people with multiple sclerosis. *Multiple Sclerosis and Related Disorders*, *72*, 104618. https://doi.org/https://doi.org/10.1016/j.msard.2023.104618

Quijoux, F., Nicolaï, A., Chairi, I., Bargiotas, I., Ricard, D., Yelnik, A., Oudre, L., Bertin-Hugault, F., Vidal, P. P., Vayatis, N., Buffat, S., & Audiffren, J. (2021). A review of center of pressure (COP) variables to quantify standing balance in elderly people: Algorithms and open-access code. *Physiol Rep*, *9*(22), e15067. https://doi.org/10.14814/phy2.15067

Rodrigues, L. A., Santos, E. G. R., Santos, P. S. A., Igarashi, Y., Oliveira, L. K. R., Pinto, G. H. L., Santos Lobato, B. L., Cabral, A. S., Belgamo, A., Costa e Silva, A. A., Callegari, B., & Souza, G. S. (2022). Wearable Devices and Smartphone Inertial Sensors for Static Balance Assessment: A Concurrent Validity Study in Young Adult Population. *Journal of Personalized Medicine*, *12*(7), 1019. https://www.mdpi.com/2075-4426/12/7/1019

Roeing, K. L., Hsieh, K. L., & Sosnoff, J. J. (2017). A systematic review of balance and fall risk assessments with mobile phone technology. *Archives of Gerontology and Geriatrics*, *73*, 222-226. https://doi.org/https://doi.org/10.1016/j.archger.2017.08.002

Sevillano-Castaño, A. I., Peroy-Badal, R., Torres-Castro, R., Cañuelo-Márquez, A. M., Rozalén-Bustín, M., Modrego-Navarro, Á., De Sousa-De Sousa, L., Ramos-Álvarez, J. J., Maté-Muñoz, J. L., & García-Fernández, P. (2023). Test–Retest Reliability and Minimal Detectable Change in Chester Step Test and 1-Minute Sit-to-Stand Test in Long COVID Patients. *Applied Sciences*, *13*(14), 8464. https://www.mdpi.com/2076-3417/13/14/8464

Suresh, K. (2011). An overview of randomization techniques: An unbiased assessment of outcome in clinical research. *J Hum Reprod Sci*, *4*(1), 8-11. https://doi.org/10.4103/0974-1208.82352

Tapanya, W., Maharan, S., Amput, P., Sangkarit, N., & Suwannakul, B. (2023). The Influence of Knee Extensor and Ankle Plantar Flexor Strength on Single-Leg Standing Balance in Older Women. *Journal of Functional Morphology and Kinesiology*, *8*(2), 67. https://www.mdpi.com/2411-5142/8/2/67

Tapanya, W., Puntumetakul, R., Swangnetr Neubert, M., & Boucaut, R. (2021). Influence of neck flexion angle on gravitational moment and neck muscle activity when using a smartphone while standing. *Ergonomics*, *64*(7), 900-911. https://doi.org/10.1080/00140139.2021.1873423

Thelen, M., Mazumder, F., Zhu, L., Tang, C., & Miller, N. S. (2022). Reliability Test of Mobile Embedded Accelerometers in Measuring Postural Stability for People With Parkinson's Disease. ASME 2022 International Mechanical Engineering Congress and Exposition,

Tivadar, B. K., & Kotnik, P. (2024). Dynamic Single-Leg Balance Tests of Physiotherapy Students: A Comparison of Body-Active Weight Shift Test and Two Sudden Disturbance Tests. *Open Access Macedonian Journal of Medical Sciences*, *12*(2), 322-329. https://doi.org/doi:10.3889/oamjms.2024.11896

Van Humbeeck, N., Kliegl, R., & Krampe, R. T. (2023). Lifespan changes in postural control. *Sci Rep*, *13*(1), 541. https://doi.org/10.1038/s41598-022-26934-0

Wang, W., Xiao, Y., Yue, S., Wei, N., & Li, K. (2019). Analysis of center of mass acceleration and muscle activation in hemiplegic paralysis during quiet standing. *PloS one*, *14*(12), e0226944. https://doi.org/10.1371/journal.pone.0226944

Xie, Y., Szeto, G. P., Dai, J., & Madeleine, P. (2016). A comparison of muscle activity in using touchscreen smartphone among young people with and without chronic neck-shoulder pain. *Ergonomics*, *59*(1), 61-72. https://doi.org/10.1080/00140139.2015.1056237

Yoong, N. K. M., Perring, J., & Mobbs, R. J. (2019). Commercial Postural Devices: A Review. *Sensors*, *19*(23), 5128. https://www.mdpi.com/1424-8220/19/23/5128

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