Reliability and Validity of *Analiz Sistem* in Plantar Pressure Assessment for Unilateral Chronic Ankle Instability

Çağlar SOYLU[*], Ceren Şevval KARATAŞ[**], Görkem AÇAR[***]

Abstract

Aim: Pedobarography is a valuable tool for understanding lower limb biomechanics and identifying deviations in plantar pressure distribution, particularly in individuals with chronic ankle instability (CAI). Accurate assessment is essential for tailoring effective rehabilitation programs. This study aims to evaluate the concurrent validity and test-retest reliability of Analiz Sistem and Sensor Medica pedobarographic devices in assessing plantar pressure distribution under static postural conditions in individuals with CAI.

Method: A total of 64 participants with unilateral CAI were included, with diagnoses confirmed via a Cumberland Ankle Instability Tool (CAIT) score of ≤24. Static postural assessments focused on surface area and impulse parameters for rearfoot, midfoot, and forefoot regions. Measurements from both systems were analyzed for agreement using Intraclass Correlation Coefficient (ICC), standard error of measurement (SEM), paired t-tests, and Bland-Altman plots.

Results: ICC values ranged from 0.80 to 0.99, demonstrating good to excellent reliability. Rearfoot metrics showed the highest reliability, with ICC values exceeding 0.94. SEM values were consistently low (<1.5 for most metrics), indicating high measurement precision. Paired t-tests revealed no significant differences between the two systems (p>0.05). Bland-Altman plots confirmed narrow limits of agreement and minimal mean bias across all metrics.

Conclusion: Analiz Sistem and Sensor Medica offer accurate and reliable measurements of plantar pressure distribution under static conditions. Their portability and cost-effectiveness make them suitable for clinical and field-based environments. Future research should focus on integrating advanced technologies like artificial intelligence to enhance their utility further.

Keywords: Pedobarography, chronic ankle instability, plantar pressure, Analiz Sistem, Sensor Medica.

Tek Taraflı Kronik Ayak Bileği İnstabilitesinde Plantar Basınç Değerlendirmesinde *Analiz Sistem*'in Güvenilirliği ve Geçerliliği

Öz

Amaç: Pedobarografi, alt ekstremite biyomekaniğini anlamak ve plantar basınç dağılımındaki sapmaları tespit etmek için değerli bir araçtır, özellikle kronik ayak bileği instabilitesi (CAI) olan bireylerde. Doğru değerlendirme, etkili rehabilitasyon programlarının oluşturulmasında kritik bir öneme sahiptir. Bu çalışma, Analiz Sistem ve Sensor Medica pedobarografi cihazlarının statik postüral koşullarda plantar basınç dağılımını değerlendirmedeki eşzamanlı geçerliliğini ve test-tekrar test güvenilirliğini incelemeyi amaçlamaktadır.

Yöntem: Tek taraflı CAI tanısı almış 64 katılımcı çalışmaya dahil edilmiştir ve tanılar Cumberland Ayak Bileği İnstabilite Aracı (CAIT) skorunun ≤24 olmasıyla doğrulanmıştır. Statik postüral değerlendirmeler, arka ayak, orta ayak ve ön ayak bölgeleri için yüzey alanı ve impuls parametrelerine odaklanmıştır. Her iki

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[*] PhD. PT., Health Sciences University, Gulhane Faculty of Physiotherapy and Rehabilitation, Ankara, Türkiye. E-mail: caglar.soylu@sbu.edu.tr ORCID https://orcid.org/0000-0002-1524-6295
[**] PT., Health Sciences University, Gulhane Institute of Health Sciences, Department of Physiotherapy and Rehabilitation, Ankara, Türkiye. E-mail: cerensevval2000@gmail.com ORCID https://orcid.org/0009-0008-1235-3707
[***] MSc. PT., Manisa Celal Bayar University, Institute of Graduate Education, Department of Sport Science, Manisa, Türkiye. E-mail: gorkemacar2@gmail.com ORCID https://orcid.org/0000-0002-0970-8625

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sistemden elde edilen ölçümler, Intraclass Correlation Coefficient (ICC), ölçüm hatası standart sapması (SEM), eşleştirilmiş t-testi ve Bland-Altman grafikleri kullanılarak analiz edilmiştir.

Bulgular: ICC değerleri 0,80 ile 0,99 arasında değişmiş ve iyi ile mükemmel güvenilirlik sağlamıştır. Arka ayak metrikleri, 0.94'ün üzerinde ICC değerleri ile en yüksek güvenilirliği göstermiştir. SEM değerleri sürekli olarak düşük bulunmuş (<1,5), bu da ölçümlerin yüksek doğruluğunu göstermiştir. Eşleştirilmiş t-testleri, iki sistem arasında anlamlı bir fark olmadığını göstermiştir (p> 0,05). Bland-Altman grafikleri, tüm metriklerde dar uyum sınırları ve minimal ortalama yanlılık doğrulamıştır.

Sonuç: Analiz Sistem ve Sensor Medica, statik koşullarda plantar basınç dağılımını değerlendirmede doğru ve güvenilir ölçümler sunmaktadır. Taşınabilirlikleri ve maliyet etkinlikleri, bu cihazları klinik ve saha ortamları için uygun hale getirmektedir. Gelecekteki araştırmalar, yapay zeka gibi ileri teknolojilerin entegrasyonuna odaklanarak bu cihazların işlevselliğini daha da artırmalıdır.

Anahtar Sözcükler: Pedobarografi, kronik ayak bileği instabilitesi, plantar basınç, Analiz Sistem, Sensor Medica.

Introduction

Pedobarography, which examines pressure distribution between the foot and a supporting surface, is essential for understanding lower limb biomechanics, gait patterns, and postural control. It has significant applications in clinical diagnostics, rehabilitation, and sports science, particularly for conditions like chronic ankle instability (CAI)[1,2]. CAI, characterized by recurrent ankle "giving way" and persistent instability, alters lower limb biomechanics, affecting plantar pressure distribution and gait mechanics[3,4]. These changes impact functional mobility, postural stability, and gait efficiency, underscoring the need for precise assessments to optimize rehabilitation strategies[5].

Plantar pressure systems are crucial for detecting these biomechanical alterations, providing insights into gait parameters and load distribution. The Analiz Sistem, a novel plantar pressure device, holds potential for improving CAI assessments; however, its clinical utility depends on validating its accuracy and reliability[6,7]. The Sensor Medica, a widely recognized electronic baropodometer, serves as the gold standard due to its proven reliability, with studies reporting ICC values ranging from 0.72 to 0.83 in various biomechanical applications[8,9]. These findings establish Sensor Medica as a benchmark for validating emerging technologies[10-12].

Research has demonstrated that CAI significantly alters plantar pressure patterns and gait parameters, reinforcing the need for accurate assessment tools[9,13]. Studies have confirmed the reliability of Sensor Medica in detecting subtle biomechanical changes, making it an ideal reference for evaluating new systems[8,14]. Advancements in wearable pedobarography have further enhanced the accuracy of gait analysis, broadening its clinical applications[12,15].

This study aims to assess the concurrent validity and test-retest reliability of the Analiz Sistem in evaluating plantar pressure distribution and spatiotemporal gait parameters in individuals with CAI. By comparing its measurements with Sensor Medica, this research will determine whether the Analiz Sistem meets the standards for accurate plantar pressure assessment. It is hypothesized that the Analiz Sistem will demonstrate high concurrent validity and test-retest reliability, supporting its applicability in clinical and research settings.

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Material and Methods

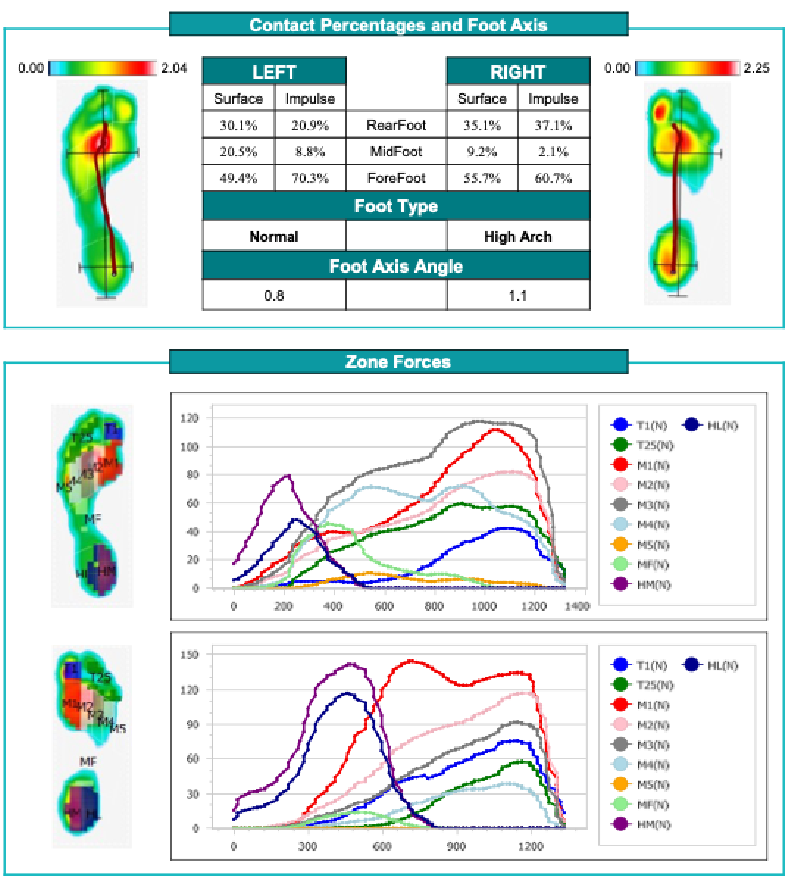
Participations and Experimental Protocol

This study evaluated the concurrent validity and test-retest reliability of the Analiz Sistem for static plantar pressure distribution. Sixty-four participants with unilateral CAI were recruited from rehabilitation centers and university sports clinics according to International Ankle Consortium guidelines, which required a history of at least one significant lateral ankle sprain, recurrent "giving way" episodes, and self-reported instability, with a CAIT score of ≤24 confirming the diagnosis[16]. Exclusion criteria were recent lower limb surgeries, fractures, systemic neurological conditions, or musculoskeletal injuries affecting balance or gait.

Based on pilot study ICC values (0.880–0.995), sample size calculations determined that at least 60 participants were needed to achieve an ICC of ≥0.90; a 10% increase for potential dropouts resulted in 64 participants, ensuring statistical robustness and minimizing Type II errors.

Data were collected using the Analiz Sistem - a high-precision pedobarographic device with advanced resistive sensors (sampling frequency up to 300 Hz) for real-time, region-specific pressure mapping (Figure 1.) and the Sensor Medica FreeMed Posturography System, a gold-standard reference featuring a 40 cm × 40 cm platform with conductive rubber resistive sensors operating at 400 Hz[17].

Figure 1. Example output of plantar pressure analysis from Analiz Sistem



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Ethics Committee Approval

The study adhered to the Declaration of Helsinki and was approved by the Gülhane Scientific Research Ethics Committee of the University of Health Sciences (approval no.: 2024-486; 2024). In a controlled laboratory environment (22 ± 2°C, 50–60% humidity), participants performed a 5-second barefoot static postural assessment on a pedobarographic platform (feet shoulder-width apart, arms at sides, gaze forward). To avoid order effects, the Analiz Sistem and Sensor Medica systems were used in a randomized, alternating sequence. Each trial was repeated three times, and the average value was analyzed. To assess test-retest reliability, all measurements were repeated after a 7-day interval under the same environmental conditions and following the identical standardized protocol. This interval was chosen to minimize both short-term adaptation effects and potential fluctuations in postural stability due to daily variability.

The assessment measured surface area (cm^2) and impulse (Ns) for the rearfoot, midfoot, and forefoot. The Sensor Medica FreeMed Posturography System (Guidonia Montecelio, Roma, Italy), equipped with conductive rubber resistive sensors, captured high-resolution plantar pressure data. Both numerical and graphical data were examined, with primary outcomes compared between systems to evaluate agreement and reliability under static conditions.

Statistical analysis

Based on pilot results (ICC: 0.880–0.995), a sample size of 60 ($\alpha = 0.05$, power ≥ 90%) was deemed sufficient to achieve an ICC ≥ 0.90; with an additional 10% for potential dropouts, 64 participants were included to ensure robust statistical power, minimize Type II errors, and improve generalizability. Normality was assessed using histograms and the Shapiro-Wilk test, with numerical variables summarized as means (95% CI) and categorical variables as frequencies. Agreement between Analiz Sistem and Sensor Medica was evaluated using a two-way mixed-effects model ICC (mean measure), where ICC values >0.76 indicated good reliability and >0.90 excellent reliability (Koo & Li, 2016)[18]; systematic differences were examined via a paired t-test, and the Spearman rank correlation coefficient (>0.70 indicating strong association) was calculated for ordinal data[19]. Test-retest reliability was further assessed using paired t-tests and a single measure ICC (two-way mixed-effects model) with 95% CI, while reproducibility was visually examined through Bland-Altman plots (mean difference ±1.96 SD). All analyses were performed in R using the "rel", "ggplot2", and "blandr" packages, with a significance level of 0.05.

Results

The study sample had a mean age of 24.00±5.72 years (52.8% male) and a mean BMI of 20.12±3.89 kg/m^2. Both systems were evaluated using the average of three consecutive measurements (Figure 2), and the findings indicate high reliability for repeated measurements. Specifically, Analiz Sistem and Sensor Medica demonstrated excellent agreement across foot metrics with ICC values exceeding 0.90 (Table 1). Rear foot surface and impulse metrics, with ICCs ranging from 0.88 to 0.94, showed minimal variability, negligible mean differences, and no statistically significant differences ($p > 0.05$), underscoring the consistent performance of both systems.

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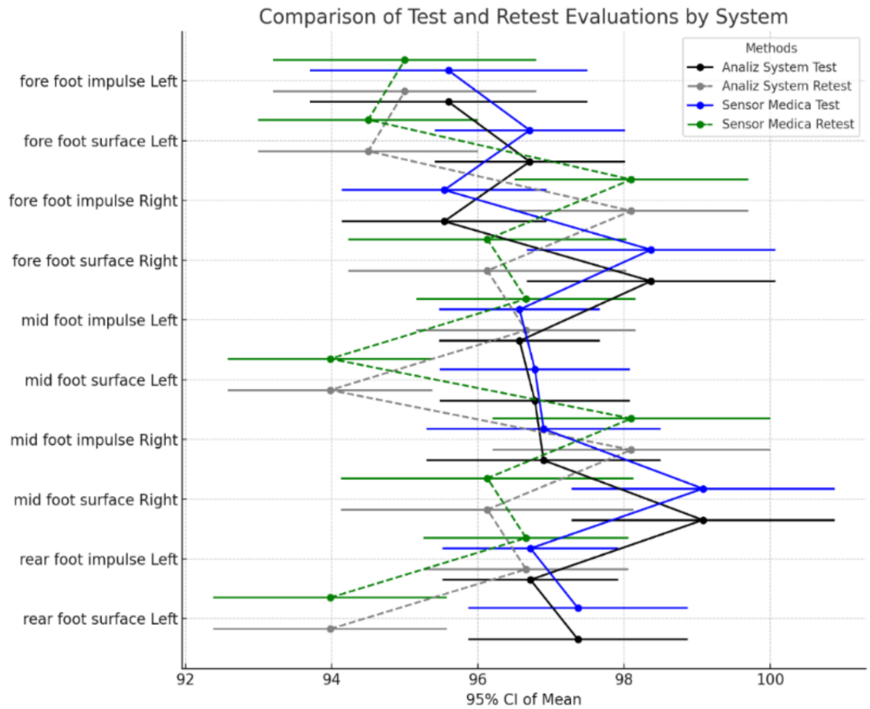
Figure 2. The mean and 95% confidence interval of the measurements obtained from Analiz system, Sensor medica, and retest evaluation



For mid-foot metrics, ICC values ranged from 0.81 to 0.92 (Table 1), indicating good to excellent reliability. Although overall agreement was robust, the right mid-foot surface showed a mean difference of -4.77 (95% CI: -6.37 to -2.63), which was not statistically significant ($p > 0.05$). Similarly, forefoot metrics demonstrated ICC values between 0.78 and 0.95, with the left forefoot impulse achieving the highest ICC (0.95, 95% CI: 0.933–0.949) and a mean difference of 1.96 (95% CI: 0.54–3.51); paired t-tests confirmed these differences were non-significant ($p > 0.05$), indicating strong overall agreement between the systems.

Table 1. Comparisons of differences between Analiz Sistem and Sensor medica

		Analiz Sistem and Sensor Medica				
		Correlation& (95% CI)	**ICC (95% CI)**	**SEM**	**Mean difference (95% CI)**	**Paired t-test p-value***
First evaluation (test)	rear foot surface left	0.88 (0.96-0.98)	0.99 (0.96-0.98)	1.05	-0.22 (-1.82-1.87)	0.795
	rear foot impulse left	0.94 (0.92-0.97)	0.98 (0.92-0.97)	0.75	-0.53 (-2.06-1.83)	0.061
	mid foot surface right	0.82 (0.96-0.98)	0.99 (0.96-0.98)	1.84	-4.77 (-6.37-2.63)	0.307
	mid foot impulse right	0.81 (0.95-0.97)	0.97 (0.95-0.97)	1.32	-1.63 (-4.62-0.08)	0.467
	mid foot surface left	0.92 (0.94-0.98)	0.98 (0.94-0.98)	0.91	-0.13 (-2.12-1.09)	0.619

	mid foot impulse left	0.9 (0.94-0.95)	0.98 (0.94-0.95)	1.39	0.55 (-0.97-2.20)	0.739
	fore foot surface right	0.84 (0.96-0.97)	0.98 (0.96-0.97)	1.08	-4.46 (-6.67-3.37)	0.796
	fore foot impulse right	0.78 (0.94-0.98)	0.98 (0.94-0.98)	1.45	4.10 (2.24-5.73)	0.467
	fore foot surface left	0.82 (0.94-0.96)	0.98 (0.94-0.96)	1.89	2.22 (-0.12-3.32)	0.157
	fore foot impulse left	0.95 (0.93-0.95)	0.98 (0.93-0.95)	1.22	1.96 (0.54-3.51)	0.758
Second evaluation (retest)	rear foot surface left	0.88 (0.96-0.98)	0.97 (0.91-0.95)	1.05	-0.13 (-2.36-1.78)	0.409
	rear foot impulse left	0.94 (0.92-0.97)	0.81 (0.92-0.97)	0.75	3.97 (-4.38- 1.3)	0.661
	mid foot surface right	0.82 (0.96-0.98)	0.93 (0.94-0.95)	1.84	3.28 (-5.49-3.99)	0.768
	mid foot impulse right	0.81 (0.95-0.97)	0.97 (0.92-0.97)	1.32	0.03 (-3.74-1.88)	0.355
	mid foot surface left	0.92 (0.94-0.98)	0.91 (0.93-0.95)	0.91	-3.39 (-1.9-3.69)	0.244
	mid foot impulse left	0.9 (0.94-0.954)	0.97 (0.92-0.96)	1.39	-0.04 (-2.88-4.35)	0.158
	fore foot surface right	0.84 (0.96-0.97)	0.86 (0.92-0.98)	1.08	2.29 (-2.64-3.03)	0.494
	fore foot impulce right	0.78 (0.94-0.98)	0.82 (0.94-0.98)	1.45	-3.97 (-2.54-4.44)	0.690
	fore foot surface left	0.82 (0.94-0.97)	0.99 (0.92-0.98)	1.89	-0.89 (-1.71-3.74)	0.463
	fore foot impulse left	0.95 (0.93-0.95)	0.87 (0.94-0.96)	1.22	-3.8 (-5.26-1.18)	0.356

ICC: Intra-class correlation coefficient (ICC, single measure, two-way mixed-effects model where people effects are random and measures effects are fixed, consistency agreement, higher than 0.76 was considered good and 0.90 was excellent reliability), CI: Confidence interval, SEM: Standard error of measurement.

**There was no statistically significant difference between the Analiz Sistem and Sensor Medica measurements (Paired t test p values>0.05)*

[&]The obtained correlation coefficient was significant (p<0.05).

Test-retest reliability was high for both systems (Table 2). For Analiz Sistem, ICC values ranged from 0.80 to 0.94, with the left rear foot surface achieving an ICC of 0.94 (95% CI: 0.948–0.981); SEM values ranged from 0.53 to 1.39, and paired t-tests showed no significant differences ($p > 0.05$). Similarly, Sensor Medica exhibited ICC values from 0.88 to 0.99, with the right mid-foot impulse reaching an ICC of 0.96 (95% CI: 0.931–0.976), and paired t-tests confirmed reproducibility ($p > 0.05$).

Table 2. Test-retest reliability values of Analiz Sistem and Sensor medica

		Test - Retest			
		ICC (95% CI)	**SEM**	**Mean difference (95% CI)**	**Paired t-test p-value***
Analiz Sistem	rear foot surface left	0.94 (0.94- 0.98)	0.53	-4.88 (-3.64- 4.8)	0.188
	rear foot impulse left	0.91 (0.90- 0.96)	1.62	-3.53 (-3.7- 1.49)	0.215
	mid foot surface right	0.9 (0.93- 0.97)	0.67	-3.37 (-5.88- 3.58)	0.115
	mid foot impulse right	0.83 (0.93- 0.98)	1.39	-1.39 (-5.62- 5.27)	0.227
	mid foot surface left	0.91 (0.95- 0.96)	0.99	-3.67 (-4.4- 4.97)	0.087
	mid foot impulse left	0.85 (0.93- 0.97)	1.36	3.18 (-2.48- 1.86)	0.698
	fore foot surface right	0.94 (0.93- 0.96)	1.16	-0.9 (-1.96- 3.15)	0.117
	fore foot impulce right	0.83 (0.94- 0.95)	0.82	4.87 (-5.96- 2.23)	0.679
	fore foot surface left	0.89 (0.94- 0.99)	2.0	1.03 (-2.26- 5.73)	0.131
	fore foot impulse left	0.8 (0.93- 0.95)	0.57	-0.42 (-4.71- 3.85)	0.213
Sensor medica	rear foot surface left	0.89 (0.93- 0.96)	1.31	3.95 (-1.4- 4.96)	0.419
	rear foot impulse left	0.88 (0.91- 0.98)	0.62	0.95 (-2.36- 2.96)	0.303
	mid foot surface right	0.94 (0.93- 0.96)	0.77	-1.12 (-2.91- 3.22)	0.469
	mid foot impulse right	0.96 (0.93- 0.97)	1.39	-1.23 (-4.47- 1.41)	0.767
	mid foot surface left	0.95 (0.92- 0.97)	1.04	-2.4 (-5.85- 5.09)	0.190
	mid foot impulse left	0.9 (0.92- 0.98)	1.74	1.8 (-5.76- 5.81)	0.499
	fore foot surface right	0.91 (0.93- 0.97)	1.5	0.05 (-2.69- 3.19)	0.525
	fore foot impulse right	0.9 (0.93- 0.95)	1.9	3.45 (-4.83- 5.23)	0.124
	fore foot surface left	0.99 (0.93- 0.97)	1.95	1.51 (-2.29- 5.0)	0.105
	fore foot impulse left	0.93 (0.91- 0.97)	1.86	-4.35 (-1.25- 1.06)	0.367

ICC: Intra-class correlation coefficient (ICC, single measure, two-way mixed-effects model where people effects are random and measures effects are fixed, absolute agreement, higher than 0.76 was considered good and 0.90 was excellent reliability), CI: Confidence interval, SEM: Standard error of measurement.

**There was no statistically significant difference between the test and re-test measurements (Paired t-test p-values>0.05).*

The Bland-Altman plots (Figure 3a-d) further supported the test-retest reliability of Analiz Sistem. These plots demonstrated narrow limits of agreement, indicating consistent measurements over time. Mean differences were close to zero, suggesting minimal systematic bias. For example, the rear foot impulse (left) exhibited a mean difference within the 95% CI range of -2.36 to 1.78. The data points were evenly distributed around the center line, further confirming the absence of systematic errors.

Discussion

To our knowledge, the present study is among the first to comprehensively evaluate the reliability and agreement of Analiz Sistem and Sensor Medica in assessing foot metrics across static and dynamic conditions. Using robust statistical methods, including intra-class correlation coefficients (ICCs), standard error of measurement (SEM), and Bland-Altman plots, this study demonstrates that both systems provide accurate and consistent

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measurements. These findings align with existing literature and underscore the utility of these systems in clinical and sports contexts.

Concurrent Validity of Analiz Sistem and Sensor Medica

The high ICC values (0.80–0.99) indicate good to excellent agreement across all foot metrics, with rearfoot metrics demonstrating ICC values exceeding 0.94. These findings are consistent with Orlin and McPoil's (2000) benchmark, which considers ICC values above 0.75 as indicative of excellent agreement[20]. Moreover, the results corroborate the observations of Burns et al. (2006), who reported that reliable plantar pressure data can facilitate effective orthotic interventions, particularly for individuals with cavus feet[21]. Consequently, the strong agreement observed between Analiz Sistem and Sensor Medica supports their application in clinical settings for the customization and evaluation of orthotic devices.

Figure 3 (a-b). The Bland-Altman plots for the test–retest reliability of Analiz Sistem right and left surface measurements (The dashed lines represent the limits of agreement and mean of differences. The dotted lines represent 95% CI upper and lower limits.)

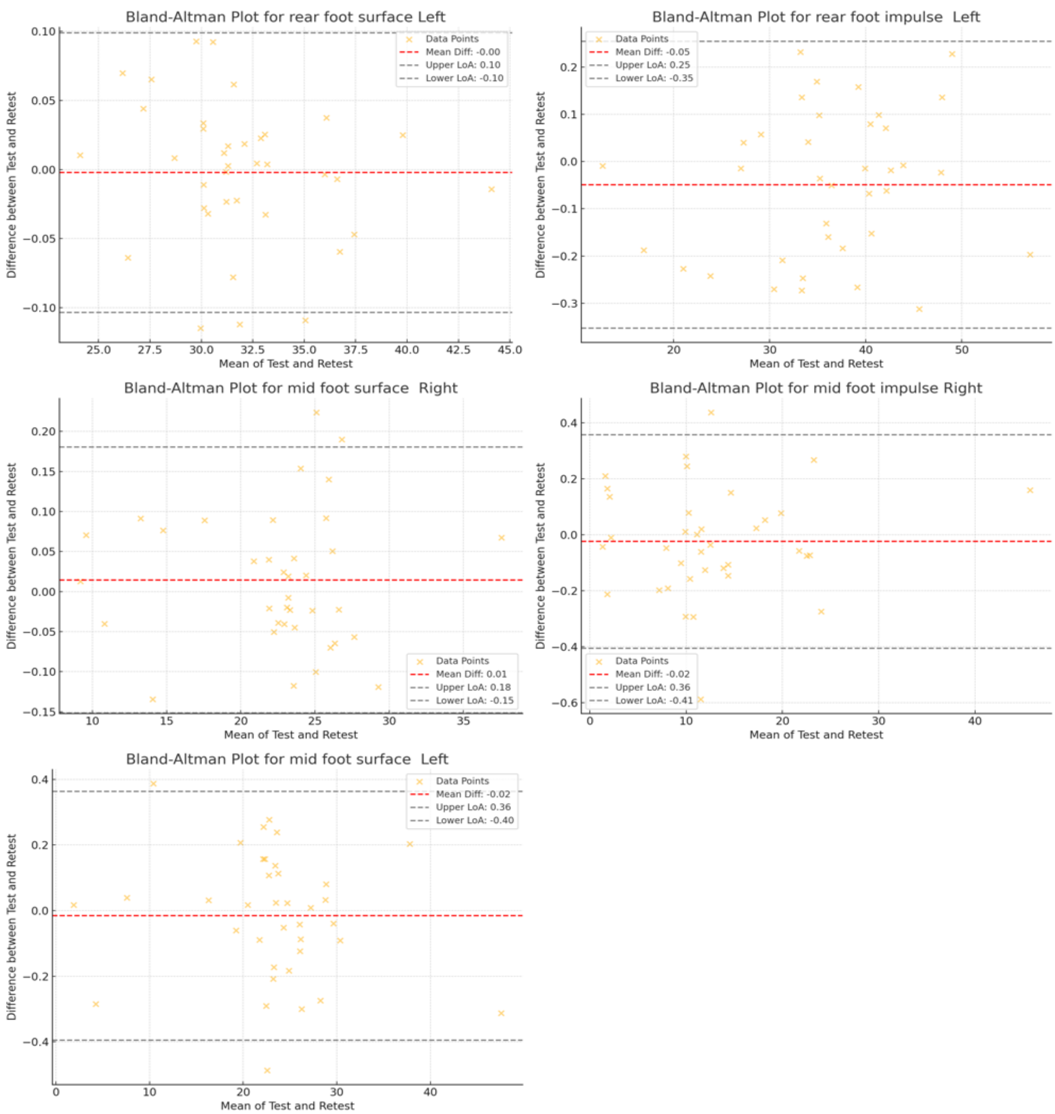

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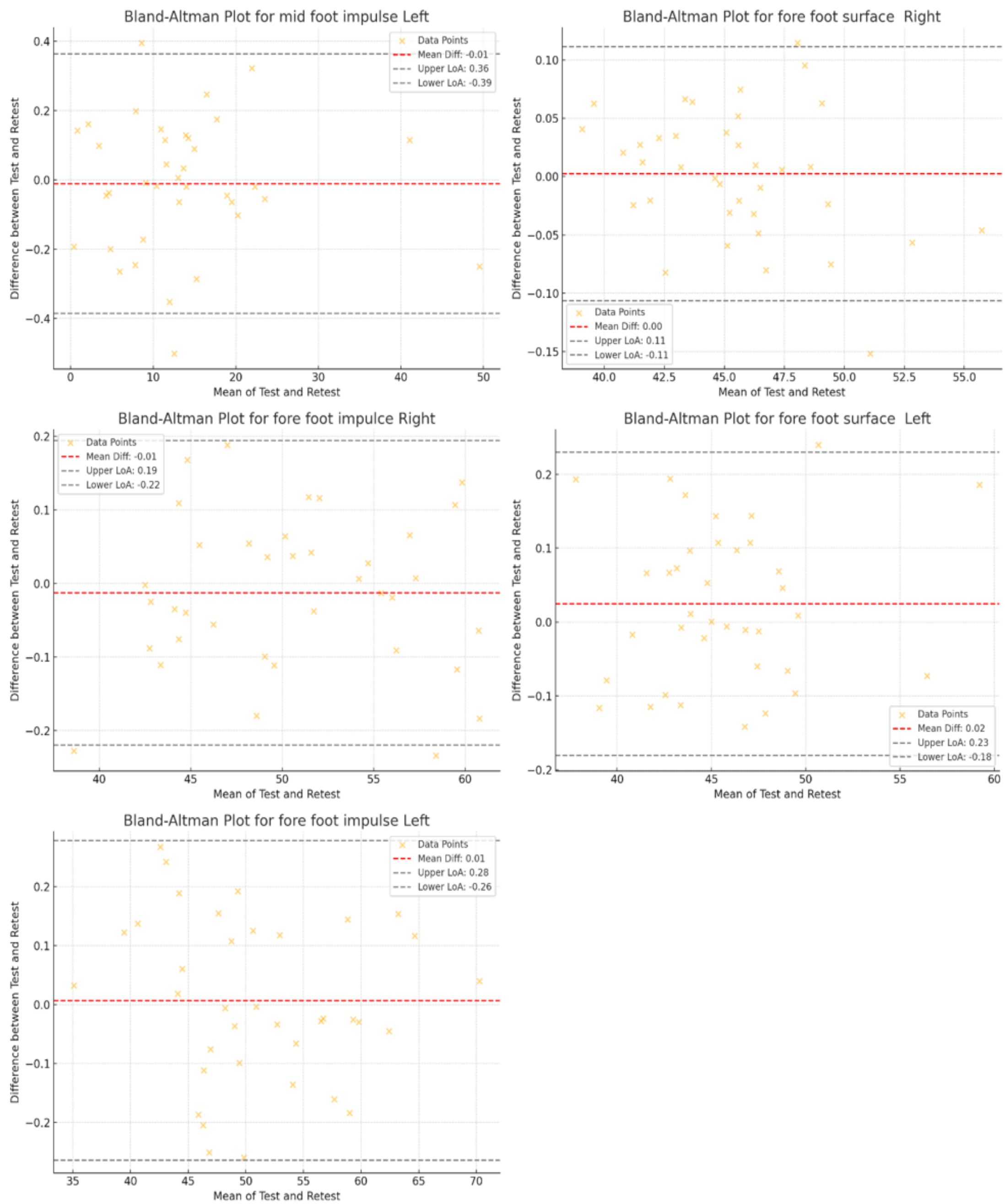
Figure 3 (c-d). The Bland-Altman plots for the test–retest reliability of Analiz Sistem right and left impulse measurements (The dashed lines represent the limits of agreement and mean of differences. The dotted lines represent 95% CI upper and lower limits.)



For midfoot metrics, while ICC values were strong (0.81 to 0.92), minor discrepancies were noted, such as the right midfoot surface (mean difference = -4.77, 95% CI: -6.37 to -2.63). These variations are consistent with findings by Rao et al. (2012) and Guiotto et al. (2013), who highlighted the challenges of capturing midfoot mechanics due to anatomical complexity and load distribution[22,23]. Despite these discrepancies, the narrow

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limits of agreement in the Bland-Altman plots confirm the systems' reliability across repeated measurements.

Test-retest reliability of both Analiz Sistem and Sensor Medica was excellent, with ICCs ranging from 0.88 to 0.99. Notably, Analiz Sistem's left rearfoot surface (ICC = 0.94, 95% CI: 0.948–0.981) and Sensor Medica's right midfoot impulse (ICC = 0.96, 95% CI: 0.931–0.976) demonstrated the highest reliability, corroborating findings by Lambrich et al.[24]. Low SEM values (<1.5 for most metrics) further confirm measurement precision, consistent with Burnie et al.[25]. Bland-Altman analyses revealed narrow limits of agreement and minimal bias (e.g., left rearfoot impulse mean difference of -0.13, 95% CI: -2.36 to 1.78), aligning with Hafer et al.[26], though slightly greater variability was noted for the Sensor Medica midfoot impulse, as observed by Razak et al.[27]. These robust reliability metrics support the application of both systems in clinical settings for diagnosing and managing conditions such as plantar fasciitis and diabetic neuropathy[21,23], as well as in sports for optimizing load distribution and performance[28,29]. Future integration of AI and wearable technologies, as suggested by Molavian et al.[30], may further enhance their utility in dynamic assessments. Limitations of this study include a relatively homogeneous sample composed solely of young adults, which may limit the generalizability of the findings to older populations or individuals with varying physical activity levels. The use of a strictly controlled laboratory environment (temperature, humidity, and standardized posture) enhances internal validity but may not fully reflect real-world variability. Additionally, the analysis was confined to static plantar pressure assessment; therefore, dynamic conditions such as walking or running were not evaluated, which could offer further insights into functional performance. Minor discrepancies in midfoot measurements also highlight the need for further system calibration and refinement in sensor sensitivity.

Conclusion

In conclusion, Analiz Sistem and Sensor Medica have demonstrated excellent reliability and agreement for assessing foot metrics across static and dynamic conditions. The high ICC values, low SEM, and minimal systematic bias validate their use as accurate and consistent tools for both clinical and sports applications. These systems offer a cost-effective and portable alternative to traditional force-plate systems, making them suitable for diverse environments, including rehabilitation clinics and athletic training settings. The Analiz Sistem, in particular, can be effectively utilized during rehabilitation processes to monitor plantar pressure changes, guide individualized treatment, and track patient progress**.** Future research should explore their integration with advanced technologies, such as AI-driven analytics, to further enhance precision and expand applicability to diverse populations, including individuals with foot pathologies and older adults. These advancements will solidify their role in improving patient outcomes and advancing the field of biomechanics.

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