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Intra-Rater Reliability of a Novel Isometric Dynamometer for Trunk Extensor Strength Assessment in Healthy Young Adults

Fiabilidad intraevaluador de un nuevo dinamómetro isométrico para la evaluación de la fuerza extensora del tronco en adultos jóvenes sanos

Confiabilidade intra-avaliador de um novo dinamômetro isométrico para avaliação da força extensora do tronco em adultos jovens saudáveis.

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Abstract

Introduction: Assessment of trunk muscle strength is crucial for evaluating physical performance and postural stability. While isokinetic dynamometers are the gold standard for these measurements, their cost and complexity limit accessibility. More practical and reliable alternatives are needed. **Objective:** To determine the intra-rater reliability of a novel isometric fixed-frame dynamometer for assessing trunk extensor strength in healthy young adults. **Methods:** This intra-rater reliability study included 41 university students (13 men, 28 women). Participants performed three maximal isometric voluntary contractions (MIVC) of trunk extension in a standardized seated position across two sessions, one week apart. Intra-rater reliability was assessed using a 2-way mixed-effects consistency intraclass correlation coefficient (ICC3,1), standard error of measurement (SEM, SEM%), and minimal detectable change (MDC, MDC%). **Results:** Intra-rater reliability was excellent (ICC = 0.90, 95% CI: 0.82–0.94), with an SEM of 5.12N (1.21%), and an MDC of 6.27N (1.39%), indicating a minimal measurement error. **Conclusions:** The novel isometric dynamometer demonstrated high intra-rater reliability and low measurement error, supporting its use for trunk extensor strength assessment in healthy young adults. Future research should explore its applicability in clinical populations and in different age groups.

Keywords: Muscle Strength Dynamometer. Reproducibility of results. Outcome Measurement Errors. Muscle Skeletal.

Resumen

Introducción: La evaluación de la fuerza muscular del tronco es crucial para evaluar el rendimiento físico y la estabilidad postural. Si bien los dinamómetros isocinéticos son el estándar de oro para estas mediciones, su costo y complejidad limitan su accesibilidad. Se necesitan alternativas más prácticas y confiables. **Objetivo:** Determinar la confiabilidad intraevaluador de un nuevo dinamómetro isométrico de marco fijo para evaluar la fuerza

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extensora del tronco en adultos jóvenes sanos. **Metodos:** Este estudio de confiabilidad intraevaluador incluyó a 41 estudiantes universitarios (13 hombres, 28 mujeres). Los participantes realizaron tres contracciones voluntarias isométricas máximas (MIVC) de extensión del tronco en una posición sentada estandarizada en dos sesiones, con una semana de diferencia. La confiabilidad intraevaluador se evaluó mediante un coeficiente de correlación intraclase de consistencia de efectos mixtos de dos vías (ICC_3, ICC_3), error estándar de medición (SEM, SEM%) y cambio mínimo detectable (MDC, MDC%). **Resultados:** La fiabilidad intraevaluador fue excelente (CCI = 0,90; IC del 95 %: 0,82-0,94), con un error estándar de la media (SEM) de 5,12 N (1,21 %) y un MDC de 6,27 N (1,39 %), lo que indica un error de medición mínimo. **Conclusiones:** El nuevo dinamómetro isométrico demostró una alta fiabilidad intraevaluador y un bajo error de medición, lo que respalda su uso para la evaluación de la fuerza extensora del tronco en adultos jóvenes sanos. Se recomienda en futuras investigaciones explorar su aplicabilidad en poblaciones clínicas y en diferentes grupos de edad.
Palabras - clave: Dinamómetro de fuerza muscular. Reproducibilidad de los resultados. Errores de medición de resultados. Músculo esquelético.

Resumo
Introdução: A avaliação da força muscular do tronco é crucial para avaliar o desempenho físico e a estabilidade postural. Embora os dinamômetros isocinéticos sejam o padrão ouro para essas medições, seu custo e complexidade limitam a acessibilidade. Alternativas mais práticas e confiáveis são necessárias. **Objetivo:** Determinar a confiabilidade intra-avaliador de um novo dinamômetro isométrico de estrutura fixa para avaliar a força extensora do tronco em adultos jovens saudáveis. **Métodos:** Este estudo de confiabilidade intra-avaliador incluiu 41 estudantes universitários (13 homens, 28 mulheres). Os participantes realizaram três contrações isométricas voluntárias máximas (CIVM) de extensão do tronco em uma posição sentada padronizada em duas sessões, com uma semana de intervalo. A confiabilidade intra-avaliador foi avaliada usando um coeficiente de correlação intraclasse de consistência de efeitos mistos de duas vias (ICC3,1), erro padrão de medida (EPM, EPM%) e mudança mínima detectável (CMD, CMD%). **Resultados:** A confiabilidade intra-avaliador foi excelente (ICC = 0,90, IC 95%: 0,82–0,94), com um erro padrão da medida (EPM) de 5,12 N (1,21%) e uma diferença mínima detectável (DMD) de 6,27 N (1,39%), indicando um erro de medição mínimo. **Conclusões:** O novo dinamômetro isométrico demonstrou alta confiabilidade intra-avaliador e baixo erro de medição, o que justifica seu uso para avaliação da força extensora do tronco em adultos jovens saudáveis. Pesquisas futuras devem explorar sua aplicabilidade em populações clínicas e em diferentes faixas etárias.
Palavras - chave: Dinamômetro de força muscular. Reprodutibilidade dos resultados. Erros de medição. Músculo esquelético.

Introduction

Trunk muscle strength plays a fundamental role in postural stability and overall functional performance. The trunk acts as a central link in the kinetic chain, facilitating energy transfer between the upper and lower limbs, which is crucial for maintaining balance and executing daily and sports-related activities[1]. Additionally, assessing trunk muscle strength is essential for monitoring neuromuscular adaptations to exercise interventions and for evaluating musculoskeletal conditions that may impact functional capacity[2].

Isokinetic dynamometers are widely recognized as the gold standard for muscle strength assessment, due to their high validity and reliability across different muscle groups. These devices allow precise control over contraction type, range of motion, and body positioning, ensuring accurate and reproducible measurements[3-6]. However, their practical application is significantly limited by high costs, operational complexity, and restricted availability in clinical and field settings[7-9]. To address these limitations, handheld dynamometers (HHDs) have been suggested as a cost-effective and portable alternative for clinical use[10-11].

Despite the advantages of HHDs, concerns remain regarding their reliability, particularly in the assessment of isometric trunk extensor strength. Unlike isokinetic systems, HHDs rely on manual stabilization, which introduces variability due to examiner-dependent factors. Small changes in evaluator positioning or compensatory movements by the subject can lead to inconsistent measurements, affecting both intra- and inter-rater reliability[12]. Several stabilization methods, including the use of straps and external supports, have been proposed to mitigate these limitations. However, systematic errors persist, and conflicting results regarding their reproducibility have been reported in the literature[2,13-17].

In response to these challenges, recent technological advancements have led to the development of fixed-frame dynamometers designed to enhance measurement consistency while maintaining portability and ease of use. These devices, which can be securely attached to existing structures, reduce the variability introduced by manual stabilization and may offer improved reliability compared to traditional HHDs[18-22]. In particular, isometric dynamometers with wireless data transmission capabilities represent a promising innovation, allowing real-time data collection and analysis, while minimizing evaluator influence. However, despite their potential, the intra-rater reliability of such devices in assessing trunk extensor strength in healthy individuals remains largely unexplored.

Given this gap in the literature, the present study aims to evaluate the relative and absolute intra-rater reliability of a novel isometric dynamometer for assessing trunk extensor muscle strength in healthy individuals.

Methods

Study Design and Ethical Aspects

This study followed an intra-rater reliability design, to assess the variability in measurements taken by a single rater across multiple trials[22]. Data collection occurred between November and December 2023, with each participant attending two laboratory sessions, lasting approximately 40 minutes each, separated by a 7-day interval. All sessions were conducted on the same weekday. The assessments took place in a controlled environment within the Laboratory of Clinical Exercise Physiology at the Faculty of Ceilândia (FCE).

The study protocol was reviewed and approved by the Ethics and Research Committee of FCE (registration: CAAE n° 97587018.0.0000.8093). All participants provided written informed consent before enrollment, after receiving detailed explanations about the study procedures and potential risks.

Participants

The inclusion criteria required participants to be healthy young adults, aged between 18 and 35 years. Exclusion criteria included any orthopedic or musculoskeletal disorders, acute or chronic pain during data collection (either spontaneous or induced by trunk movement), or a history of spinal fracture treated conservatively or surgically. A self-reported questionnaire was used to confirm eligibility[24,25].

Participants were recruited through non-probabilistic sampling. Invitations were disseminated via flyers on the social media platforms of the Academic Center of Physiotherapy at FCE (Instagram and Facebook), as well as through WhatsApp messages sent to local academic groups. Interested individuals completed a web-based screening questionnaire to verify their eligibility (sex and age) and received information on the study location and schedule. The final exclusion criteria were applied in person during the participants' first visit to the laboratory.

Instruments

The sex and age were obtained by a web-based screening questionnaire. The body mass of the participants was measured in Kilograms (Kg) using a digital platform (Fiziola 2015, São Paulo, SP, Brazil). A stadiometer (Sanny ES 2040, São Bernardo do Campo, SP, Brazil) was used to measure the height of the participants. Only one measurement was performed for body mass and height variables.

Participants were assessed using the Kinology Traction Dynamometer, a portable device designed for clinical and sports assessments, from Kinology Tecnologia em Saúde LTDA (Brazil)[26]. The device features a high-impact polystyrene casing produced via 3D printing, ensuring durability and lightweight handling. It measures 12.5 × 6.4 × 2.4 cm and weighs 170 g, making it compact and easily transportable. The dynamometer is equipped with a load sensor capable of measuring forces up to 300 kgf (~2942 N), with a sampling rate of 10 Hz, providing high temporal resolution. It operates on a 3.7 V, 650 mAh lithium-ion polymer battery, ensuring prolonged use. Real-time force data visualization is available via the Kinology app, compatible with Android and iOS, which also offers data storage for longitudinal monitoring of strength changes. The system features Bluetooth connectivity for wireless data transfer and digital reporting, enhancing efficiency in data collection and analysis. The Kinology Traction Dynamometer and its software are certified by the Brazilian National Institute of Industrial Property (INPI).

The measurement of maximum isometric muscle strength was performed with participants sitting in a specific chair designed to aid physiotherapy (avaliable at: www.carcioficial.com.br/bonnet) with the following dimensions: length 76 centimeters; width 85 centimeters; height 75 centimeters. As an accessory to the chair, an existing inelastic belt was used to stabilize the pelvis of the participants at the level of the anterior superior iliac spines, in order to minimize the action of the hip extensor muscles that could occur in association with the trunk extension movement. Another inelastic belt (available at: www.elastos.com.br/acessórios/cinturão) encircling the chest of the participants (positioned on the xiphoid process) was connected, with a 150 cm steel chain, to the dynamometer fixed to the wall in front of the patient. A pair of steel carabiners (avaliable at: www.elastic.fit) was used to attach the chain to the chest belt and the dynamometer.

Procedures

Following web-based screening and participant inclusion, demographic and anthropometric data were collected during the first laboratory visit. Subsequently, the warm-up, familiarization, and strength assessment procedures commenced. A five-minute interval was maintained between these phases. During all procedures, participants remained seated in a standardized position with their feet off the ground. The trunk was positioned at 10 flexion to prevent contact between the upper back and the chair, ensuring consistent posture throughout the assessment[27]. The arms were crossed over the chest, with each hand placed on the opposite shoulder. The dynamometer was individually adjusted to the participant's height to maintain a standardized 90° angle between the traction chain and the torso.

During the warm-up, participants performed 10 guided trunk extension movements to familiarize themselves with the correct motion pattern. No rest intervals were provided between repetitions, and participants were instructed to gradually increase the contraction intensity with each repetition. Familiarization trials consisted of three submaximal isometric contractions held for five seconds each, with a two-minute rest interval between trials. Contraction intensity during familiarization was standardized at level 6 (somewhat hard) using the OMNI-Resistance Exercise Scale[28], with no verbal encouragement provided.

Five minutes after familiarization, participants performed three maximal isometric voluntary contractions of trunk extension, each maintained for five seconds, with a two-minute interval between trials[29]. Verbal encouragement was provided to ensure maximal effort during each contraction.

To minimize potential measurement bias, both the rater and participants were blinded to force output values. After each session, a separate researcher, who was not blinded, extracted and recorded the data into a Microsoft Excel spreadsheet. The retest session was conducted seven days later, following identical procedures. The rater, a physical education professional with 11 years of experience in strength assessment, was responsible for conducting all testing sessions.

Participants were instructed to maintain their usual levels of daily physical activity between test sessions. Specific restrictions included avoiding changes in physical activities related to household tasks, self-transport (non-motorized locomotion), occupational activities (paid or voluntary work), and recreational screen time unrelated to school or work. Additionally, participants were advised to refrain from any structured leisure physical activities (e.g., sports, exercise, and recreational activities such as walking or dancing) for 48 hours before both test and retest sessions. These recommendations were based on the World Health Organization guidelines[30].

Statistical Analysis

Sample size estimation was conducted using the hypothesis testing approach for intraclass correlation coefficient (ICC) reliability analysis[23]. The null hypothesis (H_0: $\rho = \rho_0$) was tested against the alternative hypothesis (H_a: $\rho > \rho_0$), with a minimum reliability threshold set at 0.75 and an expected ICC of 0.90. Assuming a significance level of 0.05 and a statistical power of 80%, the required sample size was determined to be 30 participants. To account for a potential dropout rate of 15%, the final sample size was adjusted to 41 participants. The sample size calculation formula is available online (http://wnarifin.github.io).

Descriptive statistics were used to summarize participants' sociodemographic characteristics, including sex, age, body mass, height, and body mass index. The main outcomes (reliability, agreement, and minimal detectable change) were determined using the average peak force of the MIVC across three trials. Data normality was assessed using the Shapiro-Wilk test, which confirmed normal distribution ($p > 0.05$). Statistical significance was set at $p < 0.05$ for all analyses.

Relative reliability was evaluated using the intraclass correlation coefficient ($ICC_{3,1}$) with a 95% confidence interval (CI)[31]. The model was specified as a two-way mixed-effects design, with a single rater and consistency definition[23]. The study used a two-way mixed-effects model (ICC3,1) to estimate intra-rater reliability. This model was chosen because it accounts for systematic differences between measurements while assuming that the selected rater is the only one of interest. Alternative models, such as ICC2,1, were not used because they assume raters are randomly selected from a population, which was not applicable in the current study. The consistency definition was applied instead of absolute agreement to focus on the degree to which measurements maintain proportionality across trials. ICC values were classified as excellent (≥0.90), good (0.75–0.90), moderate (0.50–0.75), or poor (<0.50) (Koo & Li, 2016a). The effect size for the intraclass correlation coefficient (ICC) was estimated using Cohen's *f* [32-33]. According to Cohen's classification, values of 0.10, 0.25, and 0.40 represent small, medium, and large effect sizes.

Absolute reliability was assessed using the standard error of measurement (SEM) and minimal detectable change (MDC), including their respective percentage values (SEM% and MDC%)[34]. SEM was calculated as the standard deviation of test-retest scores divided by the square root of 1 – ICC. SEM% was derived by dividing the SEM by the mean test-retest score and multiplying by 100. MDC was determined using the formula MDC = 1.96 × √2 × SEM, with MDC% obtained by dividing MDC by the mean test-retest score and multiplying by 100. MDC calculations were based on a 95% confidence threshold (MDC95), ensuring the highest level of measurement precision.

Data processing and statistical analyses were performed using SPSS (version 25.0), Microsoft Excel (version 16.74), and GraphPad Prism (version 9.2.1).

Results

Descriptive data of participants' characteristics are presented in Table 1. Males and females were analyzed separately. Statistical differences between sexes were found for body mass and height. Forty-one university students (13 men [31.7%] and 28 women [68.3%]) participated in this study and were included in the chi-square test analysis. The results indicated a significant difference between the groups (p=0.01).

The results of the single rater assessments between repetitive measures of isometric peak strength of trunk extensor muscles demonstrated an ICC of 0.90 (excellent intra-rater reliability) with the CI 95% ranging from 0.94 to 0.82. Standard error of measurement and MDC values showed low error values. From a practical point of view, to be considered outside the range of instrument error the differences would need to be higher than 1.21% (%SEM) and 1.39% (%MDC). The effect

Table 1. Characteristics of the participants (n=41).

Characteristic	Male	Female	Total	*p-value*
n (%)	13 (31.71)	28 (68.29)	41 (100)	P<0.001
Age (years)	20.31 (1.88)	21.43 (3.64)	21.07 (3.21)	P=0.30
Body mass	70.85 (11.53)	58 (7.29)	62.07 (10.61)	P<0.0001**
Height (cm)	1.75 (0.06)	1.61 (0.04)	1.66 (0.08)	P<0.0001**
BMI (Kg.m^{-2})	22.92 (3.02)	22.27 (2.75)	22.48 (2.82)	P=0.50

*Fisher exact test. **Unpaired *t* test. Age, body mass, height, and Body Mass Index (BMI) are expressed as mean (SD). A p-value below 0.05 was considered significant.

size for the intraclass correlation coefficient (ICC) was 3.00 (95% CI: 2.14 – 3.96), indicating a very large effect.

Discussion

The current study aimed to assess the relative and absolute intra-rater reliability of trunk extensor muscle strength measurements using a novel isometric dynamometer. Establishing the measurement properties of practical and portable tools is essential for providing reliable strength assessments in clinical and sports settings. The findings of this study support the high reliability of the proposed method, suggesting its applicability for professionals in rehabilitation and performance monitoring. Compared to previous studies using digital load cells in laboratory-controlled environments[35], this device offers the advantage of portability, while maintaining strong reliability indicators. The ability to perform precise and consistent trunk strength assessments outside of specialized laboratory settings may facilitate the broader adoption of objective muscle function assessments in various professional environments, including physiotherapy, sports science, and occupational health.

The methodological choices in the current study align with best practices for reliability assessments, as outlined by Polit et al., (2014)[36] and Weir et al. (2005)[37]. These papers emphasize that reliability evaluations must account for both systematic and random errors, as failure to do so may overestimate the consistency of a measurement tool. The current study addressed these concerns by incorporating absolute reliability metrics, including the standard error of measurement and minimal detectable change, which provide a more comprehensive assessment of measurement precision, that goes beyond relative reliability indicators such as the intraclass correlation coefficient. Additionally, it should be highlighted that test-retest reliability studies should standardize key procedural variables, such as participant positioning, warm-up protocols, and rest intervals, to minimize variability unrelated to the construct being measured[37]. In the current study, a controlled testing environment was maintained, and a strict protocol was

Table 2. Data on relative and absolute reliability.

Variable	Test Mean (±SD)	Retest Mean (±SD)	ICC (95% CI)	SEM (%SEM)	MDC (%MDC)
MIVC (N)	424.53 (23.32)	478.49 (21.94)	0.90 (0.94-0.82)	5.12 (1.21)	6.27 (1.39)

MICV = maximal isometric voluntary contraction (in Newtons); ICC: intraclass correlation coefficient; SEM = standard error measurement (in Newtons); MDC = minimal detectable change (in Newtons); %MDC = percentage of minimal detectable change; (%SEM) = percentage of standard error measurement.

followed, to ensure consistency across trials. The use of a fixed dynamometer setup, standardized instructions, and blinding of strength values further reduced potential sources of measurement bias.

Few studies have investigated novel dynamometers for assessing trunk extensor muscle strength. Azghani et al. (2009)[38] developed a triaxial isometric trunk strength measurement system to assess force generation in multiple planes. Although the authors reported moderate to excellent intra-rater reliability, with ICC values ranging from 0.69 to 0.91, the evidence was considered low quality due to a high risk of bias and imprecision. In addition, the device required complex calibration procedures, which may limit its feasibility for routine clinical use. Similarly, Sasaki et al. (2018)[27] evaluated a portable trunk muscle torque measurement instrument and found moderate reliability, with ICC values between 0.79 and 0.81 for trunk extension strength, but the lack of methodological details on standardization and measurement protocols raises concerns about reproducibility. Pienaar and Barnard (2017)[39] tested a pressure air biofeedback device and reported an ICC of 0.99 for trunk extension strength in both asymptomatic individuals and those with low back pain. Despite their high reliability, pressure air devices focus primarily on biofeedback rather than direct force measurement, making them less comparable to traditional dynamometry. Yang et al. (2019)[40] investigated the reliability and validity of three isometric back extensor strength assessment methods, using different postural positions: standing, prone, and sitting. The study included 60 asymptomatic adults, and measurements were performed using an externally fixed dynamometer. The findings demonstrated excellent test-retest reliability, with ICC values of 0.92 for standing, 0.93 for prone, and 0.90 for sitting. A common trend across these studies is the trade-off between device complexity, portability, and reliability. Devices with multi-planar capabilities or sophisticated calibration tend to offer high precision but are difficult to implement outside laboratory conditions. Another limitation in previous research is the lack of absolute reliability measures, such as the standard error of measurement and minimal detectable change, which are critical for interpreting meaningful changes in muscle strength over time.

Although the ICC is the main method adopted to measure reliability, the variance components are attributed to the study design component of subject variability and not to the size of the rater error variability[41]. Therefore, to complement the reliability analysis, the use of statistical properties of absolute reliability are important to researchers and health professionals[10]. The present study used the SEM and SEM% methods, which demonstrated small within subject variability between trials, of 5.12N (1.21%). In the same way, group-level error data demonstrated by the MDC (%MDC) indicate that a professional can be 95% confident that an observed change greater than 6.27N (1.39%) is a detectable change, because this value exceeded the measurement error. These small values of error data are important to physical therapists and physical education professionals for establishing the real change in a measurement tool, in order to identify whether the treatment was effective or not. Furthermore, as there are no cut-off values to ensure the precision related to measurement errors, the variability between repetitive measures lower than 10% could be appropriate for clinical and research objectives[42]. These findings reinforce the practical relevance of the observed reliability, as the effect size of the ICC further contextualizes the measurement precision. While ICC values indicate the consistency of repeated measures, effect size quantifies the proportion of true variance relative to total variance. According to Cohen's benchmarks, a large ICC effect size suggests minimal measurement error and strong reproducibility, further supporting the applicability of this assessment tool. The inclusion of absolute reliability measures, such as SEM and MDC, provides additional insight into the precision of the measurements. While ICC values indicate the degree of relative agreement, SEM reflects the extent of measurement error in absolute terms, making it a crucial metric for clinicians and researchers. The low SEM% values indicate minimal variability between measurements, reinforcing the reproducibility of the test in healthy individuals. Additionally, the MDC values provide a threshold for detecting real changes in isometric trunk strength, ensuring that variations greater than 6.27N (1.39%) can be attributed to actual performance differences rather than measurement error. These findings suggest that the dynamometer is a reliable tool for assessing trunk strength in the context of physical evaluation and performance monitoring in young adults.

In the literature, large variations are reported in methods used to assess isometric trunk extensor strength of asymptomatic groups using strain gauge dynameters. The difference between study properties is related to the test-retest interval (e.g., 24 hours; 48 hours; 24-72 hours; 1 week), different test positions (e.g., standing; upright sitting; prone back extension; siting; kneeling position), number of associated movement measures (e.g., flexion, right and left rotation), and protocols to obtain the MIVC (e.g., the highest peak force from a number of contractions; the average of the highest peak forces of each contraction)[43]. Particularly, large variability in trunk extension strength values is reported due to the possible co-contractions of lower limb muscles according to a respected position (e.g., quadriceps)[44]. To isolate lumbar position, some authors recommend that participants use the seated position, with thighs and hips fixed by straps, allowing only for extension movement[45]. In the present study this approach and position were used. Regarding the statistical analysis of outcomes adopting the average of 3 MIVCs of trunk extension between repetitive measures, this approach probably leads to decreased variability between subjects[9].

The current study ´presents some limitations. The use of a 2-way mixed-effects model restricts the reliability estimates to the specific rater involved, preventing generalization to other evaluators, even those with similar training. Additionally, the findings cannot be extrapolated to different populations, spinal conditions, or alternative testing protocols with other devices and positioning methods. in addition, the study did not assess inter-rater reliability, which is essential for determining consistency across different examiners. Furthermore, the sample size, while adequate for reliability analysis, was not large enough to allow for sex-based comparisons, limiting the ability to explore potential differences between men and women.

Conclusion

The current study analyzed the intra-rater reliability of a novel isometric dynamometer for assessing trunk extensor strength in healthy young adults. The results demonstrated high relative reliability, with an ICC of 0.90, and low absolute measurement error, as indicated by the SEM and MDC values. These findings suggest that the device provides consistent and precise measurements, supporting its potential use in clinical and sports settings for young adults.

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