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Dynamic Field Assessment of Hip Adductor Function Using a Smartphone-Based Copenhagen Test: Reliability and Concurrent Associations with Isometric Strength in Amateur Football Players

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Abstract

Assessing hip adductor muscle strength is important for identifying weakness or side-to-side imbalances associated with groin injury risk. Although the Copenhagen adductor test is widely used to evaluate adductor function, the quantification of strength-related variables using inertial sensors during this task has not been systematically examined. This study aimed to evaluate the reliability of a smartphone-based Copenhagen adductor field test and its associations with established isometric hip adductor strength assessments. Twenty amateur male football players (21.1 ± 3.2 years) completed two laboratory sessions separated by one week. Reliability of the smartphone-based test was assessed for endurance (repetition count) and strength-related outcomes (mean repetition time and peak velocity) using intraclass correlation coefficients (ICC), standard error of measurement (SEM), and minimum detectable change (MDC). Participants also performed unilateral and bilateral isometric hip adductor tests using load cells and force platforms to obtain isometric peak force (IPF) and rate of force development at 150 ms (RFD150). Associations were examined using Pearson correlation coefficients. The smartphone-based test demonstrated moderate-to-good reliability (ICC = 0.63–0.83; SEM = 6.7–18.5%). Endurance-related outcomes were not significantly associated with IPF or RFD150. In contrast, peak velocity showed moderate correlations with IPF ($r = 0.50–0.64$) and RFD150 ($r = 0.48–0.63$; $p < 0.05$). These findings indicate that velocity-derived metrics provide a reliable and practical field-based complement to conventional isometric assessments, although further longitudinal research is required to determine their predictive or preventive value.

Keywords: groin injury; hip adduction torque; wearable sensors; field-based testing; consistency; rate of force development

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Introduction

Hip adductor strength assessment has become a central focus in sports medicine due to its role in groin injury risk and rehabilitation in field-based team sports [1–4]. High-intensity actions such as rapid accelerations, decelerations, changes of direction, and kicking expose the groin region to substantial mechanical stress, particularly affecting the adductor longus muscle [5,6]. Reduced adductor strength has consistently been identified as a risk factor for groin-related problems and is therefore widely monitored in both clinical and performance settings [1–4,7].

Several devices and protocols have been used to measure the hip adductor muscle strength. Although isokinetic dynamometry is considered the gold standard, its limited portability and high cost restrict field application [8]. Consequently, handheld dynamometers [9], sphygmomanometers [10], and load cell–based systems [11,12] are commonly adopted in practice and demonstrate acceptable validity and reliability [13]. However, these tools primarily assess static force production and may be limited by inter-rater variability or practical constraints in applied environments.

The Copenhagen adductor exercise [14,15] has emerged as a widely implemented strengthening strategy and has recently been explored as an assessment tool for eccentric adductor capacity [12,16]. Given its functional and sport-specific characteristics, extending its application toward objective field-based monitoring may be clinically valuable. In parallel, inertial measurement units (IMUs) have gained attention for quantifying movement velocity and repetition characteristics during bodyweight exercises [17,18] Despite this potential, no studies have examined whether velocity- or repetition-based metrics derived from IMUs during a Copenhagen adductor task align with established isometric hip adduction strength measures.

Therefore, the primary aim of this study was to evaluate the reliability of a smartphone-based Copenhagen adductor field test and to examine its associations with conventional isometric hip adductor strength assessments. Based on prior research, we hypothesized that strength-related velocity metrics would demonstrate acceptable reliability [18] and show stronger associations with isometric peak force and rate of force development than endurance-related outcomes.

Methods

Participants

Twenty amateur male football players (mean ± SD: age 21.06 ± 3.24 years; body mass 69.79 ± 9.63 kg; height 1.75 ± 0.08 m) volunteered to participate. All participants were physically active and engaged in 1–3 hours of combined football and resistance training, three to four times per week. An a priori sample size calculation was performed using G*Power (version 3.1, Düsseldorf, Germany). Based on previous methodological recommendations and comparable literature [19,20] a moderate expected correlation ($r = 0.60$) was assumed. Under these conditions, a minimum of 19 participants was required to achieve 80% statistical power at an alpha level of 0.05.

Inclusion criteria required participants to be aged between 18 and 35 years and free from lower-limb joint pathology (past six months), lower-limb muscle injury (past three months), lower-limb surgery (past 12 months), and any pain or discomfort at the time of testing. All participants were fully informed about the procedures and provided written informed consent prior to participation. The study was conducted in accordance with the Declaration of Helsinki and approved by the University Office for Research Ethics (code: DCD.JLE.01.20).

Procedures

Participants completed two testing sessions (approximately 30 min each) in a university-based biomechanics laboratory, separated by one week to minimise residual fatigue. Prior to testing, personal and medical history were recorded, along with anthropometric measurements including body mass, height, and lower-limb length (measured from the anterior superior iliac spine to the most prominent aspect of the medial malleolus) [21] (Table 1). Leg dominance was defined retrospectively as the limb producing the higher normalised isometric peak force during the unilateral hip adduction test. This approach was selected instead of self-reported kicking preference, as strength dominance may be more relevant for injury screening and does not necessarily coincide with functional preference. Limb testing order was counterbalanced to minimise potential fatigue or order effects.

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Table 1. Participants' characteristics data.

		Mean ± *SD*	**Units**
	Age	21.06 ± 3.24	years
	Body mass	69.79 ± 9.63	kg
	Height	1.75 ± 0.08	m
	Leg length	0.90 ± 0.05	m
Unilateral hip adductor test	**Normalised IPF of non-dominant leg**	2.19 ± 0.56	N·m·kg^{-1}
	Normalised IPF of dominant leg	2.53 ± 0.63	N·m·kg^{-1}
	Normalised RFD$_{150}$ of non-dominant leg	4.30 ± 1.23	N·m·kg^{-1}·s^{-1}
	Normalised RFD$_{150}$ of dominant leg	4.75 ± 2.92	N·m·kg^{-1}·s^{-1}
Supine Squeeze test	**Normalised IPF**	2.32 ± 0.62	N·m·kg^{-1}
	Normalised RFD$_{150}$	4.48 ± 1.65	N·m·kg^{-1}·s^{-1}

SD: Standard deviation; **IPF**: Isometric peak force; **RFD$_{150}$**: Rate of force development at the first 150 ms.

Before each session, participants performed a standardised football-specific warm-up consisting of dynamic running drills (two sets of 30 m each), including straight running, hip-out, hip-in, circling partner, shoulder contact, and rapid forward–backward movements, following established protocols [22]. All exercises were completed at a self-selected moderate intensity under investigator supervision to ensure consistency. Participants were familiarised with all procedures prior to data collection.

During the first session, participants performed three maximal repetitions of the unilateral isometric hip adduction test per limb (60 s rest between repetitions and limbs), followed by two 20-s sets of the Copenhagen adductor exercise per limb (2 min rest between sets). The starting limb was counterbalanced. The testing order was fixed, as the dynamic Copenhagen task was expected to induce greater fatigue than the isometric assessments.

In the second session, participants completed the supine squeeze test, followed by a repeated 20-s Copenhagen adductor task under identical conditions to assess test–retest reliability. All sessions were conducted at the same time of day to minimise diurnal variation. Participants were instructed to refrain from caffeine intake and strenuous physical activity for 24 hours prior to testing.

Measurements

Smartphone-Based Copenhagen Adductor Field Test

The inertial sensor–based Copenhagen adductor field test was performed with participants in a side-lying position, supported on the forearm with the elbow vertically aligned under the shoulder. The test leg was placed on a 45-cm bench, while the contralateral leg remained extended and relaxed beneath it (Figure 1A). A vertical reference bar positioned at pelvic height provided external feedback. Participants were instructed to raise their hips until gently contacting the bar, ensuring consistent end-range positioning across repetitions. The standardized verbal instruction was: “Raise your hips as fast as possible, repeating the movement until exhaustion or until the tester’s signal after 20 seconds.” Participants were instructed to return fully to the starting position on each repetition, consistent with recommendations for dynamic endurance tasks [23]. The non-tested leg was maintained in a horizontal position to prevent momentum from limb swing. A smartphone (iPhone® 7, Apple Inc., Cupertino, CA, USA) was secured at the lower lumbar region using an adjustable Velcro® belt. This location was selected due to its proximity to the body’s centre of mass and reduced soft-tissue artefacts. Acceleration data were sampled at 200 Hz using the ForceData application (My Jump Lab, Carlos Balsalobre, Spain).

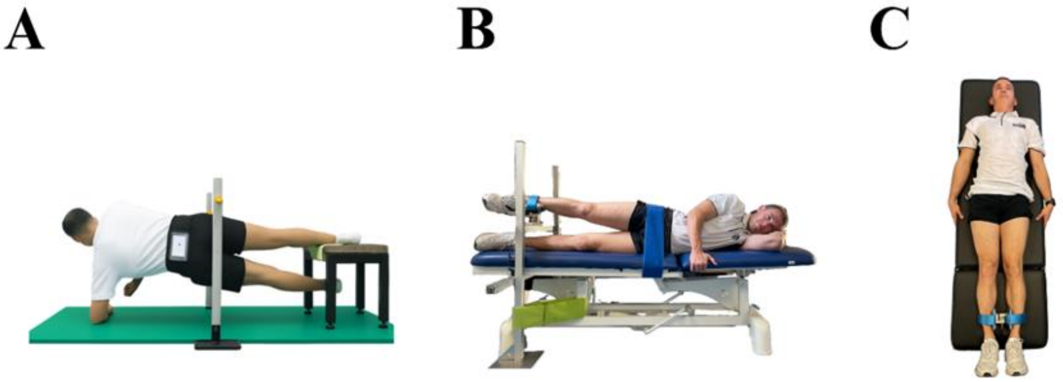

Figure 1. Assessment of hip adductor muscle strength tests: Copenhagen Adduction Exercise (A), unilateral hip adductor test (B), and Supine squeeze test (C), using an inertial sensor (A) and a load cell (B, C).

Unilateral Isometric Adductor Strength Test

For the unilateral hip adductor strength test, participants were positioned in a side-lying position on a custom-built frame, with the test limb extended and placed above a load cell mounted on an adjustable-height bench (Figure 1B). The load cell was secured 10 cm above the medial malleolus of the test limb, while the contralateral limb remained extended and relaxed beneath the bench. The pelvis was stabilised using a strap to minimise compensatory movements [24]. A portable S-Type stainless steel load cell (Model 620 Tedea-Huntleigh, Vishay Precision Group Inc., Holon, Israel) was interfaced with Chronojump software (Chronojump Bosco System, Barcelona, Spain). The load cell was calibrated before each session using a standard 10-kg weight in accordance with manufacturer guidelines. Each trial consisted of a 5-second maximal voluntary isometric contraction following the verbal cue: “Contract as hard and as fast as possible and maintain the effort until instructed to relax.” Three trials were performed per limb with 15 seconds of rest between attempts [25].

Supine Squeeze Test

For the supine squeeze test, participants lay in a supine position with both lower limbs extended. The load cell was positioned 10 cm proximal to the medial malleoli following established protocols [26] (Figure 1C). This long-lever configuration has been shown to effectively assess adductor longus function, and supine testing with fixed dynamometry demonstrates high reliability ($0.87 \leq ICC \leq 0.96$; $SEM \leq 14\%$) [26–28]. The test required a bilateral maximal adduction effort; therefore, unilateral values were not obtained. The same load cell and data acquisition system were used as in the unilateral protocol. Participants were instructed to avoid trunk or cervical flexion and rotation but were permitted to stabilise themselves by lightly gripping the stretcher.

Data Processing

Acceleration signals obtained from the smartphone’s built-in inertial sensor were processed using Python 3.7 through a custom pipeline. Raw tri-axial acceleration data were visually inspected and filtered using a low-pass Butterworth filter to attenuate high-frequency noise associated with soft-tissue artefacts. The resultant acceleration magnitude was calculated from the three orthogonal axes and numerically integrated over time to derive velocity profiles.

Individual repetitions were automatically segmented based on velocity peaks using the Detecta event-detection library (v0.0.5) [29], together with pandas (v1.5.3) [30] and xarray (v2022.12.0) [31]. Peak detection thresholds and minimum inter-peak distances were established through pilot testing to ensure accurate identification of concentric phases while minimising false detections. All signal processing and outcome extraction procedures were applied consistently across sessions and participants to ensure methodological reproducibility.

The following inertial sensor–derived outcomes were calculated:

- Normalised repetition count (per height·mass) in the first 10 s ($m \cdot kg^{-1}$): Repetition count was defined as the number of velocity peaks detected within the initial 10 s of the task. The total number of repetitions was normalised to participant height and body mass. Mean values across trials were retained for analysis.
- Mean time per repetition (s): The average repetition duration was calculated from the first 10 repetitions by determining the time interval between consecutive velocity peaks. Mean values were retained for analysis.
- Normalised peak velocity (per height·mass) of the first five repetitions ($m \cdot s^{-1} \cdot kg^{-1}$): Peak velocity was defined as the maximum value of the integrated velocity signal for each repetition. The mean of the first five repetitions was calculated and normalised to participant height and body mass. Mean values across trials were retained for analysis.

Isometric peak force (IPF) and rate of force development at 150 ms (RFD_{150}) obtained from the load cell were automatically extracted using Chronojump software (version 2.2.0-12, Chronojump Bosco System®, Barcelona, Spain) based on fitted force–time curves for dominant and non-dominant limbs. RFD_{150} was calculated as the maximal slope of the force–time curve within the first 150 ms of contraction [32].

For subsequent analyses, the mean of three trials was retained for the unilateral hip adductor test and the mean of three maximal attempts was retained for the supine squeeze test. Values were normalised by dividing by body mass and multiplying by leg length to allow inter-participant comparison.

Statistical Analysis

All data were screened for normality using the Shapiro–Wilk test. Potential outliers were identified as values exceeding ±3 standard deviations from the mean. Descriptive statistics are presented as mean ± standard deviation, and statistical significance was set at $p < 0.05$. Absolute and relative between-session reliability of the inertial sensor–based Copenhagen adductor test outcomes were assessed using the standard error of measurement (SEM), relative SEM (SEM%), minimum detectable change (MDC_{80}), and the intraclass correlation coefficient (ICC). SEM was calculated as the standard deviation of the paired differences divided by $\sqrt{2}$ and expressed relative to the mean outcome (SEM%). MDC_{80} was calculated as $SEM \times 1.28 \times \sqrt{2}$ ($\approx 1.81 \times SEM$), providing a more realistic threshold for detecting real changes in applied sport contexts [33]. ICCs and their 95% confidence intervals (CI) were estimated using a two-way mixed-effects model for absolute agreement ($ICC_{[3,1]}$). Reliability was interpreted as poor (<0.50), moderate (0.50–0.75), good (0.75–0.90), or excellent (>0.90) [34]. Reliability metrics were computed using a validated spreadsheet tool (www.sportsci.org).

Only inertial sensor–derived variables demonstrating at least moderate reliability (ICC > 0.50) were retained for subsequent analyses. Statistical analyses were performed using custom scripts in Python 3.7 with the Pandas (v2.2.2), NumPy (v2.0.2), and SciPy (v1.15.3) libraries [30,35,36].

Pearson correlation coefficients (r) with 95% CI were calculated to examine associations between inertial sensor outcomes and load-cell-derived unilateral isometric measures (IPF and RFD_{150}). Correlations were also calculated between equivalent outcomes across the unilateral and supine squeeze tests to assess inter-test alignment. Correlation magnitudes were interpreted as low (0.30–0.49), moderate (0.50–0.69), high (0.70–0.89), and very high (≥0.90) [37]. Agreement between isometric tests was further examined using Bland–Altman analyses, displaying mean differences and 95% limits of agreement for IPF and RFD_{150}.

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Results

Table 1 presents participant characteristics and normalised strength outcomes for the unilateral hip adductor and supine squeeze tests (mean ± SD).

Reliability analyses for the inertial sensor–based Copenhagen adductor field test demonstrated moderate-to-good reliability. For the endurance-related outcome, SEM ranged from 16.3% (dominant limb) to 17.7% (non-dominant limb), with ICC values of 0.76 and 0.62, respectively. Strength-related outcomes showed ICC values ranging from 0.63 to 0.83 and SEM values between 6.7% and 18.5% (Table 2).

Table 2. Descriptive statistics and absolute and relative between-session reliability for the outcomes from the novel inertial-sensor-based Copenhagen adductor field test.

			n	**Session 1**	**Session 2**	**SEM**		**MDC$_{80}$ (%)**	**ICC**
				(mean ± *SD*)	**(mean ± *SD*)**	**Mean [95% CI]**	%		**Mean [95% CI]**
Endurance-related outcome	**Normalised repetition count (per height·mass) in first 10 s (m·kg^{-1})**	**D**	**18**	**0.51 ± 0.18**	**0.57 ± 0.14**	**0.08 [0.07, 0.12]**	16.3	29.5	0.76 [0.53, 0.89]
		ND	18	0.49 ± 0.15	0.54 ± 0.12	0.09 [0.07, 0.12]	17.7	32.0	0.62 [0.30, 0.81]
Strength-related outcomes	**Mean time for a repetition (s)**	**D**	18	0.55 ± 0.11	0.47 ± 0.06	0.06 [0.04, 0.08]	10.3	18.6	0.65 [0.35, 0.83]
		ND	18	0.52 ± 0.09	0.47 ± 0.07	0.03 [0.03, 0.05]	6.7	12.1	0.83 [0.66, 0.92]
	Normalised peak velocity (per height·mass) of the first 5 repetitions (m·s^{-1}·kg^{-1})	**D**	18	0.21 ± 0.08	0.23 ± 0.07	0.04 [0.03, 0.05]	18.5	33.5	0.75 [0.51, 0.88]
		ND	18	0.20 ± 0.05	0.22 ± 0.05	0.03 [0.03, 0.05]	16.0	29.0	0.63 [0.31, 0.82]

D: Dominant leg; ND: Non-Dominant leg; n: Number of subjects; SD: Standard deviation; SEM: Standard error of measurement; MDC: Minimal detectable change; ICC: Intra-class correlation coefficient; CI: Confidence interval.

Given the established reliability, correlational analyses were conducted using data from the second assessment session. Table 3 presents associations between inertial sensor–derived outcomes and load-cell–derived unilateral isometric measures (IPF and RFD$_{150}$).

Table 3. Relationship between the outcomes from the novel inertial-sensor-based Copenhagen adductor field test and those from the load cell-based unilateral isometric adductor strength test.

Novel inertial-sensor-based Copenhagen field test	**Load cell-based unilateral isometric adductor strength test**	**Side**	***r***	***[95% CI]***
Normalised repetition count (per height·and mass) in first 10 s (m·kg^{-1})	**Normalised isometric peak force (per leg length and mass) (N·m·kg $^{-1}$)**	**D**	0.18	[-0.31, 0.60]
		ND	0.13	[-0.35, 0.57]
Mean time for a repetition (s)		**D**	-0.28	[-0.66, 0.21]
		ND	-0.26	[-0.65, 0.24]
Normalised peak velocity (per height and mass) of the first 5 repetitions (m·s^{-1}·kg^{-1})		**D**	**0.64***	**[0.23, 0.86]**
		ND	**0.50***	**[0.02, 0.79]**
Normalised repetition count (per height and mass) in first 10 s (m·kg^{-1})	**Normalised rate of force development (per leg length and mass) at the first 150 ms (N·m·kg $^{-1}$·s^{-1})**	**D**	0.15	[-0.34, 0.58]
		ND	0.21	[-0.29, 0.61]
Mean time for a repetition (s)		**D**	-0.43	[-0.75, 0.05]
		ND	-0.32	[-0.69, 0.17]
Normalised peak velocity (per height and mass) of the first 5 repetitions (m·s^{-1}·kg^{-1})		**D**	**0.63***	**[0.21, 0.85]**
		ND	**0.48***	**[0.01, 0.78]**

D: Dominant leg; **ND**: Non-Dominant leg; Correlation significance: * $p<0.05$.

No statistically significant relationships were observed between the endurance-related outcome and either IPF or RFD$_{150}$ ($p > 0.05$). In contrast, peak velocity during the first five repetitions demonstrated moderate and statistically significant positive correlations with both IPF (dominant: $r = 0.64$; non-dominant: $r = 0.50$; $p < 0.05$) and RFD$_{150}$ (dominant: $r = 0.63$; non-dominant: $r = 0.48$; $p < 0.05$). Although a small inverse trend was observed between mean repetition time and RFD$_{150}$, these associations did not reach statistical significance (dominant: $r = –0.43$; non-dominant: $r = –0.32$; $p > 0.05$).

Figure 2 illustrates the relationship between normalised peak velocity and IPF across tests. A moderate association was observed between the supine squeeze test and the non-dominant limb of the unilateral test (r = 0.57, p = 0.016). No significant association was found for the dominant limb, and no additional significant IPF associations were identified.

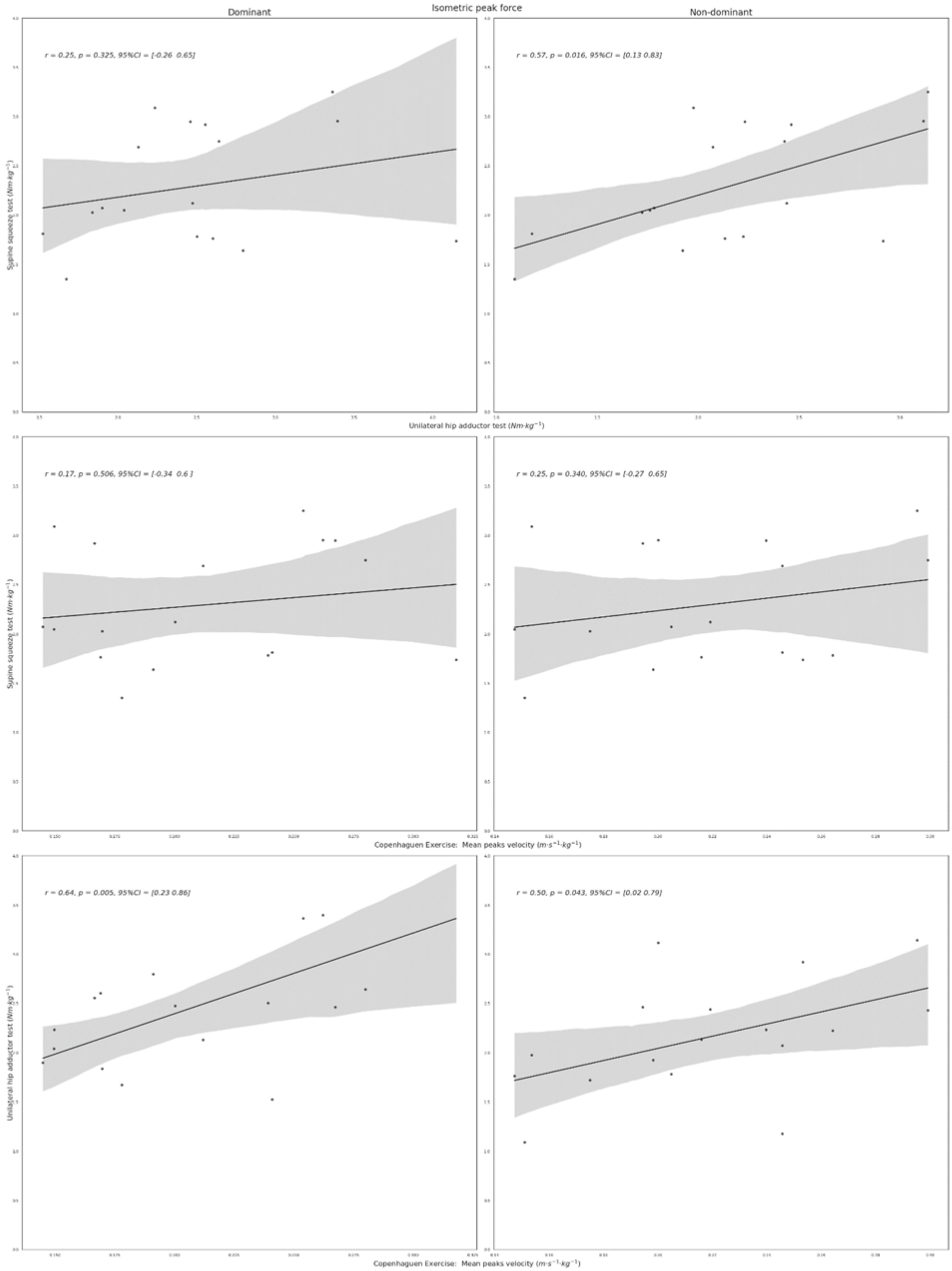

Figure 2. Alignment between isometric tests and Copenhagen adductor field-test outcomes with respect to isometric peak force (IPF). The figure displays the degree of association observed across test modalities.

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Figure 3 presents equivalent analyses for RFD_{150}. A low, non-significant association was observed between the supine squeeze test and the non-dominant limb (r = 0.39, p = 0.12), with no other significant inter-test relationships identified.

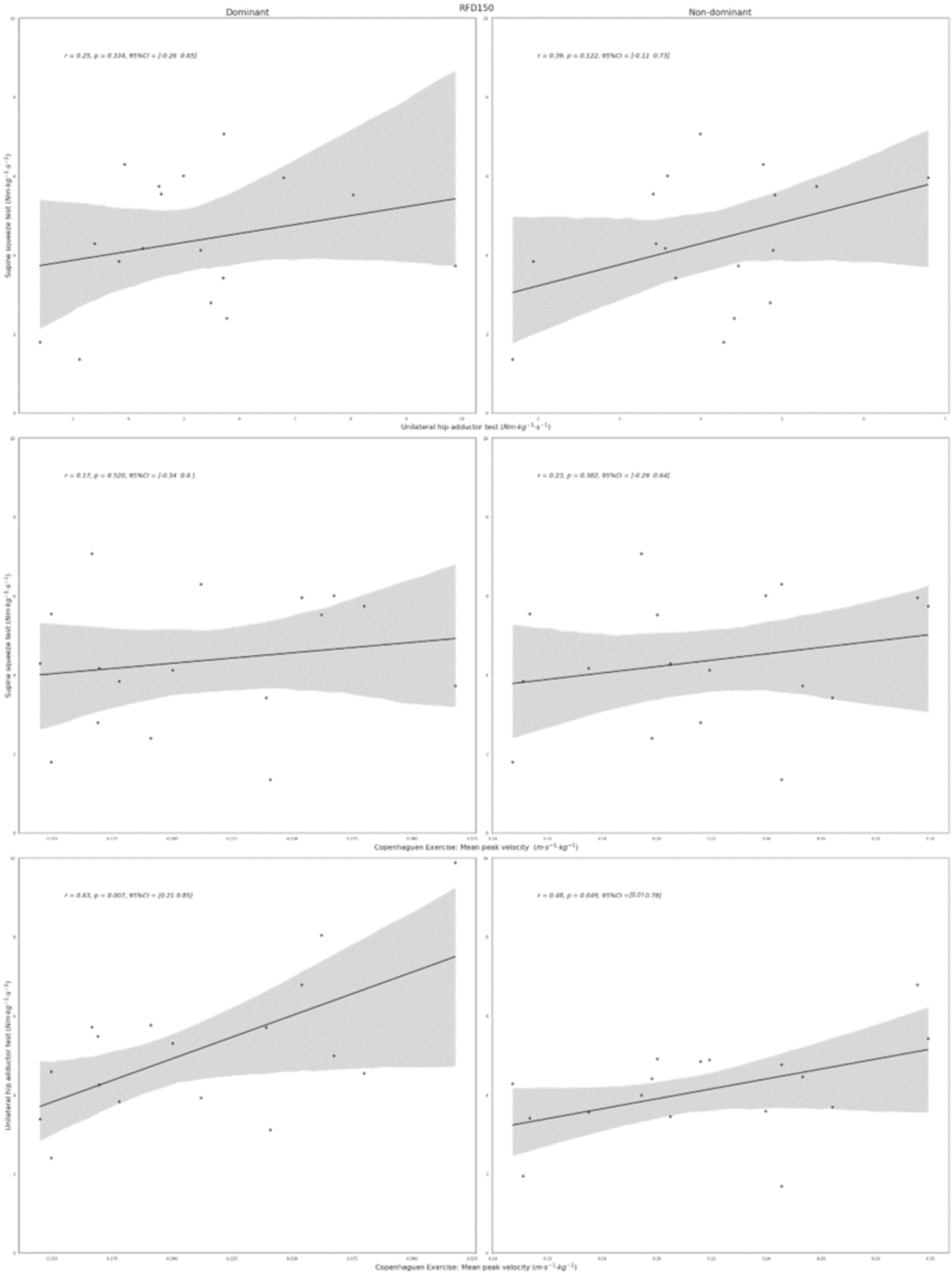

Figure 3. Alignment between isometric tests and Copenhagen adductor field-test outcomes with respect to rate of force development during the first 150 ms (RFD_{150}). The figure displays the degree of association observed across test modalities.

Bland–Altman plots (Supplementary Figures S1 and S2) illustrate agreement between paired normalised strength measurements. For IPF, analyses revealed minimal systematic bias and relatively narrow limits of agreement, indicating acceptable alignment between protocols. In contrast, RFD_{150} comparisons demonstrated larger mean biases and wider limits of agreement, suggesting reduced interchangeability. Visual inspection indicated no clear proportional bias for IPF, whereas RFD_{150} comparisons suggested increasing variability at higher values, consistent with potential heteroscedasticity.

Discussion

The present study evaluated the reliability of a smartphone-based Copenhagen adductor field test and its association with established isometric hip adductor strength assessments. The main findings were: (1) moderate-to-good reliability for strength-related outcomes, particularly peak velocity; (2) moderate associations between peak velocity and both IPF and RFD150, whereas endurance-related outcomes showed no significant relationships; and (3) limited agreement between dynamic and isometric tests, with greater agreement observed for IPF than for RFD_{150}. These findings suggest that velocity-based metrics derived from the Copenhagen task capture related, but distinct, aspects of hip adductor function compared with traditional isometric assessments.

Although several field-based tools are available to assess hip adductor strength, most focus on maximal isometric force and require external fixation systems or examiner stabilisation [12,13]. The Copenhagen test does not aim to replace these instruments but to complement them by providing examiner-independent metrics within a functional movement pattern. In particular, quantifying execution velocity during repeated dynamic contractions may offer insight into rapid force expression and neuromuscular control, qualities not captured by static assessments. Given the eccentric and dynamic demands of football actions, peak velocity may reflect functionally relevant adaptations during training or rehabilitation. While the present study does not demonstrate superiority over existing tools, the minimal equipment requirements and feasibility of repeated field-based assessments support its applied relevance.

Reliability of the Smartphone-Based Copenhagen Adductor Field Test

Strength-related outcomes demonstrated moderate-to-good reliability (ICC = 0.63–0.83; SEM% = 6.7–18.5%). Although these values fall within ranges reported for other field-based strength assessments [12,13], the higher SEM observed for peak velocity indicates that small performance changes should be interpreted cautiously. In contrast, repetition count showed lower reliability, likely reflecting the greater influence of fatigue and pacing variability during endurance-based tasks.

Associations Between the Smartphone-Based Copenhagen Test and Unilateral Isometric Hip Adductor Test Measures

Moderate correlations between peak velocity and isometric strength measures suggest that both tests assess related, yet distinct, neuromuscular qualities. Peak velocity appears to reflect the capacity for rapid force production, whereas repetition count may represent local endurance, which is not directly comparable with maximal or explosive force metrics. These findings align with previous observations showing limited interchangeability between different hip adductor strength tests due to variations in body position, contraction type, and muscle recruitment patterns [13,38].

Alignment Between Different Isometric Strength Tests

Low-to-moderate alignment among isometric tests further supports the notion that different assessment protocols capture distinct mechanical and neuromuscular characteristics. Variations in lever length, contraction mode, body positioning, and unilateral versus bilateral execution likely explain the limited interchangeability observed between tests [39]. These findings are consistent with previous research reporting discrepancies between hip adductor assessment protocols despite targeting the same muscle group [13,38].

Notably, significant relationships between protocols were primarily identified in the non-dominant limb. This pattern may reflect bilateral deficit or bilateral facilitation phenomena, whereby force production differs when muscles contract simultaneously versus independently [40]. These mechanisms are thought to arise from neural and biomechanical factors influencing motor unit recruitment, interlimb coordination, and stabilisation demands [41]. Consequently, unilateral and bilateral tests may not activate the adductor musculature in an equivalent manner, which may partly explain the observed differences in alignment.

Bland–Altman analyses revealed acceptable agreement for IPF across protocols, whereas RFD_{150} demonstrated larger biases and greater variability, particularly at higher values. These findings suggest that IPF may be compared with greater confidence across tests, while RFD_{150} should be interpreted with caution when switching between protocols.

Strengths and Limitations

This study is limited by its cross-sectional design and inclusion of non-injured amateur male players, which precludes conclusions regarding injury risk prediction or return-to-play decision-making. Electromyographic data were not collected, limiting insight into muscle activation patterns. Future research should examine injured populations, female athletes, and elite-level players, and explore longitudinal relationships between dynamic and isometric strength adaptations.

Practical Applications

From a practical perspective, peak velocity derived from the smartphone-based Copenhagen test may serve as a field-based indicator of hip adductor force capacity. Given the moderate agreement with isometric assessments and the observed measurement variability, this tool should complement rather than replace established strength tests. As dynamic and isometric protocols appear to reflect distinct neuromuscular characteristics, practitioners should avoid directly comparing values obtained from different testing modalities and instead apply each assessment according to its specific purpose. The smartphone-based approach may be particularly useful for monitoring within-athlete changes across training or rehabilitation phases, especially when laboratory-based equipment is unavailable. Combining dynamic and isometric assessments may provide a more comprehensive profile of hip adductor function.

Conclusion

In summary, the smartphone-based Copenhagen adductor field test demonstrates moderate-to-good reliability for strength-related outcomes and shows moderate associations with conventional isometric hip adductor strength measures. Although these assessments are not interchangeable, wearable inertial systems may offer a practical and accessible complement for field-based monitoring. Further longitudinal research incorporating injury and performance outcomes is required before conclusions can be drawn regarding its predictive or preventive value.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org. Bland–Altman plots (Supplementary Figures S1 and S2) illustrate agreement between paired normalised strength measurements. **Figure S1**. Bland-Altman plots comparing the normalised isometric peak force values between different hip adductor muscle strength tests. The solid line represents the difference between each paired comparison. The dashed lines represent the 95% limits of agreement of the differences. The Pearson correlation coefficient of each comparison is provided in the graphs. D: Dominant leg. ND: Non-dominant leg. **Figure S2**. Bland-Altman plots comparing the normalised rate of force development during first 150 ms (RFD_{150}) values between different hip adductor muscle strength tests. The solid line represents the difference between each paired comparison. The dashed lines represent the 95% limits of agreement of the differences. The Pearson correlation coefficient of each comparison is provided in the graphs. D: Dominant leg. ND: Non-dominant leg.

Authorship Contributions: Conceptualization, A.M.I., J.L.L.E. and V.M.P.; Methodology, J.L.L.E., M.I.T.R., and J.D.C.; Software, A.M.I.; Formal Analysis, A.M.I., TU; Investigation, A.M.I. and

J.D.L.R.C; Data Curation, A.M.I, J.D.L.R.C,.; Writing – Original Draft Preparation, A.M.I. and C.J.R.; Writing – Review & Editing, TU, J.D.L.R.C., J.L.L.E., J.D.C., M.I.T.R. and C.J.R; Supervision, V.M.P.; Project Administration, V.M.P; Funding Acquisition, V.M.P., C.J.R. and T.U." All authors have read and approved the final version of the manuscript and agree with the authors' order of submission.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the University Office for Research Ethics (code: DCD.JLE.01.20).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available from the corresponding author upon reasonable request. Data are not publicly available due to ethical restrictions related to participant confidentiality and the approved study protocol.

Conflict of Interest: The authors declare no conflict of interest.

References

1. Markovic G, Šarabon N, Pausic J, Hadžić V. Adductor muscles strength and strength asymmetry as risk factors for groin injuries among professional soccer players: A prospective study. Int J Environ Res Public Health. 2020;17(14):4946.
2. Moreno-Pérez V, Travassos B, Calado A, Gonzalo-Skok O, Coso J Del, Mendez-Villanueva A. Adductor squeeze test and groin injuries in elite football players: A prospective study. Physical therapy in sport. 2019;37:54–9.
3. Quintana-Cepedal M, Vicente-Rodríguez G, Crespo I, Olmedillas H. Is hip adductor or abductor strength in healthy athletes associated with future groin pain? A systematic review and meta-analysis. Br J Sports Med. 2025;59(7):501–9. PubMed PMID: 39532315.
4. Wollin M, Thorborg K, Welvaert M, Pizzari T. In-season monitoring of hip and groin strength, health and function in elite youth soccer: Implementing an early detection and management strategy over two consecutive seasons. J Sci Med Sport. 2018;21(10):988–93. doi:10.1016/j.jsams.2018.03.004
5. Serner A, Mosler AB, Tol JL, Bahr R, Weir A. Mechanisms of acute adductor longus injuries in male football players: a systematic visual video analysis. Br J Sports Med. 2019;53(3):158–64. PubMed PMID: 30006458.
6. Kiel J, Kaiser K. Adductor Strain. In: StatPearls. Treasure Island (FL): StatPearls Publishing LLC; 2025. PubMed PMID: 29630218.
7. Nielsen MF, Thorborg K, Krommes K, Thornton KB, Hölmich P, Peñalver JJJ, et al. Hip adduction strength and provoked groin pain: A comparison of long-lever squeeze testing using the ForceFrame and the Copenhagen 5-Second-Squeeze test. Physical Therapy in Sport. 2022;55:28–36.
8. Kambič T, Lainščak M, Hadžić V. Reproducibility of isokinetic knee testing using the novel isokinetic SMM iMoment dynamometer. PLoS One. 2020 Aug 1;15(8). doi:10.1371/journal.pone.0237842 PubMed PMID: 32866205.
9. Kemp JL, Schache AG, Makdissi M, Sims KJ, Crossley KM. Greater understanding of normal hip physical function may guide clinicians in providing targeted rehabilitation programmes. J Sci Med Sport. 2013;16(4):292–6.
10. Toohey LA, de Noronha M, Taylor C, Thomas J. The validity and reliability of the sphygmomanometer for hip strength assessment in Australian football players. Physiother Theory Pract. 2018;34(2):131–6.
11. Blättler M, Bizzini M, Schaub G, Monn S, Barrué-Belou S, Oberhofer K, et al. Assessment of hip abductor and adductor muscle strength with fixed-frame dynamometry: Considerations on the use of bilateral and unilateral tasks. Physical Therapy in Sport. 2024;70:22–8.
12. Hickey JT, Lennon C, Gillick M, Sweeney L. Measuring eccentric hip adductor strength during the Copenhagen adduction exercise: A proof-of-concept and test re-test reliability study. Physical Therapy in Sport. 2025;73:34–8.

13. Pérez-Contreras J, Loro-Ferrer JF, Merino-Muñoz P, Hermosilla-Palma F, Miranda-Lorca B, Bustamante-Garrido A, et al. Intra and Inter-Test Reliability of Isometric Hip Adduction Strength Test with Force Plates in Professional Soccer Players. J Funct Morphol Kinesiol. 2024;9(4):270.
14. Harøy J, Clarsen B, Wiger EG, Øyen MG, Serner A, Thorborg K, et al. The Adductor Strengthening Programme prevents groin problems among male football players: a cluster-randomised controlled trial. Br J Sports Med. 2019;53(3):150–7. PubMed PMID: 29891614.
15. Quintana-Cepedal M, de la Calle O, Olmedillas H. Can the Copenhagen adduction exercise prevent groin injuries in soccer players? A critically appraised topic. J Sport Rehabil. 2023;33(1):45–8.
16. Schaber M, Guiser Z, Brauer L, Jackson R, Banyasz J, Miletti R, et al. The neuromuscular effects of the Copenhagen adductor exercise: a systematic review. Int J Sports Phys Ther. 2021;16(5):1210. PubMed PMID: 34631242.
17. Sanchez-Medina L, González-Badillo JJ. Velocity loss as an indicator of neuromuscular fatigue during resistance training. Med Sci Sports Exerc. 2011;43(9):1725–34. PubMed PMID: 21311352.
18. van den Tillaar R, Ball N. Validity and reliability of kinematics measured with PUSH band vs. linear encoder in bench press and push-ups. Sports. 2019;7(9):207.
19. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 2009 Jan;41(1):3–12. doi:10.1249/MSS.0B013E31818CB278 PubMed PMID: 19092709.
20. Moreno-Pérez V, Méndez-Villanueva A, Soler A, Coso J Del, Courel-Ibáñez J. No relationship between the nordic hamstring and two different isometric strength tests to assess hamstring muscle strength in professional soccer players. Physical Therapy in Sport. 2020;46:97–103.
21. Gogia PP, Braatz JH. Validity and reliability of leg length measurements. Journal of Orthopaedic & Sports Physical Therapy. 1986;8(4):185–8.
22. Sadigursky D, Braid JA, Lira DNL De, Machado BAB, Carneiro RJF, Colavolpe PO. The FIFA 11 injury prevention program for soccer players: a systematic review. BMC Sports Sci Med Rehabil. 2017;9(1):18.
23. Freckleton G, Pizzari T. Risk factors for hamstring muscle strain injury in sport: a systematic review and meta-analysis. Br J Sports Med. 2013;47(6):351–8. PubMed PMID: 22763118.
24. Martins J, Silva JR Da, Silva MRB Da, Bevilaqua-Grossi D. Reliability and validity of the belt-stabilized handheld dynamometer in hip-and knee-strength tests. J Athl Train. 2017;52(9):809–19.
25. DeLang MD, Garrison JC, Hannon JP, McGovern RP, Christoforetti J, Thorborg K. Short and long lever adductor squeeze strength values in 100 elite youth soccer players: Does age and previous groin pain matter? Physical Therapy in Sport. 2020;46:243–8.
26. Light N, Thorborg K. The precision and torque production of common hip adductor squeeze tests used in elite football. J Sci Med Sport. 2016;19(11):888–92.
27. Drew MK, Palsson TS, Izumi M, Hirata RP, Lovell G, Chiarelli P, et al. Resisted adduction in hip neutral is a superior provocation test to assess adductor longus pain: an experimental pain study. Scand J Med Sci Sports. 2016;26(8):967–74.
28. Ishøi L, Hölmich P, Thorborg K. Measures of hip muscle strength and rate of force development using a fixated handheld dynamometer: intra-tester intra-day reliability of a clinical set-up. Int J Sports Phys Ther. 2019;14(5):715. PubMed PMID: 31598409.
29. Duarte M. detecta: A python module to detect events in data. GitHub Repos. 2020.
30. McKinney W. Data structures for statistical computing in Python. scipy. 2010;445(1):51–6.
31. Hoyer S, Hamman J. xarray: ND labeled arrays and datasets in Python. J Open Res Softw. 2017;5(1):10.
32. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P. Increased rate of force development and neural drive of human skeletal muscle following resistance training. J Appl Physiol. 2002;93(4):1318–26.
33. Hopkins WG. Measures of reliability in sports medicine and science. Sports Medicine. Adis International Ltd; 2000. p. 1–15. doi:10.2165/00007256-200030010-00001 PubMed PMID: 10907753.
34. Koo TK, Li MY. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. J Chiropr Med. 2016 Jun 1;15(2):155–63.

35. Harris CR, Millman KJ, Walt SJ Van Der, Gommers R, Virtanen P, Cournapeau D, et al. Array programming with NumPy. Nature. 2020;585(7825):357–62.
36. Virtanen P, Gommers R, Oliphant TE, Haberland M, Reddy T, Cournapeau D, et al. SciPy 1.0: fundamental algorithms for scientific computing in Python. Nat Methods. 2020;17(3):261–72.
37. Hinkle DE, Wiersma W, Jurs SG. Applied statistics for the behavioral sciences. Mass: Houg. Boston; 2003.
38. Thorborg K, Hölmich P, Christensen R, Petersen J, Roos EM. The Copenhagen Hip and Groin Outcome Score (HAGOS): development and validation according to the COSMIN checklist. Br J Sports Med. 2011;45(6):478–91. PubMed PMID: 21478502.
39. Dunne C, Callaway AJ, Thurston J, Williams JM. Validity, reliability, minimal detectable change, and methodological considerations for HHD and portable fixed frame isometric hip and groin strength testing: A comparison of unilateral and bilateral testing methods. Physical Therapy in Sport. 2022;57:46–52.
40. Škarabot J, Cronin N, Strojnik V, Avela J. Bilateral deficit in maximal force production. Eur J Appl Physiol. 2016 Dec 1;116(11–12):2057–84. doi:10.1007/s00421-016-3458-z PubMed PMID: 27582260.
41. Železnik P, Slak V, Kozinc Ž, Šarabon N. The Association between Bilateral Deficit and Athletic Performance: A Brief Review. Sports (Basel). 2022 Aug 1;10(8). doi:10.3390/sports10080112 PubMed PMID: 36006078.