applied sciences

Article

Reliability of a Portable Fixed Dynamometer During Different Isometric Hamstring Assessments

Ryan Woodbridge [1], Chloe Ryan [1], Josh Burkitt [1,2], Dana Ye-Lee [1] and John Cronin [1,3,*]

[1] Sports Performance Research Institute New Zealand, Faculty of Health and Environmental Sciences, Auckland University of Technology, Rosedale, Auckland 0632, New Zealand; chloe.ryan@aut.ac.nz (C.R.); josh.burkitt@aut.ac.nz (J.B.)
[2] Department for Health, University of Bath, Bath BA2 7AY, UK
[3] Athlete Training and Health, Katy, TX 77494, USA
* Correspondence: john.cronin@aut.ac.nz

Abstract: Hamstring strain injuries are one of the most common non-contact injuries in sport. Hamstring strength and asymmetry are two key modifiable risk factors for hamstring strain injuries; therefore, it seems important to find reliable tests for assessing hamstring strength. The purpose of this study was to determine the within- and between-session reliability of a portable fixed dynamometer for measuring hamstring strength using three different protocols. Fourteen male participants completed three hamstring isometric protocols across three testing occasions separated by seven days. Peak force, mean force and impulse all had good to excellent within- and between-session reliability for the standing hamstring, supine 90:90 and standing 90:20 assessment (CV = 2.6–11.7%, ICC = 0.74–0.99), while peak rate of force development had moderate to excellent relative consistency (ICC = 0.64–0.90) and unacceptable absolute consistency (CV = 17.1–36.6%). The 90:20 assessment produced significantly higher values (33.4–47.3%) compared to the standing and 90:90 assessments for peak force, mean force and impulse. It appears that a portable fixed dynamometer can reliably measure a range of force–time metrics during three different hamstring assessments; however, the results of the tests cannot be used interchangeably and practitioners comparing hamstring force capability between individuals/research studies need to be cognizant of this and proceed with caution.

Keywords: strain gauge; load cell; diagnostics; force; hamstring injuries

check for updates

Citation: Woodbridge, R.; Ryan, C.; Burkitt, J.; Ye-Lee, D.; Cronin, J. Reliability of a Portable Fixed Dynamometer During Different Isometric Hamstring Assessments. *Appl. Sci.* **2024**, *14*, 10202. https://doi.org/10.3390/app142210202

Academic Editor: Mon-López Daniel

Received: 27 September 2024
Revised: 4 November 2024
Accepted: 5 November 2024
Published: 6 November 2024

1. Introduction

Hamstring strains are one of the most common non-contact injuries in sports such as soccer [1], sprinting [2], rugby union [3], and many other team sports that require high-intensity bouts of maximal sprinting [4]. There are two main non-modifiable risk factors for hamstring strain injuries, such as older age and previous hamstring injuries, with reinjury rates reported at 12–13% [5,6]. However, there are several modifiable risk factors for hamstring strain injuries, such as fatigue, biceps femoris fascicle length [7], high-speed running loads [4,8], strength [9], interlimb asymmetry—the difference between left and right leg [9,10]—and intralimb asymmetry—the difference between quadriceps and hamstring strength within the same limb [2,11]. Given the importance of strength and asymmetry for minimizing hamstring strain injury risk, it seems important to screen and track hamstring strength on a regular basis.

Isokinetic dynamometry is considered the 'gold standard' screening tool for the assessment of hamstring strength [12,13]; however, the use of this equipment comes with an array of limitations, such as high cost, lack of portability and considerable training required by the assessor [14]. There have been numerous studies that have used cheaper and more portable pieces of equipment for measuring hamstring strength, such as force plates [15,16], strain gauge/load cells [17,18] and handheld dynamometers [19,20].

Force plates have been used across a range of different hamstring assessments, such as the supine 150:30° [15,16,21], supine 90:90° [16,21,22] and standing 90:20° (hip angle/knee angle) tests [22]. Research groups have reported acceptable within- (CV's = 4.85–8.61%, ICC = 0.83–0.93) and between-session (CV's = 4.34–8.72%, ICC = 0.76–0.95) reliability for peak force, as confirmed by a force plate (500–1000 Hz) measuring isometric hamstring strength during the 150:30° [15,16,21]. Additionally, Bettariga et al. [15] also reported on the within-session reliability of rate of force development (RFD) over time intervals of 50–100 ms and 100–150 ms relative to the onset of contraction; however, despite the strict methodological procedures, RFD was reported as not reliable (CV = 18.42–28.77%, ICC = 0.76–0.83). In terms of the supine 90:90° test, researchers have also reported acceptable within- (ICC = 0.82–0.85, CV = 5.32–7.72%) and between-session (ICC = 0.70–0.95, CV = 2.84–10.23%) reliability for peak force [16,18,21]. Ripley et al. [18] also reported acceptable reliability for average RFD over 100 ms and 200 ms (CV = 8.33%, ICC = 0.64, CV = 4.40%, ICC = 0.61, respectively). To the authors' knowledge, the standing 90:20° test has only been used previously by one group of researchers [22], who only reported on absolute consistency (CV = 7.3–11.0%). Though force plates have been reported to be reliable during these isometric hamstring assessments, they still pose some limitations around transportability and cost.

For many years, practitioners have utilized handheld dynamometers (HHDs) as cost-effective alternatives for isometric assessments during rehabilitation. Difficulties have been documented regarding the use of HHD, as tester strength can significantly impact the results of the test [23]. Researchers have reported acceptable inter-rater reliability for HHDs among different hamstring isometric assessments, such as prone 15° (knee flexion) (ICC = 0.74–0.83, SEM = 29–31), 90° (knee flexion) (ICC = 0.71–0.76, SEM = 23–26) [19], supine 90° (ICC = 0.71–0.83, SEM = 42–32) [24] and seated hamstring curl (ICC = 0.91) [25]. To the authors' knowledge, there is no research determining the between-session reliability of HHDs during isometric hamstring assessments.

In more recent times, the use of strain gauge and load cell technology has been implemented by practitioners. Researchers have reported acceptable reliability of this technology for within- (CV = 6.67–9.50%; ICC = 0.75–0.91) [16,20,26] and between-session reliability (CV = 6.27–10.58%, ICC = 0.68–0.91) for peak force during a range of kneeling, lying, standing and seated positions [16,20,26,27]. Miralles-Iborra et al. [27] also measured RFD, during a seated (30° knee flexion) hamstring curl; however, the results were not reported as reliable (CV = 26.3–35.1%, ICC = 0.59–0.75), potentially due to the low sampling frequency (80 Hz) of the strain gauge used, which will not provide an accurate value for RFD, given that human skeletal muscle is capable of producing >10 maximum isometric forces per second [28,29]. Therefore, technology with higher sampling frequencies is required during hamstring assessments to gain accurate RFD measures.

As evident by the current research reviewed in this manuscript, isometric hamstring strength has been tested in a range of different positions. It has been consistently noted that testing hamstring strength at long muscle lengths may reflect the larger work of the hamstring during the late swing phase and initial contact during running and sprinting [30]. However, the authors acknowledge that testing hamstrings at different angles, ranges of motion and muscle lengths emphasizes different muscles of the hamstring complex. For example, the biceps femoris muscle has been shown to be maximally activated between 15° and 30° of knee flexion (from full knee extension), whereas the semi-membranous and semi-tendinous muscle were maximally activated at angles between 90° and 105° [31]. Furthermore, it might be that a short to long muscle length approach to the testing of the hamstrings may better align with early- to late-stage rehab, given the location or the severity of the hamstring strain.

With the literature reviewed in mind, there is a need for a low-cost, high-accuracy, and high-utility alternative for measuring hamstring strength during a range of different positions that can be utilized during early to late stages of rehabilitation, as well as for tracking hamstring strength and asymmetry in healthy athletes. Additionally, many of these previously mentioned technologies only report peak force, with a small portion also presenting RFD at low sampling frequencies. These metrics may not be suitable to track for those in early-stage rehab; for example, metrics that provide insights into other aspects of force capability, such as contraction duration, mean force and impulse, may be more appropriate. Once an athlete has progressed into mid- and late-stage rehab, maximal and explosive strength variables may be of more interest to the practitioner, such as peak force and RFD. Therefore, the aim of this study was to evaluate the intra- and inter-session reliability of a commercially available, portable, low-cost and high-resolution portable fixed dynamometer for measuring different force–time variables, during a range of different hamstring assessments, which can be utilized through all stages of rehabilitation.

2. Methodology

2.1. Experimental Approach to the Problem

A cross-sectional, repeated measures design was used for comparative analysis of reliability for peak force, mean force, RFD, contraction duration and impulse during three different maximal voluntary isometric contractions (MVICs) of the hamstrings, as measured with a portable fixed dynamometer device (Hawkin TruStrength, Portland, ME, USA) at a sampling rate of 1200 Hz. Participants attended a familiarization session and three testing sessions exactly seven days apart, at the same time of day to minimize biological variability. Reliability was established using changes in the mean, ICCs and CVs.

2.2. Participants

Fourteen recreationally resistance-trained males (age, 22.71 $\pm$ 2.49 y; body mass 85.2 $\pm$ 12.44; height, 181.07 $\pm$ 6.92; resistance training experience 5.5 $\pm$ 2.79 y) volunteered to participate in this study. Participants were excluded from the study if they had a lower limb injury in the last six months that might affect their performance in the assessments. All participants were fully informed of the risk involved and gave written informed consent. This research was approved by the University's Ethics Committee (Ethics 24/184).

2.3. Procedures

Participants performed a 10 min standardized warm-up, consisting of 5 min of jogging on the treadmill at a self-selected pace, 10 walking lunges, 10 "sweep the chickens", and a 20 s quadriceps and hamstring stretch on each leg. The end of the warm-up consisted of two submaximal trials at 50% and 75% effort, using each leg for different tests. Participants completed three different hamstring protocols: the supine 90:90, standing 90:20 and the standing hip extension. The order of these tests was randomized during their first testing session and recorded and repeated for the following two sessions. Participants completed five trials per leg for each protocol, with 40 s rest between trials. If a trial was deemed unsuccessful due to the observation of compensatory movements, a repeat trial was given after 40 s rest.

2.3.1. Standing Hamstring Assessment

The HTS dynamometer was secured to a rack, while the other side had an eyelet attached as shown in Figure 1A. The eyelet had a carabiner attached to a link chain to allow an appropriate distance of the participant's ankle away from the rack (~40 cm). At the opposite end of the link chain, another carabiner with an ankle strap was attached for the participant to place around their ankle. The participant was instructed to begin in a standing position with the ankle strap attached to their working leg (Figure 1A). The participant had their non-working leg on a raised surface to ensure the testing leg was free and did not touch the ground during the movement. The participant had one arm crossed over their chest while the other was making slight contact with 2–3 fingers against the rack to help maintain balance, as shown in Figure 1B. This was to help prevent any compensatory movements occurring during the trials. Once the participant was in this position, the first tester would instruct the participant to apply force as 'hard and as fast as possible' to ensure maximal force was reached immediately. The second tester ensured the participant was keeping a strict standing position and not hinging from the hips. Once the participant had held peak maximal force for 3 s, the first tester would instruct the participant to stop. The participant rested for 40 s before completing the next trial on the same leg. The participant completed 5 trials per leg.

Figure 1. (**A**) Hawkin TruStrength attached to rack and participant's ankle. (**B**) Participant set up for standing hamstring assessment.

2.3.2. Supine 90:90 Hamstring Assessment Procedures

The Hawkin TruStrength (HTS) was attached to a base plate with a compression pad attached to the opposite side, as shown in Figure 2A. The participant was asked to lie in a supine position with the base plate at a height relative to the participant's ankle height, while the knee and hip joint were at 90 degrees. Joint angles were measured using a goniometer to ensure accuracy and repeatability for each participant. The participant was instructed to place their arms over their chest to eliminate their usage during the test, as shown in Figure 2B. The non-working leg was placed in a straight position with the hip and knee at 180 degrees, allowing the leg to rest on the floor. The second tester would apply pressure downwards (see Figure 2C) to ensure there were no compensatory movements during the trial. Once the participant was in this position, the first tester instructed the participant to apply force as 'hard and as fast as possible' to ensure maximal force was reached immediately. The participant held the isometric contraction for 3 s and was instructed when to stop by the tester. The participant then rested for 40 s before completing the next trial on the same leg. The participant completed 5 trials per leg.

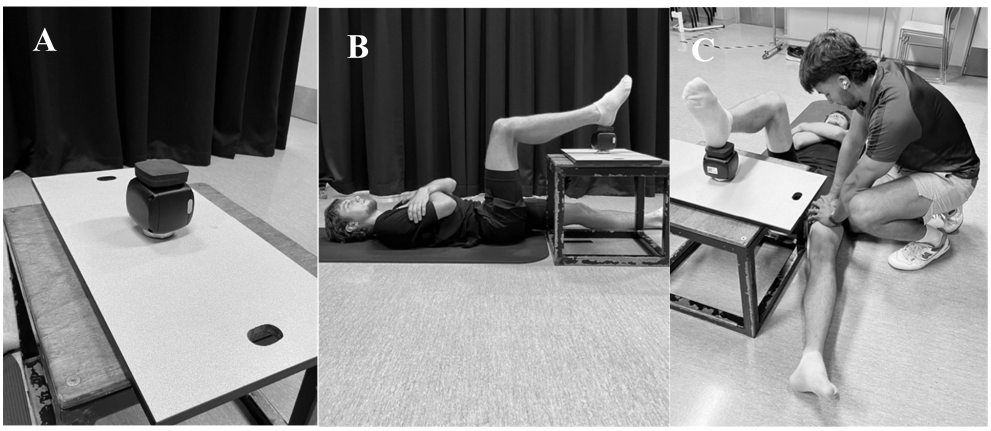

Figure 2. (**A**) Hawkin TruStrength attached to base plate, (**B**) participant set up for the 90:90 assessment, (**C**) tester 2 applying pressure to the non-working leg.

2.3.3. Standing 90:20 Hamstring Assessment Procedures

The HTS was attached to a base plate with a compression pad attached to the opposite side, as shown in Figure 1A. The participant was instructed to be in a standing position with their back, head and buttocks against the wall, arms placed across their chest, and the non-testing leg placed against the wall (see Figure 3). The participant was instructed to bring the hip of the leg being tested to 90 degrees. The base plate with the HTS attached was placed relative to the participant's hip and knee angle to ensure the hip was at 90 degrees and the knee was at 20 degrees. This was measured by the first tester using a goniometer to ensure standardization and accuracy. The second tester used both hands and applied pressure to the leg against the wall to ensure the non-testing leg was against the wall, as shown in Figure 3. Once the participant was in this position, the first tester would instruct the participant to apply force 'as hard and as fast as possible' to ensure maximal force was reached immediately. Once 3 s had elapsed, the first tester instructed the participant to stop. If any compensatory movement was detected by tester 1 or 2, for example, rotation of the lumbo-pelvic region or loss of contact with the wall, the trial was considered invalid and was then repeated. The participant would then rest for 40 s before completing the next trial on the same leg. Each participant completed 5 trials per leg.

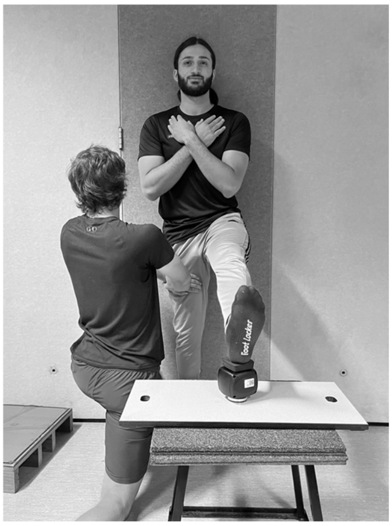

Figure 3. The 90:20 hamstring assessment set up.

2.4. Data Analyses

Data from each trial were exported from the Hawkin TruStrength mobile application (version 9.4.0) (to an excel spreadsheet. The application automatically calculates the variables of interest, which were calculated in the period between the force onset and offset, otherwise known as the contraction duration. Peak force was calculated as the absolute maximum force whilst mean force was calculated as the average of the force signal during the entire contraction duration. Peak RFD was calculated using an 8-tap FIR filter (Hawkin TruStrength, Portland, ME, USA). This filter removes some noise, without distorting the true peak and is essentially a rolling average of eight datapoints to find the peak RFD in the signal, during the contraction duration. Impulse was calculated by integrating the force signal over the contraction duration. A steady pre-tension period prior to the force onset was observed for all trials.

2.5. Statistical Analysis

All statistical analyses were performed using the IBM SPSS statistical software package (version 29.0; IBM Corporation, Armonk, NY, USA) and Hopkins spreadsheet of analysis [32]. Outlier and normality analysis was performed on the raw data. Normality was determined using the Shapiro–Wilk test. Any extreme outliers were removed before further analysis occurred. The best three trials based on peak force values were used for further analysis. Paired *t*-tests were used to determine any differences between the left and right legs for each of the variables. No significant differences occurred between the left and right leg; therefore, the reliability analysis was run on the right leg only. Data were reported as mean and standard deviations for each variable of interest. Systematic biases were determined using a repeated measures ANOVA with Bonferroni post hoc comparisons. Absolute and relative consistency were used to quantify reliability. Absolute consistency between trials and sessions was quantified using CVs, where measures less than or equal to 10% were deemed acceptable [33]. Relative consistency between trials (ICC 3,1) and sessions (ICC 3,k) was determined using an ICC, and classified as follows: 'very poor' (<0.20), 'poor' (0.20–0.49), 'moderate' (0.50–0.74), 'good' (0.75–0.90) or 'excellent' (>0.90) [34,35]. Finally, a repeated measures ANOVA with Bonferroni post hoc comparisons on the average of the best three trials for session three was used to determine if there were any significant differences in force outputs between each test.

3. Results

The within-session results are reported in Table 1 and between-session results in Table 2. There was no significant ($p < 0.05$) systematic change within the variables across the three trials and sessions. This means that any changes in the data were random and not due to factors such as learning effects.

Table 1. Within-session reliability.

Variable	Mean ± SD			% Change in Mean (95% CI)		CV (95% CI)		ICC (95% CI)	
	Trial 1	Trial 2	Trial 3	Trial 2-1	Trial 3-2	Trial 2-1	Trial 3-2	Trial 2-1	Trial 3-2
Standing									
Peak force (N)	319.4 ± 68.2	320.5 ± 69.1	320.0 ± 67.8	0.3 (−3.6–4.3)	−0.2 (−3.1–2.8)	5.0 (3.6–8.1)	3.7 (2.6–6.0)	0.96 (0.88–0.99)	0.98 (0.93–0.99)
Mean force (N)	264.4 ± 52.5	267.3 ± 52.7	265.4 ± 51.7	1.0 (−4.9–7.3)	−0.7 (−3.4–2.1)	7.7 (5.5–12.7)	3.5 (2.5–5.7)	0.88 (0.67–0.96)	0.98 (0.93–0.99)
Impulse (N·s)	829.7 ± 170.0	833.8 ± 134.8	826 ± 159	1.0 (−5.5–8.0)	−1.3 (−5.2–2.7)	8.5 (6.1–14.1)	5.1 (3.7–8.3)	0.83 (0.54–0.94)	0.94 (0.83–0.98)
Peak RFD (N·s^{-1})	1503.0 ± 730.6	1562.5 ± 569.3	1569 ± 790	8.0 (−14.8–36.9)	−9.7 (−21.1–3.3)	28.3 (19.0–54.9)	17.1 (12.0–29.7)	0.72 (0.24–0.91)	0.90 (0.71–0.97)
Supine 90:90									
Peak force (N)	337.5 ± 77.4	337.2 ± 74.0	341.0 ± 76.3	0.1 (−3.1–3.4)	1.1 (−1.3–3.5)	4.1 (3.0–6.7)	3.0 (2.2–4.9)	0.98 (0.94–0.99)	0.99 (0.96–1.00)
Mean force (N)	293.5 ± 69.3	286.5 ± 64.2	297.6 ± 68.2	−2.1 (−6.2–2.1)	3.7 (0.5–7.1)	5.4 (3.9–8.8)	3.9 (2.8–6.4)	0.96 (0.89–0.99)	0.98 (0.94–0.99)
Impulse (N·s)	962.3 ± 237.0	947.6 ± 199.6	968.8 ± 218.9	−0.6 (−5.3–4.3)	1.9 (−1.0–4.9)	6.1 (4.4–10.0)	3.6 (2.6–5.9)	0.96 (0.87–0.99)	0.98 (0.95–0.99)
Peak RFD (N·s^{-1})	1414.3 ± 601.1	1502.1 ± 613.3	1694.5 ± 677.3	0.7 (−16.2–20.9)	11.8 (−4.3–30.6)	23.9 (16.6–42.4)	21.0 (14.8–35.9)	0.76 (0.39–0.92)	0.83 (0.55–0.94)
Standing 90:20									
Peak force (N)	487.2 ± 136.3	479.3 ± 129.0	484.1 ± 133.8	−1.3 (−3.4–0.8)	0.8 (−1.6–3.1)	2.6 (1.9–4.3)	2.9 (2.1–4.7)	0.99 (0.98–1.00)	0.99 (0.98–1.00)
Mean force (N)	418.4 ± 118.3	411.4 ± 108.5	415.8 ± 111.4	−1.2 (−3.4–1.1)	1.0 (−2.0–4.0)	2.8 (2.1–4.6)	3.7 (2.7–6.1)	0.99 (0.98–1.00)	0.99 (0.96–1.00)
Impulse (N·s)	1386.9 ± 419.1	1321.8 ± 339.9	1325.1 ± 373.5	−3.4 (−8.6–2.0)	−0.5 (−4.4–3.4)	6.9 (5.0–11.4)	4.9 (3.5–8.0)	0.96 (0.88–0.99)	0.98 (0.93–0.99)
Peak RFD (N·s^{-1})	1552.1± 858.0	1413.5 ± 599.2	1382.5 ± 651.9	9.5 (−7.1–29.1)	−9.9 (−23.8–6.5)	20.1 (13.9–36.5)	19.2 (13.1–36.2)	0.88 (0.64–0.96)	0.87 (0.60–0.96)

Table 2. Between-session reliability.

Variable	Mean ± SD			% Change in Mean (95% CI)		CV (95% CI)		ICC (95% CI)	
	Session 1	Session 2	Session 3	Session 2-1	Session 3-2	Session 2-1	Session 3-2	Session 2-1	Session 3-2
Standing									
Peak force (N)	308.6 ± 70.9	310.9 ± 60.9	320.0 ± 67.1	1.7 (−4.3–8.1)0	2.6 (−2.1–7.5)	7.8 (5.6–12.8)	5.9 (4.2–9.6)	0.91 (0.75–0.97)	0.94 (0.82–0.98)
Mean force (N)	254.2 ± 60.0	263.4 ± 51.3	265.7 ± 50.3	4.7 (−2.5–12.4)	1.0 (−3.9–6.2)	9.1 (6.5–15.0)	6.3 (4.5–10.4)	0.88 (0.67–0.96)	0.92 (0.77–0.97)
Impulse (N·s)	819.2 ± 167.7	839.6 ± 155.7	830.1 ± 146.1	2.8 (−2.6–8.6)	−1.0 (−5.8–4.2)	6.9 (5.0–11.4)	6.4 (4.6–10.4)	0.90 (0.73–0.97)	0.91 (0.73–0.97)
Peak RFD (N·s^{-1})	1495.3 ± 856.3	1428.4 ± 579.9	1712.1 ± 894.3	2.5 (−16.4–25.6)	16.1 (−5.8–43.2)	28.3 (19.8–49.3)	29.2 (20.4–51.1)	0.80 (0.49–0.93)	0.74 (0.36–0.91)
Supine 90:90									
Peak force (N)	321.7 ± 75.3	326.3 ± 78.0	333.6 ± 75.9	1.1 (−4.0–6.6)	2.7 (−2.4–8.2)	6.7 (4.8–10.9)	6.5 (4.7–10.7)	0.95 (0.86–0.98)	0.95 (0.86–0.98)
Mean force (N)	277.7 ± 66.0	279.0 ± 70.8	292.5 ± 66.4	−0.1 (−6.9–7.1)	5.8 (−1.9–14.1)	8.9 (6.4–14.8)	9.7 (7.0–16.1)	0.92 (0.77–0.97)	0.90 (0.72–0.97)
Impulse (N·s)	956.5 ± 194.7	948.2 ± 241.0	959.6 ± 215.8	−2.2 (−13.0–10.0)	2.1 (−3.7–8.2)	15.4 (10.9–26.0)	7.4 (5.3–12.2)	0.74 (0.36–0.91)	0.94 (0.83–0.98)
Peak RFD (N·s^{-1})	1388.4 ± 580.0	1672.9 ± 641.5	1574.3 ± 634.9	20.9 (2.8–42.2)	−5.1 (−16.5–7.9)	22.0 (15.5–37.7)	17.0 (12.1–28.8)	0.83 (0.55–0.94)	0.88 (0.68–0.96)
Standing 90:20									
Peak force (N)	475.7 ± 117.5	475.0 ± 128.6	483.5 ± 132.7	−0.5 (−7.3–6.7)	1.7 (−3.3–6.9)	8.9 (6.4–14.8)	6.3 (4.5–10.3)	0.93 (0.80–0.98)	0.97 (0.90–0.99)
Mean force (N)	400.8 ± 98.7	410.5 ± 106.3	408.1 ± 115.2	2.3 (−4.4–9.4)	−1.1 (−7.8–6.0)	8.6 (6.2–14.3)	8.9 (6.4–14.8)	0.93 (0.79–0.98)	0.93 (0.79–0.98)
Impulse (N·s)	1354.8 ± 372.7	1344.0 ± 390.6	1344.6 ± 373.9	−0.7 (−9.3–8.7)	0.5 (−6.9–8.4)	11.7 (8.4–19.6)	9.7 (7.0–16.1)	0.90 (0.73–0.97)	0.93 (0.79–0.98)
Peak RFD (N·s^{-1})	1415.1 ± 730.0	1334.5 ± 609.8	1545.4 ± 759.7	−4.3 (−25.8–23.4)	14.9 (−5.8–40.1)	36.6 (25.4–65.3)	27.5 (19.3–48.0)	0.64 (0.18–0.87)	0.78 (0.45–0.92)

3.1. Standing Hamstring Assessment

With regard to the standing hamstring assessment, peak force, mean force and impulse were all found to have acceptable absolute consistency (CV = 3.7–8.5%) and good to excellent relative consistency (ICC = 0.83–0.98) for within-session reliability. The largest change was observed between trials 3 and 2 for peak RFD (−9.7%), which was found to have moderate within-session reliability (CV = 17.1–28.3%, ICC = 0.72–0.90). Similar results were found for between-session reliability, where peak force, mean force and impulse were all found to be reliable (CV = 5.9–9.1, ICC = 0.88–0.94), while peak RFD was found to have good relative reliability (ICC = 0.74–0.80); however, absolute reliability was not found to be acceptable (CV = 28.3–29.2%).

3.2. Supine 90:90 Assessment

Once more, peak force, mean force and impulse were found to have excellent within-session reliability (CV = 3.0–6.1%, ICC = 0.96–0.99), while peak RFD had good relative reliability (ICC = 0.76–0.83) and poor absolute reliability (CV = 21.0–23.9%,). The largest between-trial change was observed between trials 3 and 2 for peak RFD (11.8%). In terms of between-session reliability, peak and mean force had excellent reliability (CV = 6.5–9.7%, ICC = 0.90–0.95), while impulse had moderate to excellent reliability

(CV = 7.4–15.4, ICC = 0.74–0.94). The largest change between sessions was observed for peak RFD (20.9%), which had moderate reliability (CV = 17.0–22.0%, ICC = 0.83–0.88).

3.3. Standing 90:20 Assessment

In terms of the 90:20 assessment, peak force, mean force and impulse all had excellent within-session reliability (CV = 2.6–6.9%, ICC = 0.96–0.99), while peak RFD had good relative reliability (ICC = 0.87–0.88) and poor absolute within-session reliability (CV = 19.2–20.1%). The largest change between trials was observed between 2 and 1 for peak RFD (20.1%). Similar results were observed between sessions with peak force, mean force and impulse all having excellent relative reliability (ICC = 0.90–0.97), while peak and mean force had acceptable absolute reliability (CV= 6.3–8.9%). Impulse had acceptable between-session reliability for session 3-2 (9.7%); however, session 2-1 was slightly over the 10% threshold (11.7%). The largest between-session change was found between sessions 3 and 2 for peak RFD (14.9%).

3.4. Between Assessment Comparisons

The comparisons for each variable across assessments are presented in Table 3. No significant differences were found for peak force, mean force and peak RFD between the standing hamstring assessment and the supine 90:90 (mean difference = −26.85–28.95, $p > 0.05$); however, there was a significant difference for the impulse variable (mean difference = −129.44, $p = 0.045$). Peak force, mean force and impulse were all significantly different when comparing the standing hamstring assessment and the standing 90:20 assessment (mean difference = −514.46–149.52, $p < 0.001$) and comparing the supine 90:90 and the standing 90:20 (mean difference = −385.02–122.67, $p < 0.001$). Peak RFD was not significantly different across assessments (mean difference = 28.91–57.86, $p > 0.05$).

Table 3. Comparison of outputs across the three testing positions.

Variable	Peak Force (N)		Mean Force (N)		Impulse (N·s)		Peak RFD (N·s^{-1})	
	Mean Difference ± SE	*p*-Value	Mean Difference ± SE	*p*-Value	Mean Difference ± SE	*p*-Value	Mean Difference ± SE	*p*-Value
Standing vs. 90:90	−18.62 ± 14.36	0.652	−26.85 ± 12.34	0.146	−129.44 ± 46.22	0.045	28.95 ± 164.88	1.00
Standing vs. 90:20	−163.6 ± 23.42	<0.001	−149.5 ± 21.46	<0.001	−514.46 ± 75.82	<0.001	57.86 ± 195.55	1.00
90:90 vs. 90:20	−144.9 ± 21.10	<0.001	−122.7 ± 17.71	<0.001	−385.02 ± 69.88	<0.001	28.91 ± 152.22	1.00

4. Discussion

The purpose of this study was to evaluate the within- and between-session reliability of a portable fixed dynamometer for measuring different force–time variables during a range of different hamstring assessments. To gain insight into the full reliability of a measure, it is recommended that systematic changes in mean, absolute and relative consistency are all reported [34]. The main findings were as follows: (1) all variables except peak RFD had acceptable CVs and had good to excellent ICCs for within- and between-session reliability for the standing hamstring assessment; (2) for the supine 90:90 assessment, peak force, mean force and impulse had good to excellent relative within- and between-session reliability, while absolute reliability was found to be acceptable for all but between sessions 2 and 1 for impulse; (3) the 90:20 hamstring assessment had good to excellent relative within- and between-session reliability for all variables except peak RFD, and acceptable absolute reliability for all but between sessions 2 and 1 for impulse; and (4) for most of the variables assessed, values increased depending on the test used, with the lowest values recorded for the standing hamstring test and the greatest values for the 90:20 test.

To the authors' knowledge, this was the first study to determine the reliability of a portable fixed dynamometer in measuring a range of different force–time variables during a standing hip extension assessment. In terms of within-session reliability, systematic biases were non-significant, and absolute and relative consistency was good to excellent—CVs were ≤8.5% and ICCs > 0.83 for peak force, mean force and impulse across the three trials. Similar results were observed for within-session reliability, with peak force, mean force and impulse all having good to excellent reliability—CVs were ≤9.1% and ICCs were >0.88, and peak RFD was moderate at best (CVs = 28.3–29.2%; ICCs = 0.74–0.80). With regard to previous research, there is limited research that has been performed in this standing position. Kawaguchi and Babcock [36] compared a standing hip extension isometric contraction measured with an isokinetic dynamometer to a prone position with 90° knee flexion. The authors did not report on the ICC of the standing position as measured via isokinetic dynamometry. Another research group reported on the within-session reliability of a standing hip isometric endurance protocol measured via EMG (ICC = 0.631–0.98, SEM = 3.39–8.20); however, no force–time metrics were reported. Therefore, this study appears to be the first to quantify the reliability of a novel standing hip extension assessment, which may be suitable for athletes and those in late-stage or return-to-play rehabilitation.

With regard to the supine 90:90 hamstring assessment, peak force, mean force and impulse all had moderate to excellent relative consistency (ICC = 0.74–0.95), whereas the only between-session variable that did not have acceptable absolute consistency was impulse (CV = 15.4%). Once again, peak RFD was reported to have unacceptable absolute consistency (CV = 17.0–23.9%), whereas relative consistency was deemed good (ICC = 0.76–0.88). Previous researchers have determined the reliability of the supine 90:90 hamstring assessment measured via a force plate. Cuthbert et al. [16] reported good within-session reliability (CV = 5.32–7.33%, ICC = 0.82–0.85) and moderate between-session reliability (CV = 7.52–10.23%, ICC = 0.70–0.80) for peak force measured via a force plate (sampling frequency—1000 Hz) in female soccer players. Better between-session reliability was reported by McCall et al. [21], as measured via a force plate (CV = 4.34–5.48%, ICC = 0.95) in elite male soccer players. Both research groups only reported peak force measures. Similar within- and between-session results were reported in this study (CV = 3.0–6.7%, ICC = 0.95–0.99). Ripley et al. [18] also reported reliable between-session peak force as measured via a force plate (CV = 2.84%, ICC = 0.98); however, they also reported on rapid force-generating measures. Interestingly, the authors observed acceptable absolute reliability for average RFD over 100 and 200 ms, with moderate relative reliability (CV = 4.40–8.33%, ICC = 0.61–0.64), which is largely different from the results observed in this study (CV = 17.0–22.0%, ICC = 0.83–0.88). These differences may be due to several different reasons. First, the metrics, though both are rapid force-generating measures, are not calculated the same; peak RFD was reported in this study rather than its average at certain epochs. Second, instructions given to athletes may have differed; however, Ripley et al. did not report on the instructions given to their participants [18]. Third, the differences in technology, i.e., force plates measuring at 1000 Hz, compared to a portable fixed dynamometer measuring at 1200 Hz may account for the differences. Lastly, the populations differed between studies, with resistance-trained males being used in this study as compared to female soccer players.

The third assessment performed was the 90:20 hamstring assessment, which had similar within- and between-session reliability to the standing hip extension and 90:90 hamstring assessment. Once more, peak force, mean force and impulse all had acceptable to excellent reliability (CV = 2.6–11.7%, ICC = 0.90–0.99) across trials and testing occasions, with peak RFD having unacceptable absolute consistency (CV = 19.2–36.3%) and moderate to good relative consistency (ICC = 0.64–0.88). To the authors' knowledge, only one other research group has determined the reliability of the 90:20 hamstring assessment measured via force plate technology (500 Hz) [22]. The authors only reported between-session absolute reliability (CV = 7.3–11.0%) for peak force, which was similar to our results (CV = 6.3–8.9%). Other research groups have investigated similar knee and hip angles during an isometric hamstring assessment in a lying and seated position [16,19–21,25,27]. For example, McCall et al. [21] determined the reliability of a lying hamstring assessment with a knee angle of 30°, measured via a force plate (1000 Hz). The authors reported good to excellent within-session reliability for peak force during this position (CV = 4.84–6.31%, ICC = 0.86–0.93). Miralles-Iborra et al. [27] determined the between-session reliability of a seated hamstring isometric assessment at long muscle lengths (knee flexion = 30°, hip flexion = 90°) measured via a load cell. They also reported good to excellent reliability (CV = 9.1–9.6%, ICC = 0.88–0.90) for peak force and poor reliability for peak RFD (CV = 26.3–35.1%, ICC = 0.59–0.75), which was similar to the results of this study.

To the authors' knowledge, this is the first study to compare hamstring tests. Our results show significantly higher peak force (35.26–40.71%), mean force (34.67–43.92%), and total impulse (33.42–47.31%) during the 90:20 assessment, compared to the standing hamstring and 90:90 assessment. Only impulse was found to be significantly different between the standing hip assessment and the 90:90 assessment (14.46%), with greater impulse being produced during the 90:90 assessment. These differences in findings are likely due to two key factors. Firstly, the length–tension relationship of muscle will influence how much force can be produced at longer compared to shorter muscle lengths [37]. Secondly, different angles put emphasis on different muscles of the hamstring complex; for example, the biceps femoris muscle has been shown to be maximally activated between 15° and 30° of knee flexion, i.e., the 90:20 assessment, whereas the semi-membranous and semi-tendinous muscles are maximally activated at knee angles between 90° and 105, i.e., the 90:90 assessment [31]. Therefore, when choosing a hamstring assessment, practitioners should consider these factors. Given the findings of the current study, it appears that the results of each test are not interchangeable, and therefore, each test needs to be performed in isolation, i.e., comparisons cannot be made across tests. Furthermore, it might be that a short to long muscle length approach to the testing of the hamstrings may better align with early- to late-stage rehab, given the location or the severity of the hamstring strain.

Given the prevalence of hamstring injuries in sport [1–4] and the modifiable risk factors such as strength and asymmetry, it seems important to have reliable assessments that can assess hamstring strength at a range of different muscle lengths, and during all stages of rehabilitation. As mentioned previously, for the majority of the existing research, peak force is typically the only variable reported. Whilst it is an important variable to measure and monitor, it only represents an athlete's force capability for a small moment in time, i.e., 1/1200th of a second in this study. Variables such as mean force and impulse are more representative of overall force capability and may better represent hamstring strength. All mean force and impulse measures had acceptable reliability within and between sessions. Based on the results of this study and previous research [18,27], RFD metrics appear to be unreliable. This finding is consistent with the literature, which states that RFD is typically less reliable than maximum force and substantially so during the early phase of contraction [29]. Therefore, further instructions in the methodology may be required to improve the consistency of this measure. It needs to be noted that the subjects of this study were self-reported injury-free healthy males; therefore, these results should only be generalized to that specific population. Future research should focus on determining the reliability of this device in females and specific sporting populations.

5. Summary

This study was the first to examine the within- and between-session reliability of a portable fixed dynamometer for measuring hamstring strength in three different positions. All variables except for peak RFD were found to be reliable both within and between sessions. These results were found to be comparable to other technologies. Additionally, the high sampling rate of the portable fixed dynamometer allows for higher-resolution force–time data across a variety of different variables that many other technologies do not provide (mean force and impulse). Finally, each test recorded the hamstring force capability at different ranges of motion/muscle lengths, which resulted in different force outputs dependent on position. This means that the results of the tests cannot be used interchangeably and practitioners comparing hamstring force capability between individuals/research studies need to be cognizant of this and proceed with caution.

Author Contributions: Conceptualization, R.W., J.B. and J.C.; methodology, R.W., C.R., J.B., J.C. and D.Y.-L.; software, D.Y.-L.; validation, C.R.; formal analysis, C.R.; investigation, R.W. and J.B.; resources, D.Y.-L. and J.C.; data curation, D.Y.-L. and C.R.; writing—original draft preparation, C.R., and J.C.; writing—review and editing, C.R. and J.C.; visualization, C.R.; supervision, J.C., C.R. and D.Y.-L.; project administration, D.Y.-L. and J.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Auckland University of Technology Ethics Committee (24/184 approved 6 August 2024).

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

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: The authors would like to thank the athletes for their participation in this study.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Ekstrand, J.; Hägglund, M.; Waldén, M. Epidemiology of muscle injuries in professional football (soccer). *Am. J. Sports Med.* **2011**, *39*, 1226–1232. [CrossRef] [PubMed]
2. Yeung, S.S.; Suen, A.M.Y.; Yeung, E.W. A prospective cohort study of hamstring injuries in competitive sprinters: Preseason muscle imbalance as a possible risk factor. *Br. J. Sports Med.* **2009**, *43*, 589–594. [CrossRef]
3. Brooks, J.H.M.; Fuller, C.W.; Kemp, S.P.T.; Reddin, D.B. Epidemiology of injuries in English professional rugby union: Part 1 match injuries. *Br. J. Sports Med.* **2005**, *39*, 757–766. [CrossRef] [PubMed]
4. Wing, C.; Bishop, C. Hamstring strain injuries: Incidence, mechanisms, risk factors, and training recommendations. *Strength Cond. J.* **2020**, *42*, 40–57. [CrossRef]
5. Dalton, S.L.; Kerr, Z.Y.; Dompier, T.P. Epidemiology of hamstring strains in 25 NCAA sports in the 2009–2010 to 2013–2014 academic years. *Am. J. Sports Med.* **2015**, *43*, 2671–2679. [CrossRef] [PubMed]
6. Ekstrand, J.; Waldén, M.; Hägglund, M. Hamstring injuries have increased by 4% annually in men's professional football, since 2001: A 13-year longitudinal analysis of the UEFA Elite Club injury study. *Br. J. Sports Med.* **2016**, *50*, 731–737. [CrossRef] [PubMed]
7. Timmins, R.G.; Bourne, M.N.; Shield, A.J.; Williams, M.D.; Lorenzen, C.; Opar, D.A. Short biceps femoris fascicles and eccentric knee flexor weakness increase the risk of hamstring injury in elite football (soccer): A prospective cohort study. *Br. J. Sports Med.* **2016**, *50*, 1524–1535. [CrossRef] [PubMed]
8. Hulin, B.T.; Gabbett, T.J.; Lawson, D.W.; Caputi, P.; Sampson, J.A. The acute: Chronic workload ratio predicts injury: High chronic workload may decrease injury risk in elite rugby league players. *Br. J. Sports Med.* **2016**, *50*, 231–236. [CrossRef] [PubMed]
9. Bourne, M.N.; Opar, D.A.; Williams, M.D.; Shield, A.J. Eccentric knee flexor strength and risk of hamstring injuries in rugby union: A prospective study. *Am. J. Sports Med.* **2015**, *43*, 2663–2670. [CrossRef]
10. Croisier, J.-L.; Ganteaume, S.; Binet, J.; Genty, M.; Ferret, J.-M. Strength imbalances and prevention of hamstring injury in professional soccer players: A prospective study. *Am. J. Sports Med.* **2008**, *36*, 1469–1475. [CrossRef]
11. Lee, J.W.Y.; Mok, K.-M.; Chan, H.C.K.; Yung, P.S.H.; Chan, K.-M. Eccentric hamstring strength deficit and poor hamstring-to-quadriceps ratio are risk factors for hamstring strain injury in football: A prospective study of 146 professional players. *J. Sci. Med. Sport* **2018**, *21*, 789–793. [CrossRef]
12. Harding, A.T.; Weeks, B.K.; Horan, S.A.; Little, A.; Watson, S.L.; Beck, B.R. Validity and test–retest reliability of a novel simple back extensor muscle strength test. *SAGE Open Med.* **2017**, *5*, 2050312116688842. [CrossRef] [PubMed]
13. Mondin, D.; Owen, J.A.; Negro, M.; D'Antona, G. Validity and reliability of a non-invasive test to assess quadriceps and hamstrings strength in athletes. *Front. Physiol.* **2018**, *9*, 405727. [CrossRef] [PubMed]
14. Opar, D.A.; Piatkowski, T.; Williams, M.D.; Shield, A.J. A novel device using the Nordic hamstring exercise to assess eccentric knee flexor strength: A reliability and retrospective injury study. *J. Orthop. Sports Phys. Ther.* **2013**, *43*, 636–640. [CrossRef] [PubMed]
15. Bettariga, F.; Bishop, C.; Martorelli, L.; Turner, A.; Lazzarini, S.G.; Algeri, C.; Maestroni, L. Acute effects of a fatiguing protocol on peak force and rate of force development of the hamstring muscles in soccer players. *J. Sci. Sport Exerc.* **2023**, *6*, 177–185. [CrossRef]

16. Cuthbert, M.; Comfort, P.; Ripley, N.; McMahon, J.J.; Evans, M.; Bishop, C. Unilateral vs. bilateral hamstring strength assessments: Comparing reliability and inter-limb asymmetries in female soccer players. *J. Sports Sci.* **2021**, *39*, 1481–1488. [CrossRef] [PubMed]
17. Moreno-Pérez, V.; Méndez-Villanueva, A.; Soler, A.; Del Coso, J.; Courel-Ibáñez, J. No relationship between the nordic hamstring and two different isometric strength tests to assess hamstring muscle strength in professional soccer players. *Phys. Ther. Sport* **2020**, *46*, 97–103. [CrossRef]
18. Ripley, N.J.; Fahey, J.; Cuthbert, M.; McMahon, J.J.; Comfort, P. Rapid force generation during unilateral isometric hamstring assessment: Reliability and relationship to maximal force. *Sports Biomech.* **2023**, 1–12. [CrossRef] [PubMed]
19. Reurink, G.; Goudswaard, G.J.; Moen, M.H.; Tol, J.L.; Verhaar, J.A.N.; Weir, A. Strength measurements in acute hamstring injuries: Intertester reliability and prognostic value of handheld dynamometry. *J. Orthop. Sports Phys. Ther.* **2016**, *46*, 689–696. [CrossRef]
20. Wollin, M.; Purdam, C.; Drew, M.K. Reliability of externally fixed dynamometry hamstring strength testing in elite youth football players. *J. Sci. Med. Sport* **2016**, *19*, 93–96. [CrossRef]
21. McCall, A.; Nedelec, M.; Carling, C.; Le Gall, F.; Berthoin, S.; Dupont, G. Reliability and sensitivity of a simple isometric posterior lower limb muscle test in professional football players. *J. Sports Sci.* **2015**, *33*, 1298–1304. [CrossRef] [PubMed]
22. Matinlauri, A.; Alcaraz, P.E.; Freitas, T.T.; Mendiguchia, J.; Abedin-Maghanaki, A.; Castillo, A.; Martínez-Ruiz, E.; Carlos-Vivas, J.; Cohen, D.D. A comparison of the isometric force fatigue-recovery profile in two posterior chain lower limb tests following simulated soccer competition. *PLoS ONE* **2019**, *14*, e0206561. [CrossRef] [PubMed]
23. Stone, C.A.; Nolan, B.; Lawlor, P.G.; Kenny, R.A. Hand-held dynamometry: Tester strength is paramount, even in frail populations. *J. Rehabil. Med.* **2011**, *43*, 808–811. [CrossRef] [PubMed]
24. Kristiansen, J.; Eddy, C.; Magnusson, S.P. Reliability and Validity of the End Range Hamstring Strength Test with Handheld Dynamometry. *Int. J. Sports Phys. Ther.* **2024**, *19*, 268. [CrossRef] [PubMed]
25. Whiteley, R.; Jacobsen, P.; Prior, S.; Skazalski, C.; Otten, R.; Johnson, A. Correlation of isokinetic and novel hand-held dynamometry measures of knee flexion and extension strength testing. *J. Sci. Med. Sport* **2012**, *15*, 444–450. [CrossRef] [PubMed]
26. Holzhauer, L.; Julian, R.; Hughes, J. You don't run lying down—A novel tool to assess standing isometric hip-extension strength: A pilot study. *Sport Perform. Sci. Rep.* **2022**, *1*.
27. Miralles-Iborra, A.; Moreno-Pérez, V.; Del Coso, J.; Courel-Ibáñez, J.; Elvira, J.L.L. Reliability of a Field-Based Test for Hamstrings and Quadriceps Strength Assessment in Football Players. *Appl. Sci.* **2023**, *13*, 4918. [CrossRef]
28. De Ruiter, C.J.; Jones, D.A.; Sargeant, A.J.; De Haan, A. Temperature effect on the rates of isometric force development and relaxation in the fresh and fatigued human adductor pollicis muscle. *Exp. Physiol.* **1999**, *84*, 1137–1150. [CrossRef]
29. Maffiuletti, N.A.; Aagaard, P.; Blazevich, A.J.; Folland, J.; Tillin, N.; Duchateau, J. Rate of force development: Physiological and methodological considerations. *Eur. J. Appl. Physiol.* **2016**, *116*, 1091–1116. [CrossRef] [PubMed]
30. Sun, Y.; Wei, S.; Zhong, Y.; Fu, W.; Li, L.; Liu, Y. How joint torques affect hamstring injury risk in sprinting swing–stance transition. *Med. Sci. Sports Exerc.* **2015**, *47*, 373. [CrossRef] [PubMed]
31. Onishi, H.; Yagi, R.; Oyama, M.; Akasaka, K.; Ihashi, K.; Handa, Y. EMG-angle relationship of the hamstring muscles during maximum knee flexion. *J. Electromyogr. Kinesiol.* **2002**, *12*, 399–406. [CrossRef] [PubMed]
32. Hopkins, W.G. Spreadsheets for analysis of validity and reliability. *Sportscience* **2017**, *21*, 36.
33. Lloyd, R.S.; Oliver, J.L.; Hughes, M.G.; Williams, C.A. Reliability and validity of field-based measures of leg stiffness and reactive strength index in youths. *J. Sports Sci.* **2009**, *27*, 1565–1573. [CrossRef] [PubMed]
34. Hopkins, W.G. Measures of reliability in sports medicine and science. *Sports Med.* **2000**, *30*, 1–15. [CrossRef] [PubMed]
35. Koo, T.K.; Li, M.Y. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J. Chiropr. Med.* **2016**, *15*, 155–163. [CrossRef]
36. Kawaguchi, J.K.; Babcock, G. Validity and reliability of handheld dynametric strength assessment of hip extensor and abductor muscles. *Athl. Train. Sports Health Care* **2010**, *2*, 11–17. [CrossRef]
37. Ter Keurs, H.E.; Iwazumi, T.; Pollack, G.H. The sarcomere length-tension relation in skeletal muscle. *J. Gen. Physiol.* **1978**, *72*, 565–592. [CrossRef]