biomechanics

MDPI

Article

Intraday and Interday Reliability of Horizontal Upper Body Push and Pull Isometric Strength Qualities Using the VALD DynaMo Max Dynamometer

Ivan Curovic [1,*], Milan Markovic [2], Lazar Toskic [2,3], Jill Alexander [1] and Damian J. Harper [1]

[1] Institute of Coaching and Performance, University of Lancashire, Preston PR1 2HE, UK
[2] Faculty of Sport and Physical Education, University of Priština in Kosovska Mitrovica, 38218 Leposavić, Serbia
[3] Faculty of Sport, University Union-Nikola Tesla, 11070 Belgrade, Serbia
* Correspondence: icurovic@lancashire.ac.uk; Tel.: +44-38164-04-30-375

Abstract

Background/Objectives: To evaluate the intraday and interday reliability of seated horizontal upper body (UB) isometric push and pull tests performed with the VALD DynaMo Max dynamometer. Methods: Fifty-two recreationally active individuals (41 men, 11 women; 25.0 ± 6.1 years) completed two sessions 48 h apart, each comprising three maximal-effort push and pull trials at 90° elbow flexion using a custom-built rig with the attached dynamometer. Peak force (PF), peak rate of force development (RFD), impulse, and time-to-PF were extracted from 1200 Hz force–time data. Reliability was assessed using the intraclass correlation coefficient (ICC), coefficient of variation (CV%), standard error of measure (SEM) and minimal detectable change (MDC). Results: PF demonstrated excellent reliability (ICC = 0.97–0.99) with low absolute error (CV < 6%; MDC = 128–149 N). Impulse showed good-to-excellent reliability (ICC = 0.90–0.94; CV < 10%; MDC ≈ 755–790 N·s), whereas RFD displayed good reliability but greater variability (ICC = 0.80–0.81; CV < 20%; MDC = 2574–2925 N·s^{-1}). Time-to-PF was the least reliable (ICC = 0.68–0.71; CV > 24%; MDC = 1.5–1.7 s). Conclusions: Horizontal isometric push and pull tests using the VALD DynaMo Max dynamometer provide reliable measures of PF and impulse for athlete profiling and tracking substantial longitudinal changes. Peak RFD may be cautiously used for broad cross-sectional comparisons, although its higher variability limits precision in distinguishing smaller inter-individual differences and appears less sensitive to within-individual changes. Time-to-PF demonstrated insufficient reliability for practical application.

Keywords: strength assessment; rate of force development; impulse; longitudinal monitoring; athlete profiling

Academic Editor: DirkJan H.E.J. Veeger

Received: 28 January 2026
Revised: 26 February 2026
Accepted: 27 February 2026
Published: 3 March 2026

1. Introduction

Isometric and dynamic strength tests are widely used in performance settings to analyse force production across a variety of sports [1]. While both methods can provide important insights, isometric tests stand out for being able to quickly and safely quantify force production capabilities of specific muscle groups [2], making them ideal for regular monitoring without disrupting training practices. Moreover, isometric tests are sensitive and effective measures of maximal strength qualities [3,4], even in well-trained athletes who exhibit subtle changes after prolonged training periods [5]. These tests can also indicate acute performance alterations during recovery from high-volume resistance exercise [6].

Isometric strength measures are therefore commonly used to evaluate force production capabilities, demonstrating strong correlations with dynamic athletic performances [7], including jumping [8], sprinting [9], change in direction [10,11] and kayaking [12].

Upper body (UB) isometric assessments are commonly used to measure strength qualities relevant for sports where UB strength is deemed important for performance outcomes [13–15]. For example, athletes competing in multidirectional sports with an emphasised need for physical duels and collisions (i.e., rugby, Australian Rules Football and handball) can benefit from increased levels of pressing strength [16–18], which can be reliably revealed with isometric testing [3,19]. Furthermore, athletes with pulling force requirements (e.g., rowers) can obtain a valid and reliable assessment of their pulling strength through isometric row tests [20]. Hence, UB pressing and pulling motions are key multi-joint exercises used in the conditioning of athletes across a wide variety of sports [21]. As such, they are capable of revealing various maximal strength qualities of UB muscles when conjointly conducted [14].

UB isometric push and pull results consistently show excellent test–retest reliability for peak force (PF) measures [3,13–15,20,22–25]. These assessments, however, are typically conducted in a lying (vertical) position [3,13,14,19,20,24]. This vertical posture more closely mimics the trunk position during key phases of rowing and kayaking strokes, as well as during preparatory bracing and contact situations in sports such as rugby and handball. For example, greater UB pressing strength may enhance maximal sprinting speed [18] and repeated sprint ability [26,27], movements performed with an upright posture, making it logical to recommend testing in this position for a more accurate assessment of its impact on sprinting performances [28]. To the authors' knowledge, only one study has tested push and pull strength isometrically in a seated, upright position, demonstrating high reliability and reproducibility [25]. However, this investigation did not include explosive strength metrics [25] such as the rate of force development (RFD), which may be more relevant for high-intensity movements where a rapid application of high force in short time periods is necessary [29].

Recent advances in portable dynamometry have made field-based testing of strength characteristics more feasible [30]. While force plates are commonly used to capture explosive force–time metrics, portable dynamometers with built-in load cells now provide a practical and reliable alternative [24,30,31]. The VALD DynaMo Max, sampling at 1200 Hz, offers high precision and strong agreement with force plates [30], thereby revealing that externally fixed tension-based tests are more reliable than compression-based ones [30]. Yet, its reliability for capturing explosive force–time characteristics (i.e., impulse and RFD) during horizontal UB push and pull tasks [22] has not been evaluated. Therefore, we aimed to investigate the intraday and interday reliability of multiple UB force–time measures, including PF, peak RFD, impulse, and time-to-PF, using the VALD DynaMo Max dynamometer during horizontal UB push and pull isometric tests in a seated, upright position. This is the first study to evaluate the reliability of the DynaMo Max for capturing these explosive force–time characteristics during seated horizontal push and pull tasks, addressing a clear gap in the current literature. We hypothesised that PF and impulse would demonstrate excellent intraday and interday reliability, while peak RFD would show good reliability, and time-to-PF would demonstrate the lowest reliability, consistent with the typical hierarchy of reliability for maximal versus explosive strength metrics [13,20,24,25]. The remainder of this paper details the methods, results, discussion, and conclusions of this investigation.

2. Materials and Methods

2.1. Participants

Fifty-two recreationally active individuals (male = 41, female = 11; mean age: 25.0 ± 6.12 years) were recruited for the study. This sample size exceeds the recommended minimum of 50 for reliability studies aiming to produce stable ICC estimates with narrow confidence intervals [32]. The inclusion criteria required all participants to be aged 18 years or older, healthy, and recreationally active, with no history of UB injury or other contraindications that could interfere with the study's procedures. Recreationally active was defined as engagement in moderate-to-vigorous physical activity at least three times per week [33]. Prior to participation, the risks and benefits of the study were fully explained to each participant, and written informed consent was obtained. The study protocol was reviewed and approved by the University Research Ethics Committee (HEALTH 0330 Phase_4), conducted in accordance with the Declaration of Helsinki.

2.2. Experimental Design

A repeated-measures design was employed to assess the intraday and interday reliability of isometric horizontal UB push and pull tests with elbows at 90° positions in recreationally active participants. It has been proposed that this is the optimal joint angle for accurately assessing UB strength capacity [19,25,34]. Testing occurred on two separate occasions at approximately the same time of day to avoid potential influences of circadian and diurnal variations, with sessions spaced 48 h apart.

2.3. Procedures

All testing was performed using a custom-built metal rig designed for isometric horizontal UB push and pull strength assessments (Figure 1). The custom-built rig provided trunk and limb stabilisation and enabled direct horizontal force application without pulley friction and loose bar movements. The apparatus consisted of a rectangular welded steel frame with an adjustable padded seat and a vertically aligned backrest, allowing participants to maintain an upright seated position with knees flexed at approximately 90°. A DynaMo Max (VALD, Brisbane, Australia) dynamometer was mounted horizontally to the front crossbar of the rig using a steel chain and carabiner system, which enabled quick transitions between push and pull configurations while ensuring minimal slack and high-tension stability. The height and horizontal position of the dynamometer were individually adjusted so that the transducer aligned with the participant's sternum level in the seated position, ensuring a purely horizontal line of force. For the push test, participants pressed forward against the dynamometer handle while the rig's stabilising crossbar prevented any forward displacement. To allow the handle to move smoothly and maintain horizontal alignment during pressing, external holders were attached to support the bar, ensuring consistent contact and minimising vertical movement (Figure 1). For the pull test, the same rig and stabilising bar were used. Notably, the pulling chain was already integrated into the setup, allowing participants to pull horizontally toward the body from a fixed anchor point while maintaining full back contact with the pad to minimise trunk involvement (Figure 2). The seat and chain geometry ensured that the elbow joint remained close to 90° throughout both actions, effectively isolating the UB pushing and pulling musculature.

A familiarisation session was conducted on the first testing day, immediately prior to data collection. This single-day familiarisation protocol was implemented primarily due to logistical constraints concerning participant availability. This session was designed to acquaint participants with the testing procedures and equipment [35] while minimising the risk of fatigue. Participants first performed two submaximal practice efforts (approximately 50% and 75% of perceived maximum) [24] for both the push and pull exercises, focusing on correct posture and bracing. This was followed by a single maximal effort for each movement to establish a movement-specific reference without inducing significant fatigue. A rest period of 15 min was provided between the final familiarisation trial and the commencement of the experimental trials to ensure full recovery.

https://doi.org/10.3390/biomechanics6010026

Figure 1. Custom-built metal rig designed for isometric horizontal upper body push and pull strength assessments.

Figure 2. Isometric upper body pull assessment using DynaMo Max (VALD).

2.4. Assessment of Horizontal Isometric Upper Body Push and Pull Force Metrics

After completing a standardised warm-up phase [24], subjects performed maximal bilateral horizontal isometric push and pull tests at 90-degree elbow joint angles. Elbow positions and grip distances were determined during the familiarisation session using a handheld goniometer. Participants were allowed to choose their "strongest position" for shoulder placement, which was then maintained consistently throughout the tests [13].

Subjects were instructed to push or pull against the immovable bar with as much force and speed as possible using the prompt "push/pull as hard and fast as you can" [13,36]. They were given a three-second countdown prior to each trial, with verbal encouragement throughout [13,36]. Each subject performed three trials with a 2 min rest between attempts [24], completing the push test first, followed by the pull test. Force data were collected using the DynaMo Max device (VALD, Brisbane, Australia) using a 1200 Hz sampling rate for both tests. From the force–time data, the following variables were recorded for analysis [36]:

- Absolute PF (N), calculated as the maximum force value achieved.
- Time-to-PF (s), calculated as the duration from force onset to the point of PF.
- Peak RFD ($N{\cdot}s^{-1}$), calculated as the highest instantaneous slope of the force-time curve over a rolling 100 ms window.
- Impulse (N·s), calculated as the area under the force-time curve from onset (first sample where force > 30 N above resting baseline, averaged over 500 ms pre-initiation) until force returned below this threshold. Baseline force was subtracted from all signals.

2.5. Statistical Analysis

All statistical analyses were conducted using Statistical Package for the Social Sciences software (SPSS, Version 28.0, IBM, Armonk, NY, USA). The normality of the data for all variables was confirmed using the Shapiro–Wilk test. Descriptive statistics are presented as mean ± standard deviation (SD).

Intraday reliability was evaluated using mean data from all three trials collected on a single day. Relative reliability was determined using two-way mixed-effects, absolute-agreement, average-measures ICC (i.e., $ICC_{3,k}$). This model was selected because the measurement conditions (device, rater, and posture) were identical and treated as fixed effects for the within-session analysis. The corresponding standard error of measurement (SEM) was calculated as: SEM = Pooled SD × $\sqrt{(1 - ICC)}$, in accordance with Weir [37]. The variability was quantified using the coefficient of variation (CV%).

Interday reliability was assessed by comparing the average score of the three trials from day 1 with the average score from day 2. Relative reliability was calculated using two-way random-effects, absolute-agreement, average-measures ICC (i.e., $ICC_{2,k}$), using the mean of 3 trials per day (k = 3). This model was used to allow for generalisation of the reliability estimate beyond the two specific testing days included in this study, treating both participants and testing days as random effects. For absolute reliability, the SEM was calculated from the SD of the difference scores between days: SEM = SD of Difference Scores/$\sqrt{2}$ [19]. This formula derives the SEM for change scores between two time points, as recommended by Hopkins [38]. The interday SEM was then used to calculate the minimal detectable change (MDC) at a 95% confidence level: MDC = 1.96 × $\sqrt{2}$ × SEM [37].

ICC values were interpreted as: <0.50 poor, 0.50–0.75 moderate, 0.75–0.90 good, and >0.90 excellent [32]. CV% values were classified as: <5% excellent, 5–10% good, 10–15% moderate, and >15% poor. Paired-sample *t*-tests were used to examine systematic changes in mean scores between day 1 and day 2. A repeated-measures ANOVA was used to test for significant trial effects within each day. The threshold for statistical significance was set at $p < 0.05$.

3. Results

Descriptive statistics and intraday reliability for all UB push and pull variables across trials on day 1 and day 2 are presented in Table 1 and Table 2, respectively. The interday reliability and comparative analysis for all UB push and pull variables are presented in Table 3. Sex-specific descriptive statistics for all upper-body push and pull force–time variables are provided in Supplementary Table S1.

https://doi.org/10.3390/biomechanics6010026

Table 1. Descriptive statistics, intraday reliability and comparative analysis of upper body PULL and PUSH variables for trials on the first day.

		Mean per Trial			Standard Error		Intraclass Coefficient			Coefficient of Variation	
Pattern	**Variables**	**Trial**	**Mean**	**Std. Dev.**	**SEM**	**95% CI**	**ICC**	**95% CI**	**Rating**	**CV%**	**95% CI**
PULL	Peak Force (N)	1 2 3	830.87 837.65 817.40	191.06 201.54 180.84	30.64	24.6–41.15	0.973 **	0.958–0.984	Excellent	3.70	2.97–4.97
	RFD (N/s)	1 2 3	5004.40 4873.63 4389.73	1735.09 2222.83 2010.55	717	575.75–962.93	0.827 **	0.726–0.895	Good	15.08	12.11–20.25
	Time to Peak Force (s)	1 2 3	2.34 2.00 2.29	1.26 1.11 0.96	0.56	0.45–0.75	0.479 *	0.174–0.684	Poor	25.34	20.35–34.03
	Impulse (N·s)	1 2 3	2871.13 2786.15 2746.15	610.59 650.21 646.97	203.03	163.03–272.67	0.872 **	0.797–0.922	Good	7.25	5.82–9.74
PUSH	Peak Force (N)	1 2 3	929.65 933.08 933.13	219.20 216.54 233.42	32.41	26.03–43.53	0.978 **	0.966–0.987	Excellent	3.48	2.79–4.67
	RFD (N/s)	1 2 3	5252.42 5579.94 6328.21	2068.97 2144.99 2060.18	786.09	631.23–1055.72	0.803 **	0.687–0.88	Good	13.74	11.03–18.45
	Time to Peak Force (s)	1 2 3	2.03 1.86 1.88	1.14 1.22 1.13	0.46	0.37–0.62	0.769 **	0.634–0.86	Good	23.96	19.24–32.18
	Impulse (N·s)	1 2 3	3174.04 3123.48 3059.92	981.33 842.13 902.66	251.55	201.99–337.83	0.910 **	0.858–0.946	Excellent	8.06	6.47–10.82

* Significant at ≤0.05, ** significant at ≤0.001.

Table 2. Descriptive statistics, intraday reliability and comparative analysis of upper body PULL and PUSH variables for trials on the second day.

		Mean per Trial			Standard Error		Intraclass Coefficient			Coefficient of Variation	
Pattern	**Variables**	**Trial**	**Mean**	**Std. Dev.**	**SEM**	**95% CI**	**ICC**	**95% CI**	**Rating**	**CV%**	**95% CI**
PULL	Peak Force (N)	1 2 3	838.85 843.79 839.00	214.21 212.78 212.39	21.1	16.94–28.34	0.990 **	0.984–0.994	Excellent	2.51	2.02–3.37
	RFD (N/s)	1 2 3	5099.63 5385.92 4792.10	1753.56 1819.83 1798.28	627.81	504.13–843.15	0.837 **	0.742–0.901	Good	12.33	9.9–16.56
	Time to Peak Force (s)	1 2 3	2.34 2.18 2.34	1.06 1.05 1.06	0.47	0.38–0.63	0.677 **	0.488–0.804	Moderate	20.52	16.48–27.56
	Impulse (N·s)	1 2 3	3026.83 3080.75 2966.52	848.44 874.00 775.80	205.28	164.84–275.69	0.931 **	0.89–0.958	Excellent	6.79	5.45–9.12
PUSH	Peak Force (N)	1 2 3	941.92 926.77 931.65	265.15 226.53 213.50	45.45	36.5–61.04	0.960 **	0.937–0.976	Excellent	4.87	3.91–6.54
	RFD (N/s)	1 2 3	5735.13 5556.08 5612.87	2645.82 1811.45 1912.03	753.75	605.26–1012.29	0.838 **	0.743–0.901	Good	13.38	10.74–17.97
	Time to Peak Force (s)	1 2 3	2.26 2.19 2.02	1.18 1.11 1.10	0.5	0.4–0.67	0.687 **	0.504–0.81	Moderate	23.15	18.59–31.09
	Impulse (N·s)	1 2 3	3348.65 3285.88 3366.08	912.35 854.23 907.40	264.78	212.62–355.6	0.893 **	0.831–0.935	Good	7.94	6.38–10.66

** Significant at ≤0.001.

Table 3. Descriptive statistics, interday reliability and comparative analysis of upper body PULL and PUSH variables.

			Mean per Trial		Absolute Reliability			Relative Reliability		Intraclass Coefficient		
Pattern	**Variables**	**Day**	**Mean**	**Std. Dev.**	**SEM**	**95% CI**	**MDC**	**CV%**	**95% CI**	**ICC**	**95% CI**	**Rating**
PULL	Peak Force (N)	I II	828.64 840.54	186.45 210.98	46.3	37.18–62.18	128	5.55	4.46–7.45	0.972 **	0.952–0.984	Excellent
	RFD RFD (N/s)	I II	4755.92 5092.55	1723.84 1555.02	929.25	746.19–1247.98	2574	18.87	15.15–25.34	0.809 **	0.668–0.891	Good
	T to PF	I II	2.21 2.29	0.78 0.82	0.56	0.45–0.75	1.5	24.88	19.98–33.41	0.681 **	0.444–0.817	Moderate
	Impulse (N·s)	I II	2801.15 3024.70	567.49 781.48	285.39	229.17–383.28	790	9.80	7.87–13.16	0.904 **	0.833–0.945	Excellent
PUSH	N max Force Impulse (N·s)	I II	931.96 933.45	218.51 227.23	53.74	43.15–72.17	149	5.76	4.63–7.74	0.970 **	0.948–0.983	Excellent
	RFD	I II	5720.19 5634.69	1771.09 1872.70	1055.89	847.88–1418.06	2925	18.60	14.94–24.98	0.798 **	0.649–0.884	Good
	Max Force (N)	I II	1.92 2.16	0.96 0.89	0.62	0.5–0.83	1.7	30.35	24.37–40.76	0.705 **	0.487–0.831	Moderate
	Impulse (N·s)	I II	3119.15 3333.54	838.50 809.47	272.52	218.83–365.99	755	8.45	6.79–11.35	0.942 **	0.899–0.967	Excellent

** Significant at ≤0.001.

3.1. Intraday Reliability

PF and impulse demonstrated the highest level of reliability for both the pull and push movements. Across both testing days, PF consistently had excellent intraday reliability, with ICCs ranging from 0.96 to 0.99 and excellent CV% values (<5%). Similarly, impulse exhibited good-to-excellent reliability, with ICCs ranging from 0.87 to 0.93 and CV% values consistently below 9%. In contrast, peak RFD had good relative reliability (ICCs 0.80–0.83), but higher within-session variability, evidenced by substantially greater CV% values, which ranged from 12% to 15%, indicating less consistency between trials. As expected, the least reliable variable was time-to-PF. It displayed poor-to-moderate relative reliability on day 1 (ICC = 0.48 for pull, 0.77 for push), which improved to moderate on day 2 (ICCs = 0.68 for pull and 0.69 for push). However, its CV% values exceeded 20% on both days, highlighting considerable trial-to-trial variation in the time taken to reach maximal force.

Examination of the trial-by-trial data in Tables 1 and 2 reveals that mean PF values remained stable across the three attempts, with no evidence of systematic fatigue or learning effects (e.g., Day 1 pull: 830.9 N→817.4 N; Day 1 push: 929.7 N→933.1 N). The low SEM values for PF (30.6–32.4 N on Day 1; 21.1–45.5 N on Day 2) indicate that an individual's "true" score falls within a narrow range around their observed score, further supporting the precision of this metric. In contrast, RFD showed greater trial-to-trial fluctuation (e.g., Day 1 push RFD ranged from 5252.4 N/s to 6328.2 N/s), reflected in substantially larger SEM values (627.8–786.1 N/s) and CV% exceeding 12%.

3.2. Interday Reliability

PF again demonstrated the highest level of consistency between the testing sessions. The interday reliability for this metric was excellent, with near-perfect ICCs of 0.97 for both push and pull, accompanied by low variability (CV < 6%) and MDC values of 128 N for the pull and 149 N for the push, which corresponded to MDC percentages of 15.3% and 16.0%, respectively. Similar to the intraday analysis, impulse showed excellent relative reliability (ICCs > 0.90) and good CV scores (CV < 10%) with MDC of 790 N·s for the pull and 755 N·s for the push, representing 27.1% and 23.3% of the mean impulse, respectively. In contrast, the reliability for peak RFD was only in a good range (ICCs ~0.80) and was characterised by notably high CVs (≈18%) and large MDCs for both patterns (>2500 $N{\cdot}s^{-1}$; ~54% for pull and ~51% for push), reflecting substantial day-to-day variability in this explosive strength metric. Time-to-PF remained the least reliable variable across days, exhibiting moderate relative reliability (ICCs ~0.69) and the highest interday variability (CV% > 24%; MDC = 1.5–1.7 s) with MDC percentages exceeding 65%.

Inspection of the day-to-day mean values in Table 3 indicates a slight systematic increase for some metrics (e.g., pull impulse: 2801.1 N·s→3024.7 N·s; push impulse: 3119.2 N·s→3333.5 N·s), although these changes were not statistically significant ($p > 0.05$). The MDC values provide practical benchmarks for interpreting change: for PF, an increase of approximately 15–16% is required to exceed measurement error, while for RFD, changes smaller than ~2500–2900 N/s (51–54%) cannot be distinguished from noise.

4. Discussion

The purpose of this study was to evaluate the intraday and interday reliability of seated horizontal UB isometric push and pull tests using the VALD DynaMo Max dynamometer. The key finding is a clear hierarchy in measurement quality of the different metrics used to capture maximal and explosive isometric force of UB push and pull actions. Maximal strength and force–time metrics (i.e., PF and impulse) demonstrated excellent relative reliability (ICC > 0.90) with low variability (CV < 10%), making them highly suitable for both athlete profiling and tracking longitudinal training-induced changes. While the explosive strength metric (i.e., peak RFD) showed sufficient reliability for cross-sectional comparisons (ICC ~0.80), a high interday variability (CV ~18%; MDC > 2500 N/s) limits its sensitivity for tracking meaningful change. Additionally, time-to-PF proved insufficiently reliable (ICC < 0.71; CV > 24%) for monitoring changes in most practical settings. In summary, practitioners can use these tests for UB push and pull isometric strength assessment, but must exercise caution when interpreting explosive force production characteristics, especially when monitoring within-athlete progress in longitudinal training programmes.

Our findings for PF (ICC = 0.97–0.99, CV < 6%) and RFD (ICC ≈ 0.80, CV = 12–19%) align with previous research on UB isometric strength testing. In elite athletes, isometric bench press PF across multiple elbow angles was reliable (ICC ≈ 0.89–0.97; CV < 2%), yet peak RFD had lower scores (ICC = 0.43; CV < 8%) despite rigorous standardisation [13], suggesting more intrinsic noise of early-phase RFD metrics compared with maximal force outcomes. In UB pulling, the isometric prone bench pull showed excellent PF reliability (ICC = 0.99; CV ≈ 3%) with high validity versus dynamic prone maximal bench pull, while RFD reliability remained in a "good" range (ICC = 0.88; CV ≈ 6–7%) [24]. Furthermore, a recent study on isometric row testing in collegiate rowers similarly reported excellent reliability (ICC = 0.91) with high variability (CV ≈ 20%) and strong associations between isometric and dynamic strength tests, thereby reinforcing the usefulness of UB isometrics for classification ranking [20]. Our results confirm that this reliability profile is maintained in a seated, horizontal testing configuration, demonstrating its robustness across different postural setups.

Beyond lying bench-supported positions, the only previous study to examine test–retest reliability in a seated, upright testing configuration is that of Andrades-Ramírez et al. [25], who evaluated isometric and isometric–vibratory strength protocols for the bilateral seated push and pull using functional electromechanical dynamometry. Their results demonstrated extremely high reliability for both tests (ICC = 0.92–0.99; CV = 4–10%), with no systematic bias and near-perfect inter-session correlations (r = 0.84–0.98) [25]. Notably, the authors included only the PF metric and attributed the superior reliability compared with previous prone tests to the enhanced postural stability afforded by the seated position, which minimises the potential compensatory movements from whole-body bracing and balance adjustments. Our findings support that the seated horizontal configuration produces ICCs and CVs within the same high range, confirming that a stabilised, seated setup enables reproducible measurement of maximal UB isometric force output. Importantly, while Andrades-Ramírez et al. [25] employed sampling at 1000 Hz, our protocol utilised a more stable, custom-built rig in combination with a dynamometer (i.e., DynaMo Max) operating at 1200 Hz. This configuration was essential for the attempt to accurately capture explosive force–time characteristics. Nevertheless, the relative reliability for PF remained nearly identical (ICC $\geq$ 0.97 in both studies), suggesting that increases in sampling frequency beyond this level may yield diminishing returns for PF once mechanical noise and movement artefact are adequately controlled.

Our PF ICC values are consistent with other studies and confirm strong rank-order discrimination [13,24]. However, the MDCs for the push (~149 N) and pull (~128 N) tests represented 15–16% of the force results. This indicates that, although PF is well-suited for intraday ranking and group comparisons, detecting subtle within-athlete improvements across sessions is unlikely without data aggregation (e.g., block-level means). Similarly, impulse demonstrated excellent interday reliability (ICC = 0.90–0.94) but a large MDC (~755–790 N·s), while peak RFD's good reliability (ICC = 0.80–0.81) was accompanied by very high MDC values (~2574–2925 $N \cdot s^{-1}$), highlighting substantial noise in explosive metrics. The greater variability of RFD compared to PF can be attributed to several factors: (1) its reliance on rapid neural drive and motor unit recruitment, which exhibit inherent trial-to-trial fluctuations [28]; (2) its heightened sensitivity to subtle variations in technique, posture, or bracing at the onset of force production; and (3) the potential insufficiency of a separate familiarisation session to stabilise the highly skill-dependent coordinative patterns required for maximal explosive efforts. Hence, while PF and impulse are robust for distinguishing individuals and assessing meaningful changes in larger magnitude, explosive metrics such as RFD remain highly sensitive to small postural or technical deviations. To enhance the reproducibility for explosive variables, multiple familiarisation sessions conducted on separate days may be required before formal data collection to minimise the influence of neuromuscular adaptation and technique variability [13].

A key limitation of the present study is that the familiarisation session was conducted on the same day before the first testing session due to logistical constraints. Although a 15 min recovery period was provided to minimise potential fatigue or potentiation, this approach may not have allowed sufficient neuromuscular adaptation to stabilise performance, particularly for an explosive metric such as RFD. That said, no consistent improvement or decline across trials was detected, suggesting the absence of systematic learning or fatigue effects that might have biased the results. Moreover, the isometric horizontal push–pull setup utilised a custom-fabricated steel rig with chain and carabiner attachments to secure the dynamometer. While this design provided stability and allowed precise adjustment of seat height and dynamometer alignment, the manual repositioning between sessions may have introduced minor inconsistencies in alignment and chain tension that a fully integrated, factory-calibrated system would likely minimise. Finally, the sample comprised trained but non-elite participants, with a predominance of males (n = 41) relative to females (n = 11). Consequently, the reliability and error metrics reported here are primarily based on male responses and may not be fully generalizable to specific populations such as female athletes or elite performers, where differing neuromuscular characteristics, technical proficiency, or strength capacities could influence test stability. Future research should examine the reliability of this protocol in elite athlete populations and across different genders. Studies should also establish their criterion validity against dynamic strength measures, including both the pressing and pulling actions.

5. Conclusions

The seated horizontal UB isometric push and pull test appears to provide a reliable and practical method for assessing maximal strength through PF and impulse, making these metrics suitable for athlete profiling and tracking longitudinal changes. Peak RFD offers sufficient reliability for cross-sectional comparison between athletes but lacks the sensitivity for detecting small, within-individual changes over time. Time-to-PF demonstrated insufficient reliability for practical application. The test configuration used in this study offers a robust and functionally relevant posture for a standardised UB isometric push and pull strength assessment, provided practitioners select metrics based on their specific monitoring objectives. It is recommended to prioritise PF and impulse for routine monitoring, while using RFD cautiously only for broad comparisons.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/biomechanics6010026/s1, Table S1: Sex-specific descriptive statistics for horizontal upper-body push and pull force–time variables.

Author Contributions: Conceptualisation, I.C., D.J.H. and J.A.; methodology, I.C., M.M. and L.T.; validation, D.J.H. and J.A.; formal analysis, I.C., M.M. and L.T.; investigation, I.C., M.M. and L.T.; data curation, I.C.; writing—original draft preparation, I.C.; writing—review and editing, I.C., M.M., L.T., D.J.H. and J.A.; supervision, D.J.H. 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 in accordance with the Declaration of Helsinki and approved by the University of Lancashire Research Ethics Committee (HEALTH 0330 Phase_4).

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

Data Availability Statement: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments: We would like to thank Igor Curovic for his assistance with participant testing.

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

Abbreviations

The following abbreviations are used in this manuscript:

ANOVA	Analysis of variance
CV	Coefficient of variation
ICC	Intraclass correlation coefficient
$ICC_{2,k}$	Two-way random-effects, average-measures intraclass correlation coefficient
$ICC_{3,k}$	Two-way mixed-effects, average-measures intraclass correlation coefficient
MDC	Minimal detectable change
PF	Peak force
RFD	Rate of force development
SD	Standard deviation
SPSS	Statistical Package for the Social Sciences
UB	Upper body

References

1. Dos'Santos, T.; Thomas, C.; Comfort, P.; McMahon, J.J.; Jones, P.A. Relationships between Isometric Force-Time Characteristics and Dynamic Performance. *Sports* **2017**, *5*, 68. [CrossRef]
2. Drake, D.; Kennedy, R.; Wallace, E. The Validity and Responsiveness of Isometric Lower Body Multi-Joint Tests of Muscular Strength: A Systematic Review. *Sports Med. Open* **2017**, *3*, 23. [CrossRef]
3. Bellar, D.; Marcus, L.; Judge, L.W. Validation and Reliability of a Novel Test of Upper Body Isometric Strength. *J. Hum. Kinet.* **2015**, *47*, 189–195. [CrossRef]
4. Lynch, A.E.; Davies, R.W.; Jakeman, P.M.; Locke, T.; Allardyce, J.M.; Carson, B.P. The Influence of Maximal Strength and Knee Angle on the Reliability of Peak Force in the Isometric Squat. *Sports* **2021**, *9*, 140. [CrossRef]
5. Hornsby, W.G.; Gentles, J.A.; MacDonald, C.J.; Mizuguchi, S.; Ramsey, M.W.; Stone, M.H. Maximum Strength, Rate of Force Development, Jump Height, and Peak Power Alterations in Weightlifters across Five Months of Training. *Sports* **2017**, *5*, 78. [CrossRef]
6. Bartolomei, S.; Totti, V.; Griggio, F.; Malerba, C.; Ciacci, S.; Semprini, G.; Di Michele, R. Upper-Body Resistance Exercise Reduces Time to Recover After a High-Volume Bench Press Protocol in Resistance-Trained Men. *J. Strength Cond. Res.* **2021**, *35*, S180–S187. [CrossRef] [PubMed]
7. Verma, S.; Juneja, H.; Khanna, G. Isometric Strength and Its Relationship to Dynamic Performance: A Systematic Review. *J. Exerc. Sci. Physiot* **2010**, *6*, 60–69.
8. Giles, G.; Lutton, G.; Martin, J. Scoping Review of the Isometric Mid-Thigh Pull Performance Relationship to Dynamic Sport Performance Assessments. *J. Funct. Morphol. Kinesiol.* **2022**, *7*, 114. [CrossRef] [PubMed]
9. Tillin, N.A.; Pain, M.T.G.; Folland, J. Explosive force production during isometric squats correlates with athletic performance in rugby union players. *J. Sports Sci.* **2013**, *31*, 66–76. [CrossRef] [PubMed]
10. Thomas, C.; Comfort, P.; Jones, P.A.; Dos'sAntos, T. A Comparison of Isometric Midthigh-Pull Strength, Vertical Jump, Sprint Speed, and Change-of-Direction Speed in Academy Netball Players. *Int. J. Sports Physiol. Perform.* **2017**, *12*, 916–921. [CrossRef]
11. Mason, L.; Kirkland, A.; Steele, J.; Wright, J. The relationship between Isometric Mid-Thigh Pull variables and athletic performance measures: Empirical study of English professional soccer players and meta-analysis of extant literature. *J. Sports Med. Phys. Fit.* **2021**, *61*, 645–655. [CrossRef]

12. Ualí, I.; Herrero, A.J.; Garatachea, N.; Marín, P.J.; Alvear-Ordenes, I.; García-López, D. Maximal strength on different resistance training rowing exercises predicts start phase performance in elite kayakers. *J. Strength Cond. Res.* **2012**, *26*, 941–946. [CrossRef]
13. Young, K.P.; Haff, G.G.; Newton, R.U.; Sheppard, J.M. Reliability of a novel testing protocol to assess upper-body strength qualities in elite athletes. *Int. J. Sports Physiol. Perform.* **2014**, *9*, 871–875. [CrossRef]
14. Augustsson, J.; Gunhamn, T.; Andersson, H. An Assessment of the Ratio between Upper Body Push and Pull Strength in Female and Male Elite Swedish Track and Field Throwers. *Sports* **2024**, *12*, 201. [CrossRef]
15. Parsonage, J.; Secomb, J.; Dowse, R.; Ferrier, B.; Sheppard, J.; Nimphius, S. The Assessment of Isometric, Dynamic, and Sports-Specific Upper-Body Strength in Male and Female Competitive Surfers. *Sports* **2018**, *6*, 53. [CrossRef] [PubMed]
16. Bilsborough, J.C.; Greenway, K.; Livingston, S.; Cordy, J.; Coutts, A.J. Changes in anthropometry, upper-body strength, and nutrient intake in professional Australian football players during a season. *Int. J. Sports Physiol. Perform.* **2016**, *11*, 234–240. [CrossRef] [PubMed]
17. Gorostiaga, E.; Granados, C.; Ibanez, J.; Izquierdo, M. Differences in physical fitness and throwing velocity among elite and amateur male handball players. *Int. J. Sports Med.* **2005**, *26*, 225–232. [CrossRef]
18. Young, W.B.; Newton, R.U.; Doyle, T.L.; Chapman, D.; Cormack, S.; Stewart, C.; Dawson, B. Physiological and anthropometric characteristics of starters and non-starters and playing positions in elite Australian Rules Football: A case study. *J. Sci. Med. Sport.* **2005**, *8*, 333–345. [CrossRef]
19. Sigvaldsen, E.; Loturco, I.; Larsen, F.; Bruusgaard, J.; Kalhovde, J.M.; Haugen, T. Validity and reliability of upper body push and pull tests to determine one-repetition maximum. *PLoS ONE* **2023**, *18*, e0288649. [CrossRef] [PubMed]
20. Pineda, D.; Hudak, J.; Bingham, G.E.; Taber, C.B. Validity and Reliability of an Isometric Row in Quantifying Maximal Force Production in Collegiate Rowers. *J. Strength Cond. Res.* **2023**, *37*, e462–e465. [CrossRef]
21. Kritz, M.; Cronin, J.; Hume, P. Screening the Upper-Body Push and Pull Patterns Using Body Weight Exercises. *Strength Cond. J.* **2010**, *32*, 72. [CrossRef]
22. Reichert, L.; Müller, T.; Wieland, B.; Fleddermann, M.-T.; Zentgraf, K. Upper-body isometric horizontal strength in game sport athletes. *Front. Sports Act. Living* **2023**, *5*, 1213957. [CrossRef]
23. Ashworth, B.; Hogben, P.; Singh, N.; Tulloch, L.; Cohen, D.D. The Athletic Shoulder (ASH) test: Reliability of a novel upper body isometric strength test in elite rugby players. *BMJ Open Sport Exerc. Med.* **2018**, *4*, e000365. [CrossRef]
24. Lum, D.; Aziz, L. Validity and Reliability of the Isometric Prone Bench Pull Test. *Int. J. Sports Med.* **2020**, *41*, 520–527. [CrossRef]
25. Andrades-Ramírez, O.; Ulloa-Díaz, D.; Alfaro Castillo, B.; Arroyo-Jofré, P.; Castillo-Paredes, A.; Chirosa-Ríos, L. Test-Retest Reliability of an Isometric and Isometric/Vibratory Muscular Strength Protocol with Functional Electro-Mechanical Dynamometry. *Sports* **2024**, *12*, 175. [CrossRef] [PubMed]
26. Balsalobre-Fernández, C.; Tejero-González, C.; Campo-Vecino, J.; Bachero-Mena, B.; Sanchez-Martinez, J. Relationships among repeated sprint ability, vertical jump performance and upper-body strength in professional basketball players. *Arch. Med. Deporte* **2014**, *31*, 148–153.
27. Ingebrigtsen, J.; Jeffreys, I. Relationship between speed, strength and jumping abilities in elite junior handball players. *Serb. J. Sports Sci.* **2012**, *6*, 83–88.
28. Curovic, I.; Grecic, D.; Rhodes, D.; Alexander, J.; Harper, D.J. Potential Importance of Maximal Upper Body Strength-Generating Qualities and Upper Body Strength Training for Performance of High-Intensity Running and Jumping Actions: A Scoping Review. *Sports* **2024**, *12*, 357. [CrossRef] [PubMed]
29. Maffiuletti, N.A.; Aagaard, P.; Blazevich, A.J.; Folland, J.J.; Tillin, N.; Duchateau, J. Rate of force development: Physiological and methodological considerations. *Eur. J. Appl. Physiol.* **2016**, *116*, 1091–1116. [CrossRef]
30. Collings, T.J.; Goodlich, B.I.; Hams, A.H.; Bourne, M.N. Reliability of VALD DynaMo dynamometer to assess upper and lower body isometric strength in healthy adults. *Phys. Ther. Sport* **2025**, *75*, 135–143. [CrossRef]
31. Nikodelis, T.; Savvoulidis, S.; Athanasakis, P.; Chalitsios, C.; Loizidis, T. Comparative Study of Validity and Reliability of Two Handgrip Dynamometers: K-Force Grip and Jamar. *Biomechanics* **2021**, *1*, 73–82. [CrossRef]
32. 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] [PubMed]
33. Garber, C.E.; Blissmer, B.; Deschenes, M.R.; Deschenes, M.R.; Franklin, B.A.; Lamonte, M.J.; Lee, I.-M.; Nieman, D.C.; Swain, D.P. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Med. Sci. Sports Exerc.* **2011**, *43*, 1334–1359. [CrossRef] [PubMed]
34. Lum, D.; Haff, G.G.; Barbosa, T.M. The Relationship between Isometric Force-Time Characteristics and Dynamic Performance: A Systematic Review. *Sports* **2020**, *8*, 63. [CrossRef]
35. Courel-Ibáñez, J.; Hernández-Belmonte, A.; Cava-Martínez, A.; Pallarés, J.G. Familiarization and Reliability of the Isometric Knee Extension Test for Rapid Force Production Assessment. *Appl. Sci.* **2020**, *10*, 4499. [CrossRef]

36. Haff, G.G.; Ruben, R.P.; Lider, J.; Twine, C.; Cormie, P. A Comparison of Methods for Determining the Rate of Force Development During Isometric Midthigh Clean Pulls. *J. Strength Cond. Res.* **2015**, *29*, 386. [CrossRef] [PubMed]
37. Weir, J.P. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J. Strength Cond. Res.* **2005**, *19*, 231–240.
38. Hopkins, W.G. A New View of Statistics. 2016. Available online: https://www.sportsci.org/resource/stats/ (accessed on 1 September 2020).