

Research article

Reliability of Isometric Mid-Thigh Pull in Youth Male Basketball Players Across Age Categories

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Abstract

The aim of this study was to examine the reliability of peak force (PF) and rate of force development (RFD) from the Isometric Mid-Thigh Pull (IMTP) in 59 male basketball players from a Japanese professional club's youth academy classified into three age categories (U12: n = 18, U15: n = 27, and U18: n = 14). Each athlete completed three IMTP sessions, from which PF and mean RFD were calculated over time intervals of 0 - 50, 0 - 100, 0 - 150, 0 - 200, and 0 - 250 ms. Within-session and between-day reliabilities were evaluated using the intraclass correlation coefficient (ICC), coefficient of variation (CV), and standard error of measurement (SEM). PF demonstrated consistently high reliability across all age categories for both within-session and between-day analyses (ICC 0.77 - 0.98, CV 3.4 - 8.2%), with small SEM values (7.65 - 91.86 N, 0.60 - 4.13%) indicating limited measurement error. In contrast, RFD displayed poor reliability in shorter time windows (0 - 50 and 0 - 100 ms; ICC < 0.50), particularly in categories U12 and U15. Although longer time windows (0 - 150 and 0 - 250 ms) achieved higher reliability (ICC > 0.75) and lower SEM values than those previously reported, the CV values remained high (10.7 - 34.8%). Such a large variability may obscure true performance changes. Consequently, the PF is recommended as a robust metric for young athletes across all age groups. In contrast, the current protocol limits the ability of RFD to accurately detect individual changes. Therefore, RFD requires careful interpretation and protocol modifications, such as extended familiarization, to improve stability and precision.

Key words: Peak force, Rate of force development, Biological maturation, Long-term athlete development.

Introduction

Assessing muscular strength in young athletes is essential for guiding training and determining appropriate loads based on developmental stage. However, because body size, muscle mass, and other physical characteristics change rapidly during youth, strength measurements are strongly influenced by biological maturity (Malina et al., 2004), highlighting the need for valid and reliable evaluation methods. With physical growth and neuromuscular development, force generation and motor control capabilities undergo substantial transformations. Therefore, even if the measurement method is valid at a certain developmental stage, its reliability may differ across stages.

Traditionally, one-repetition maximum (1RM) testing has been the standard method for strength assessment (Micke et al., 2025). Although free-weight 1RM testing (e.g., back squats and bench presses) has been shown to be

a reliable measure in adolescent and inexperienced athletes (Comfort and McMahon, 2015; Faigenbaum et al., 2012), these studies also indicate that achieving such reliability requires adequate familiarization and a prerequisite level of technical competency. Consequently, the need to dedicate time for acquiring technique remains a practical limitation in youth athletic settings (Stricker et al., 2020; Warncke et al., 2023). Furthermore, in populations experiencing rapid morphological changes, 1RM testing values may be influenced by technical factors and lifting skill (Van Every et al., 2022). These limitations indicate the need for an alternative strength assessment that can complement 1RM testing, offering greater safety and reduced time.

An alternative approach is the isometric midthigh pull (IMTP). Through extensive foundation research, the methodological considerations, and standardized protocols for the IMTP have been firmly established (Beckham et al., 2018; Comfort et al., 2019; Dos Santos et al., 2017; Guppy et al., 2019; Haff et al., 2015). Because it involves a brief isometric contraction rather than dynamic lifting, the IMTP provides a highly safe and reliable (intraclass correlation coefficient [ICC]: 0.73 - 0.99, coefficient of variation [CV]: 0.7 - 11.0%) assessment tool for clinical and competitive setting (Grgic et al., 2022; Palmer et al., 2023). A further advantage of the IMTP is an isometric assessment performed on a force plate that allows measurement of the peak force (PF) and neuromuscular indices, such as rate of force development (RFD) (Grgic et al., 2022). Furthermore, the IMTP is less influenced by training proficiency than 1RM testing (Giles et al., 2022) and is less affected by morphological differences when joint angles are standardized (Comfort et al., 2015).

Previous research on the IMTP has indicated that while PF demonstrates high reliability in young adult athletes, RFD reliability is relatively low (CVs > 10%) (Brady et al., 2020; Guppy et al., 2019). This is likely because RFD is calculated over short-term windows and is strongly influenced by sampling precision and minor movement variations during trials (D'Emanuele et al., 2021). Furthermore, recent studies have highlighted that both the magnitude and reliability of RFD are highly sensitive to the specific testing protocols employed such as the duration of the pull and the subsequent analysis choices (Guppy et al., 2022; Suarez et al., 2022). Although similar trends in reliability have been reported in studies of young athletes, the available data remain limited compared with those for young adult populations. Furthermore, given the substantial changes in physical characteristics and neuromuscular

control associated with growth, verifying measurement reliability across various chronological age categories is essential for young athletes.

The aim of this study was to examine the within-session and between-day reliabilities of PF and RFD in the IMTP of young athletes. Furthermore, by grouping participants by age category (U12, U15, and U18), this study aimed to clarify the influence of developmental stages on measurement reliability. It was hypothesized that while PF maintains stability across all categories, the technical difficulty of generating rapid force may compromise RFD reliability differently across stages, particularly in younger age groups.

Methods

Subjects

Fifty-nine male basketball players from the Youth Academy of a professional basketball club in Japan participated in the study. The team operated on three chronological age categories: U18 ($n = 14$), U15 ($n = 27$), and U12 ($n = 18$) (Table 1). Additionally, as an additional analysis to account for biological maturation, the timing of peak height velocity (PHV) was estimated using the maturity offset method (Murayama et al., 2023). Based on the estimated maturity offset, participants were classified into three groups: pre-PHV (more than one year before PHV), circa-PHV (within one year of PHV), and post-PHV (more than one year after PHV). All participants engaged in resistance training at least twice a week for a minimum of 3 months. After joining their respective teams, the players consistently followed structured resistance-training programs. Resistance training experience was calculated as the number of years since team entry to the date of measurement. Players aged 13 years underwent barbell-based resistance training approximately twice per week, whereas players aged 12 years

primarily performed basic resistance training using body-weight exercises. None of the participants had prior experience in performing an isometric mid-thigh pull (IMTP). Therefore, a comprehensive familiarization protocol was implemented prior to testing. Height and seated height were measured to the nearest 0.1 cm using a stadiometer (Seca 213; Seca GmbH, Co. KG, Hamburg, Germany), and body weight was measured to the nearest 0.1 kg using a digital scale (HBF-214; Omron Healthcare Co., Ltd., Kyoto, Japan). Leg length was calculated by subtracting seated height from standing height. Age was calculated as the number of days from birth to the date of measurement. The participants and their guardians received comprehensive explanations of the purpose, methods, and risks of the study, and written consent was obtained from the guardians prior to participation. This study was conducted in accordance with the principles of the Declaration of Helsinki and approved by the University Ethics Committee for Research Involving Human Subjects (approval number: 2024-586).

Study design

Measurements were conducted during the pre-season over 3 days, with intervals of at least 48 h between sessions. Each session included three trials, with a rest period of 1 - 3 min between trials (Figure 1). Before the initial session, a familiarization session was conducted to ensure proper form acquisition. During this session, each participant practiced the IMTP until the lead researcher verified their technical competencies. This process involved two to three submaximal trials separated by 60 s of rest. Technical competency was determined on the basis of the ability to maintain a stable, upright torso position without visible countermovement. Additionally, the force traces from these practice trials were observed to ensure a stable baseline period before movement initiation and verify a clean force onset pattern.

Table 1. Participant characteristics. Data are presented as mean \pm SD.

	U12 ($n = 18$)	U15 ($n = 27$)	U18 ($n = 14$)
Age (year)	10.11 \pm 0.74	12.84 \pm 1.09	15.93 \pm 0.80
Height (cm)	143.64 \pm 10.02	169.04 \pm 10.13	178.04 \pm 6.43
Weight (kg)	36.84 \pm 6.96	58.69 \pm 10.16	75.44 \pm 7.46
Training Experience (years)	0.98 \pm 0.65	1.67 \pm 1.23	3.26 \pm 1.90

U12 = under 12 years of age; U15 = under 15 years of age; U18 = under 18 years of age; SD = standard deviation.

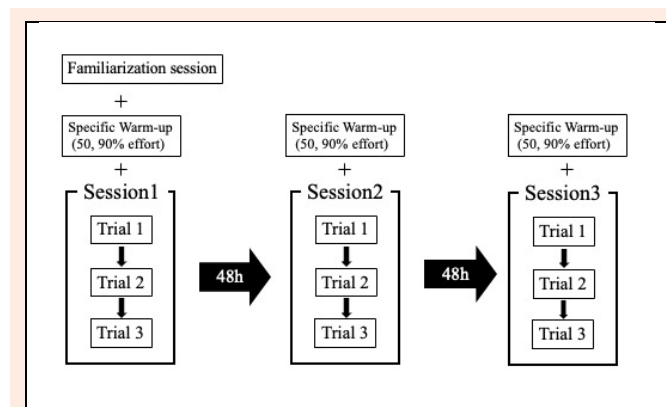


Figure 1. Experimental design and timeline of the study. The familiarization session included technical instruction to verify competency and 2 - 3 submaximal trials separated by a 60-s rest. A stable upright torso and stable baseline waveforms on force traces were verified without countermovement. All measurements were conducted following a complete day off from scheduled team practice, and trials were separated by rest periods of 1 to 3 minutes.

The participants were instructed to wear the same clothing and footwear during all three testing sessions. All measurements were performed on days following team rest to avoid external fatigue effects, and were conducted after 16:00 during the team's regular activity hours.

Procedures

Measurements were performed using a dual-force plate system (1000 Hz: PASCO Scientific, Roseville, CA, USA). Participants performed the IMTP with the torso held upright, hip joint angles of $140^\circ \pm 5^\circ$, and knee joint angles of $125^\circ \pm 5^\circ$. These angles were selected based on previous research that reported that this position maximizes PF production (Beckham et al., 2018; Comfort et al., 2019). Joint angles were set based on the right leg and were measured by the same examiner using a manual goniometer (Sakai Medical Co., Ltd., Tokyo, Japan) across all testing sessions. The bar height was individually adjusted to ensure the specified joint angles were achieved, thereby replicating the posture at the start of the second pull phase of a clean. A rig adjustable in 5-cm increments (Zeus Isometric Force Rig, Zeus Fitness, British Columbia, Canada) was used to modify the height and position of the bar at the nearest level corresponding to the mid-thigh. This height was recorded and replicated across all the testing sessions to ensure consistency. Participants stood upright with fully extended elbows and gripped the bar with an overhand grip. Lifting straps (Gold Gym, Tokyo, Japan) were provided to all the participants to eliminate the influence of grip strength. Prior to data collection in each session, participants performed two practice pulls (one at approximately 50% and the other at 90% of maximal effort), followed by a 2-min rest period before the actual measurement. Participants were instructed to "Pull as fast and as hard as possible until I say stop" (Comfort et al., 2019; Dos'Santos et al., 2018; Haff et al., 1997). Data collection was initiated at the command "Hold still," followed by a countdown of "3, 2, 1, pull." Participants performed the IMTP with maximal effort for 3 s (Moeskops et al., 2018). The force-time curves were monitored in real-time to confirm a force plateau within 3 s. All participants received strong, standardized verbal encouragement to ensure maximal effort (Comfort et al., 2019). Trials were excluded as invalid, and retesting was performed under the following conditions: when countermovement was observed, when the hands came off the bar during the trial, when excessive flexion of the knee or hip joints was visually confirmed during the measurement, when the examiner determined that the effort was clearly not maximal, or when the participant self-reported a submaximal effort. Prior to the pull, participants were instructed to apply slight pre-tension to remove slack and remain still for a 3-s baseline period. Onset was defined as the time point at which the force exceeded the baseline mean plus five standard deviations (SD), calculated from the most stable 1-s window within the baseline period (Dos'Santos et al., 2017). The collected force-time data were processed using a custom Python script that applied a bidirectional fourth-order Butterworth low-pass filter with a cutoff frequency of 50 Hz. The following variables were calculated: peak force (PF), defined as the maximum gross vertical ground reaction force

recorded during the trial, and rate of force development (RFD), defined as the average slope of the force-time curve. RFD was calculated for time intervals of 0 - 50, 0 - 100, 0 - 150, 0 - 200, and 0 - 250 ms (Haff et al., 2015) from the onset of force generation using the following equation: $RFD = (F_t - F_{onset}) / t$, where F_t represents the force at a specific time point, F_{onset} represents the gross force at the onset of contraction, and t represents the time duration from the onset.

Statistical analyses

Reliability was evaluated from two perspectives: within-session and between-days. Within-session reliability was assessed by independently calculating the consistency among the three trials on each testing day. For between-day reliability, the trial with the highest peak force on each testing day, along with its corresponding RFD value, was selected as the representative score. The intraclass correlation coefficient, specifically ICC (2, 1) (absolute agreement), was calculated using a two-way random effects model to determine the reliability of a single measure. Normality was assessed using the Shapiro-Wilk test and visual inspection of Q-Q plots. These assessments indicated no substantial deviations from normality. All descriptive data are presented as mean \pm standard deviation (SD). Additionally, to evaluate absolute reliability, the coefficient of variation (CV) and standard error of measurement (SEM) were calculated. ICC interpretation followed Koo and Li (2016) criteria: ≥ 0.90 as "excellent," 0.75 - 0.90 as "good," 0.5 - 0.75 as "moderate," < 0.5 as "poor" (Koo and Li, 2016). The interpretation of the ICC values was based on their point estimates. CV values of $< 10\%$ were interpreted as "good" (Hopkins, 2000). SEM was calculated using the following formula:

$$SEM = SD \times \sqrt{1-ICC}$$

To evaluate the learning effects across the three testing days, the Shapiro-Wilk test was used to assess normality. One-way repeated-measures analysis of variance was performed for variables that met the normality assumption. For variables where the Shapiro-Wilk test indicated a violation of normality (RFD 0 - 50 and 0 - 100 ms in the U15 and U18 categories, respectively), the non-parametric Friedman test was used instead. Following Bonferroni correction for three pairwise comparisons between testing days, statistical significance was adjusted to $p < 0.0167$. When a significant main effect was observed, Bonferroni-corrected post hoc pairwise comparisons were performed to identify specific differences between the testing days, and Cohen's d was used to determine the magnitude of these differences. Reliability analyses were conducted according to age categories (U12, U15, and U18). To account for the potential influence of biological maturation on measurement reliability, additional analyses were conducted for maturity groups (pre-PHV, $n = 20$; circa-PHV, $n = 22$; post-PHV, $n = 17$) using the same methods. Customized Python scripts were developed to process the raw force-time data and calculate all the performance variables.

Results

The mean values and standard deviations for each category (U12, U15, and U18) per day are listed in Table 2. The within-session and between-session reliability indices (ICC, CV, and SEM) are presented in Table 3 and Table 4.

Regarding the learning effects across testing days, the main effects of time were significant in the U12 and U15 groups. Specifically, the U12 group showed significant increases in PF ($p = 0.011$) and RFD at 0 - 250 ms ($p = 0.011$) from days 1 to 2. The U15 group exhibited significant increases for PF ($p < 0.001$) and RFD variables of longer time windows (RFD 0 - 150 to 0 - 250 ms; $p \leq 0.002$). In contrast, the U18 group demonstrated no significant learning effects on any of the variables (Table 5).

In the analysis of within-session reliability, PF demonstrated high ICC values (0.80 - 0.98) across all age categories, with CV values ranging from 3.4 to 5.6%. RFD showed considerable variability depending on the time and age categories. Particularly in the shorter time windows (0 - 50 and 0 - 100 ms) of the U12 and U15 categories, ICC frequently fell below 0.50 and was classified as “poor.” However, most windows after 150 ms demonstrated “moderate” to “excellent” reliability, with ICC exceeding 0.50. In the U18 category, although ICC values were unstable in the shorter time windows, the values for all windows from 0 to 150 to 0 - 250 ms demonstrated “moderate” to “good,” confirming improved reliability. However, the CV remained elevated across all groups and windows (11.9 - 59.7%), exceeding 10%. Regarding SEM, PF showed relatively low values (7.65 - 83.31 N, 0.6 - 3.2%), while RFD exhibited high values in the shorter time windows of 0 - 50 and 0 - 100 ms (294.98 - 1846.93 N·s⁻¹, 23.7 - 56.6%). However, SEM decreased in longer time windows, ranging

from 128.49 to 441.83 N·s⁻¹ (9.9 - 10.3%) at the 250 ms window. Detailed within-session reliability results for all RFD time windows across age categories are presented in Supplementary Table 1.

Between-day reliability showed similar trends. PF consistently demonstrated “good” ICC values of 0.77 - 0.95 across all groups, with CV values of 6.7 - 8.2%, classified as “good.” Conversely, RFD showed low ICC values, particularly in the shorter time windows of the U12 and U15 categories, which were classified as “poor” (U12:0.35; U15:0.08 - 0.33) and indicated insufficient reliability. In contrast, the U18 athletes demonstrated “moderate” or better ICC values (0.70 - 0.79). The RFD CV values were high across all time points (10.7 - 28.4%) but showed a decreasing trend over longer time windows. The SEM for between-day reliability followed a trend similar to that of the within-session SEM. In contrast to PF, where SEM values remained low (39.01 - 91.86 N, 2.1 - 4.1%), RFD showed large variations depending on the time window and group. This was particularly evident in the shorter time windows of 0 - 50 and 0 - 100 ms, which exhibited high SEM values (450.89 - 2182.95 N·s⁻¹, 24.7 - 62.9%).

As additional analysis, the descriptive data (Table 6) and the reliability of the IMTP variables (Tables 7 and 8) was evaluated by maturity group. Similar patterns were observed in the maturity group analyses. For PF, reliability ranging from excellent to good was confirmed across all age categories (ICC: 0.79 - 0.98, CV: 3.5 - 8.3%). For RFD variables, higher reliability was observed in longer time windows (0 - 150 ms and 0 - 250 ms) and in groups with advanced maturity statuses. Detailed within-session reliability results for all RFD time windows across maturity groups are provided in Supplementary Table 2.

Table 2. Mean values and standard deviations of IMTP variables by testing day and age categories.

Category	Variable	Day 1	Day 2	Day 3
All	PF (N)	1722.1 ± 716.1	1891.3 ± 706.7	1856.9 ± 730.3
	RFD50 (N·s ⁻¹)	1952.7 ± 2171.9	2455.0 ± 2039.2	2714.5 ± 2162.0
	RFD100 (N·s ⁻¹)	2369.4 ± 2199.0	2916.5 ± 2203.3	2973.5 ± 1967.1
	RFD150 (N·s ⁻¹)	2505.6 ± 1964.0	3003.3 ± 1957.6	3110.8 ± 1806.7
	RFD200 (N·s ⁻¹)	2547.7 ± 1670.5	3130.3 ± 1785.8	3300.9 ± 1683.3
	RFD250 (N·s ⁻¹)	2551.8 ± 1441.3	3075.9 ± 1551.8	3131.0 ± 1469.4
U12	PF (N)	946.2 ± 176.5	1056.0 ± 191.7	994.7 ± 159.4
	RFD50 (N·s ⁻¹)	1088.9 ± 673.8	1381.8 ± 895.1	1429.3 ± 868.9
	RFD100 (N·s ⁻¹)	1243.7 ± 731.4	1469.3 ± 871.6	1497.4 ± 695.8
	RFD150 (N·s ⁻¹)	1364.9 ± 740.5	1597.1 ± 821.7	1542.3 ± 619.2
	RFD200 (N·s ⁻¹)	1372.7 ± 626.3	1779.9 ± 732.3	1653.7 ± 648.9
	RFD250 (N·s ⁻¹)	1298.0 ± 510.4	1726.2 ± 544.2	1591.7 ± 540.6
U15	PF (N)	1788.4 ± 430.6	1941.7 ± 504.9	1875.5 ± 501.6
	RFD50 (N·s ⁻¹)	1624.4 ± 1417.3	2462.0 ± 1790.3	3107.3 ± 2260.6
	RFD100 (N·s ⁻¹)	2149.0 ± 1367.9	2819.7 ± 1538.8	3060.5 ± 1732.7
	RFD150 (N·s ⁻¹)	2229.8 ± 1067.5	2869.6 ± 1435.8	3117.1 ± 1486.4
	RFD200 (N·s ⁻¹)	2322.8 ± 1003.4	2975.1 ± 1432.9	3358.3 ± 1282.2
	RFD250 (N·s ⁻¹)	2491.3 ± 931.3	2954.5 ± 1129.4	3186.7 ± 1081.9
U18	PF (N)	2591.7 ± 472.1	2632.8 ± 403.3	2626.8 ± 427.3
	RFD50 (N·s ⁻¹)	3696.3 ± 3381.2	3515.4 ± 2679.1	3262.5 ± 2381.9
	RFD100 (N·s ⁻¹)	4241.5 ± 3325.6	4543.5 ± 2996.8	4201.3 ± 2237.2
	RFD150 (N·s ⁻¹)	4504.2 ± 2769.5	4657.6 ± 2374.6	4557.0 ± 1833.2
	RFD200 (N·s ⁻¹)	4492.1 ± 1927.6	4769.0 ± 1861.6	4736.1 ± 1576.1
	RFD250 (N·s ⁻¹)	4280.6 ± 1322.5	4651.2 ± 1525.7	4468.7 ± 1241.8

Data are presented as mean ± SD. PF = peak force; RFD = rate of force development; RFD50–250 = rate of force development at time intervals of 0 - 50, 0 - 100, 0 - 150, 0 - 200, and 0 - 250 ms; SD = standard deviation.

Table 3. Within-session reliability for PF and selected RFD across age categories.

Variable	Day	Mean ± SD	ICC (95% CI)	ICC Interpretation	CV (%) (95% CI)	SEM (95% CI)
PF (All)	1	1722.1 ± 716.1	0.97 (0.96 - 0.98)	Excellent	4.6 (3.8 - 5.3)	17.94 (16.15 - 19.74)
	2	1891.3 ± 706.7	0.98 (0.97 - 0.99)	Excellent	4.3 (3.5 - 5.1)	12.46 (11.21 - 13.70)
	3	1856.9 ± 730.3	0.97 (0.95 - 0.98)	Excellent	4.9 (3.9 - 5.9)	22.97 (20.67 - 25.26)
RFD50 (All)	1	1952.7 ± 2171.9	0.74 (0.63 - 0.82)	Moderate	53.4 (47.5 - 59.3)	562.18 (505.96 - 618.39)
	2	2455.0 ± 2039.2	0.55 (0.39 - 0.68)	Moderate	49.6 (42.3 - 57.0)	921.58 (829.42 - 1013.73)
	3	2714.5 ± 2162.0	0.35 (0.18 - 0.53)	Poor	49.1 (41.8 - 56.4)	1403.20 (1262.88 - 1543.52)
RFD250 (All)	1	2551.8 ± 1441.3	0.85 (0.78 - 0.90)	Good	19.4 (15.3 - 23.4)	218.14 (196.33 - 239.96)
	2	3075.9 ± 1551.8	0.86 (0.78 - 0.91)	Good	17.4 (13.2 - 21.7)	221.53 (199.37 - 243.68)
	3	3131.0 ± 1469.4	0.90 (0.85 - 0.94)	Excellent	14.5 (11.3 - 17.6)	140.38 (126.34 - 154.42)
PF (U12)	1	946.2 ± 176.5	0.96 (0.90 - 0.98)	Excellent	3.5 (2.3 - 4.7)	7.65 (6.88 - 8.41)
	2	1056.0 ± 191.7	0.85 (0.69 - 0.95)	Good	5.4 (2.6 - 8.2)	27.73 (24.96 - 30.51)
	3	994.7 ± 159.4	0.91 (0.79 - 0.97)	Excellent	4.2 (2.7 - 5.8)	14.24 (12.82 - 15.67)
RFD50 (U12)	1	1088.9 ± 673.8	0.41 (0.13 - 0.69)	Poor	45.2 (36.9 - 53.5)	394.38 (354.94 - 433.82)
	2	1381.8 ± 895.1	0.38 (0.06 - 0.70)	Poor	46.3 (30.6 - 62.1)	551.17 (496.05 - 606.29)
	3	1429.3 ± 868.9	0.15 (0.00 - 0.53)	Poor	53.9 (38.9 - 68.9)	730.37 (657.33 - 803.41)
RFD250 (U12)	1	1298.0 ± 510.4	0.75 (0.53 - 0.88)	Moderate	18.0 (9.3 - 26.8)	128.49 (115.64 - 141.34)
	2	1726.2 ± 544.2	0.55 (0.23 - 0.80)	Moderate	17.7 (7.0 - 28.4)	242.08 (217.88 - 266.29)
	3	1591.7 ± 540.6	0.65 (0.35 - 0.86)	Moderate	20.5 (11.4 - 29.5)	187.04 (168.34 - 205.75)
PF (U15)	1	1788.4 ± 430.6	0.93 (0.87 - 0.96)	Excellent	4.7 (3.5 - 6.0)	29.71 (26.74 - 32.68)
	2	1941.7 ± 504.9	0.98 (0.96 - 0.99)	Excellent	3.4 (2.7 - 4.1)	11.68 (10.51 - 12.85)
	3	1875.5 ± 501.6	0.95 (0.90 - 0.98)	Excellent	5.2 (3.8 - 6.6)	27.25 (24.53 - 29.98)
RFD50 (U15)	1	1624.4 ± 1417.3	0.49 (0.26 - 0.70)	Poor	59.7 (51.1 - 68.3)	718.45 (646.61 - 790.30)
	2	2462.0 ± 1790.3	0.40 (0.15 - 0.63)	Poor	51.7 (41.1 - 62.4)	1069.01 (962.11 - 1175.91)
	3	3107.3 ± 2260.6	0.31 (0.08 - 0.59)	Poor	44.5 (34.5 - 54.4)	1570.90 (1413.81 - 1727.99)
RFD250 (U15)	1	2491.3 ± 931.3	0.60 (0.39 - 0.77)	Moderate	20.6 (14.6 - 26.6)	368.73 (331.85 - 405.60)
	2	2954.5 ± 1129.4	0.69 (0.50 - 0.83)	Moderate	18.6 (12.5 - 24.6)	345.41 (310.87 - 379.95)
	3	3186.7 ± 1081.9	0.84 (0.70 - 0.92)	Good	11.9 (7.9 - 15.8)	175.49 (157.94 - 193.04)
PF (U18)	1	2591.7 ± 472.1	0.87 (0.73 - 0.95)	Good	5.6 (3.8 - 7.4)	59.23 (53.31 - 65.15)
	2	2632.8 ± 403.3	0.89 (0.75 - 0.96)	Good	5.0 (4.0 - 6.0)	44.26 (39.83 - 48.69)
	3	2626.8 ± 427.3	0.80 (0.59 - 0.92)	Good	5.2 (2.5 - 7.9)	83.31 (74.97 - 91.64)
RFD50 (U18)	1	3696.3 ± 3381.2	0.75 (0.50 - 0.90)	Moderate	51.7 (35.2 - 68.1)	846.19 (761.57 - 930.81)
	2	3515.4 ± 2679.1	0.54 (0.22 - 0.79)	Moderate	49.0 (32.2 - 65.8)	1209.39 (1088.45 - 1330.33)
	3	3262.5 ± 2381.9	0.22 (0.00 - 0.58)	Poor	52.2 (34.5 - 70.0)	1846.93 (1662.24 - 2031.62)
RFD250 (U18)	1	4280.6 ± 1322.5	0.66 (0.37 - 0.86)	Moderate	18.8 (10.5 - 27.0)	441.83 (397.65 - 486.01)
	2	4651.2 ± 1525.7	0.80 (0.58 - 0.92)	Good	15.1 (7.1 - 23.1)	310.25 (279.22 - 341.27)
	3	4468.7 ± 1241.8	0.78 (0.54 - 0.91)	Good	13.2 (8.2 - 18.1)	269.80 (242.82 - 296.78)

PF = peak force; RFD = rate of force development; SD = standard deviation; ICC = intraclass correlation coefficient; CI = confidence interval; CV = coefficient of variation; SEM = standard error of measurement.

Table 4. Between-day reliability for PF and RFD across age categories.

Category	Variable	Mean ± SD	ICC (95% CI)	ICC Interpretation	CV (%) (95% CI)	SEM (95% CI)
All	PF	1898.93 ± 748.81	0.95 (0.92 - 0.97)	Excellent	7.6 (6.6 - 8.6)	39.01 (35.11 - 42.91)
	RFD50	3349.71 ± 2411.45	0.48 (0.32 - 0.64)	Poor	39.3 (33.4 - 45.2)	1282.64 (1154.37 - 1410.90)
	RFD100	3555.87 ± 2271.47	0.73 (0.62 - 0.83)	Moderate	27.8 (23.6 - 32.0)	614.53 (553.08 - 675.99)
	RFD150	3513.91 ± 2025.33	0.79 (0.71 - 0.87)	Good	22.9 (19.5 - 26.4)	416.52 (374.87 - 458.17)
	RFD200	3501.99 ± 1786.05	0.81 (0.75 - 0.89)	Good	19.6 (16.3 - 22.8)	338.10 (304.29 - 371.92)
	RFD250	3289.96 ± 1531.18	0.87 (0.82 - 0.93)	Good	14.7 (12.4 - 17.1)	205.23 (184.71 - 225.75)
U12	PF	1036.19 ± 184.02	0.77 (0.61 - 0.93)	Good	7.5 (5.4 - 9.6)	41.24 (37.11 - 45.36)
	RFD50	1812.85 ± 792.50	0.35 (0.04 - 0.71)	Poor	33.6 (21.3 - 45.8)	520.12 (468.10 - 572.13)
	RFD100	1822.43 ± 738.51	0.35 (0.02 - 0.69)	Poor	26.3 (16.2 - 36.3)	450.89 (405.80 - 495.98)
	RFD150	1823.32 ± 708.99	0.46 (0.12 - 0.76)	Poor	23.9 (16.9 - 30.9)	362.69 (326.42 - 398.96)
	RFD200	1875.15 ± 608.47	0.59 (0.31 - 0.85)	Moderate	19.3 (14.4 - 24.3)	246.15 (221.53 - 270.76)
	RFD250	1747.53 ± 521.38	0.58 (0.35 - 0.86)	Moderate	16.6 (12.7 - 20.4)	205.75 (185.17 - 226.32)
U15	PF	1946.07 ± 494.25	0.85 (0.78 - 0.94)	Good	8.2 (6.6 - 9.8)	71.88 (64.70 - 79.07)
	RFD50	3469.93 ± 2297.85	0.08 (0.00 - 0.38)	Poor	49.2 (40.0 - 58.4)	2182.95 (1964.66 - 2401.25)
	RFD100	3543.24 ± 1647.33	0.33 (0.10 - 0.61)	Poor	32.7 (26.5 - 38.8)	1131.70 (1018.53 - 1244.87)
	RFD150	3424.35 ± 1427.75	0.47 (0.28 - 0.74)	Poor	25.6 (19.9 - 31.3)	760.71 (684.64 - 836.78)
	RFD200	3417.90 ± 1284.60	0.45 (0.30 - 0.75)	Poor	23.7 (18.0 - 29.4)	703.89 (633.50 - 774.28)
	RFD250	3263.41 ± 1028.98	0.60 (0.47 - 0.83)	Moderate	16.1 (12.0 - 20.3)	405.29 (364.76 - 445.82)
U18	PF	2738.00 ± 435.94	0.79 (0.55 - 0.91)	Good	6.7 (4.9 - 8.5)	91.86 (82.67 - 101.05)
	RFD50	4778.79 ± 2816.51	0.70 (0.43 - 0.88)	Moderate	28.4 (21.5 - 35.4)	822.23 (740.00 - 904.45)
	RFD100	5435.97 ± 2813.88	0.79 (0.56 - 0.92)	Good	21.3 (14.7 - 28.0)	571.56 (514.40 - 628.71)
	RFD150	5487.32 ± 2190.50	0.79 (0.56 - 0.91)	Good	17.7 (11.8 - 23.7)	458.38 (412.55 - 504.22)
	RFD200	5397.21 ± 1609.62	0.79 (0.55 - 0.91)	Good	13.0 (8.7 - 17.2)	338.72 (304.84 - 372.59)
	RFD250	4990.62 ± 1208.25	0.75 (0.50 - 0.90)	Good	10.7 (7.3 - 14.1)	293.14 (263.82 - 322.45)

PF = peak force; RFD = rate of force development; SD = standard deviation; ICC = intraclass correlation coefficient; CI = confidence interval; CV = coefficient of variation; SEM = standard error of measurement.

Table 5. Learning effects for PF and RFD variables across three testing sessions by age category.

Age	Variable	Day 1 vs Day 2 (d)	Day 1 vs Day 3 (d)	Day 2 vs Day 3 (d)	p-value (Main Effect)	Trend
U12	PF	0.953	0.403	-0.487	0.011	Day 1 < Day 2
	RFD50	0.359	0.655	0.218	0.119	-
	RFD100	0.276	0.273	0.022	0.590	-
	RFD150	0.285	0.027	-0.168	0.673	-
	RFD200	0.827	0.520	-0.220	0.062	-
	RFD250	1.010	0.719	-0.228	0.011	Day 1 < Day 2
U15	PF	0.748	0.637	0.158	< 0.001	Day 1 < Day 2
	RFD50	0.338	0.595	0.346	0.032	-
	RFD100	0.421	0.467	0.131	0.065	-
	RFD150	0.492	0.671	0.343	0.002	Day 1 < Day 2
	RFD200	0.570	0.989	0.486	< 0.001	Day 1 < Day 2
	RFD250	0.672	0.914	0.322	< 0.001	Day 1 < Day 2
U18	PF	0.051	0.094	0.012	0.962	-
	RFD50	-0.183	-0.130	0.014	1.000	-
	RFD100	-0.019	-0.014	0.007	0.683	-
	RFD150	-0.119	-0.104	0.060	0.869	-
	RFD200	-0.043	0.077	0.105	0.925	-
	RFD250	0.183	0.118	-0.118	0.733	-

PF = peak force; RFD = rate of force development; d = Cohen's d effect size.

Table 6. Mean values and standard deviations of IMTP variables by testing day and maturity groups.

Category	Variable	Day1	Day2	Day3
All	PF (N)	1722.05 ± 716.09	1891.27 ± 706.65	1856.87 ± 730.29
	RFD50 (N·s ⁻¹)	1952.65 ± 2171.87	2455.04 ± 2039.23	2714.47 ± 2162.03
	RFD100 (N·s ⁻¹)	2369.35 ± 2199.00	2916.46 ± 2203.27	2973.49 ± 1967.10
	RFD150 (N·s ⁻¹)	2505.61 ± 1964.02	3003.26 ± 1957.61	3110.82 ± 1806.73
	RFD200 (N·s ⁻¹)	2547.69 ± 1670.48	3130.29 ± 1785.77	3300.87 ± 1683.29
	RFD250 (N·s ⁻¹)	2551.82 ± 1441.29	3075.91 ± 1551.79	3130.97 ± 1469.38
Pre	PF (N)	978.43 ± 200.44	1101.94 ± 231.03	1038.02 ± 197.99
	RFD50 (N·s ⁻¹)	1024.89 ± 662.53	1410.31 ± 1239.56	1514.48 ± 956.09
	RFD100 (N·s ⁻¹)	1241.23 ± 768.17	1515.79 ± 1030.90	1560.04 ± 762.92
	RFD150 (N·s ⁻¹)	1355.36 ± 735.28	1545.13 ± 812.75	1590.86 ± 658.71
	RFD200 (N·s ⁻¹)	1374.60 ± 606.53	1662.13 ± 691.62	1656.89 ± 614.64
	RFD250 (N·s ⁻¹)	1352.29 ± 535.85	1682.05 ± 549.90	1602.76 ± 510.02
Circa	PF (N)	1775.81 ± 404.68	1911.92 ± 481.18	1861.28 ± 462.29
	RFD50 (N·s ⁻¹)	1580.37 ± 1186.57	2523.49 ± 1630.46	3233.71 ± 2380.53
	RFD100 (N·s ⁻¹)	2085.45 ± 1268.03	2897.83 ± 1449.03	3157.64 ± 1765.11
	RFD150 (N·s ⁻¹)	2208.39 ± 965.68	2969.27 ± 1264.78	3193.67 ± 1508.07
	RFD200 (N·s ⁻¹)	2280.40 ± 906.55	3121.29 ± 1256.59	3401.81 ± 1191.08
	RFD250 (N·s ⁻¹)	2416.48 ± 874.38	3010.14 ± 979.33	3178.61 ± 915.15
Post	PF (N)	2527.32 ± 464.63	2608.65 ± 383.50	2619.30 ± 404.67
	RFD50 (N·s ⁻¹)	3525.91 ± 3242.72	3353.75 ± 2602.29	3222.86 ± 2289.39
	RFD100 (N·s ⁻¹)	4063.96 ± 3109.99	4257.76 ± 2882.63	4079.93 ± 2192.20
	RFD150 (N·s ⁻¹)	4243.49 ± 2634.91	4417.60 ± 2377.48	4437.40 ± 1793.00
	RFD200 (N·s ⁻¹)	4273.69 ± 1880.36	4523.20 ± 1952.57	4722.24 ± 1508.45
	RFD250 (N·s ⁻¹)	4138.20 ± 1289.05	4469.03 ± 1558.93	4507.10 ± 1196.04

Data are presented as mean ± SD. PF = peak force; RFD50-250 = rate of force development at time intervals of 0 - 50, 0 - 100, 0 - 150, 0 - 200, and 0 - 250 ms; SD = standard deviation; Pre = pre-PHV; Circa = circa-PHV; Post = post-PHV; PHV = peak height velocity. Supplementary Table 2. Within-session reliability for PF and RFD across maturity groups

Discussion

This study examined the reliability of PF and RFD during the IMTP in young athletes stratified by age. The PF demonstrated high reliability across all age categories for both within-session and between-day measurements. In contrast, the RFD exhibited considerable variability depending on the group and time window, with particularly low reliability observed in shorter time windows (0 - 50 ms and 0 - 100 ms) for the U12 and U15 categories. Although stability tended to improve over longer time windows (0 - 150 to 0 - 250 ms) across all groups, the CV remained

relatively high. Therefore, these findings suggest that, while PF serves as a robust metric for young athletes, RFD metrics require careful interpretation because of their inherent variability and susceptibility to measurement errors.

PF demonstrated typically high reliability across within-session and between-day conditions (ICC = 0.77 - 0.98; CV = 3.4 - 8.2%). This high reliability is consistent with previous studies in adult athletes (ICC = 0.95; CV = 2.4%) (Godhe et al., 2025) as well as the existing literature on non-elite youth athletes, which also reports excellent PF reliability (ICC = 0.97 - 0.99, CV = 3.3 - 5.1%) (Hill et al., 2021). The consistent results observed across all age

categories in this study further strengthen the evidence that PF is a highly robust metric regardless of age, developmental stage, or athletic background. Furthermore, SEM, which represents absolute measurement error (0.6 - 4.1%), was comparable to values reported in previous research (57.2 N; 95% CI = 48.4 - 70.5N) (Rago et al., 2024), indicating that measurement error was limited to an acceptable range. These results support previous reports that the PF demonstrates high reliability even with minimal familiarization (Grgic et al., 2022), indicating that high reliability can be achieved in young athletes with limited experience in maximal lower-body isometric force production. Therefore, the PF can be utilized as a regular monitoring indicator in practical settings and may be useful for evaluating growth and training effects.

In contrast to the high stability of the PF, the RFD demonstrated lower reliability, particularly in shorter time windows, which is consistent with previous findings (Brady et al., 2020; Moeskops et al., 2018). This is potentially because extremely short RFD time windows are highly susceptible to subtle movement fluctuations, force initiation delays, signal processing influences, and individual differences in technical proficiency and start strategies (Maffiuletti et al., 2016). Several shorter time-window comparisons (0 - 50 ms and 0 - 100 ms) showed an ICC below 0.50, indicating limitations in measurement consistency. Although stability improved in longer time windows (0 - 150 to 0 - 250 ms), where the ICC values reached 0.75 or higher, the CV values consistently exceeded the 10% threshold across all age categories and time windows.

Table 7. Within-session reliability for PF and RFD across maturity groups.

Variable	Day	Mean ± SD	ICC (95% CI)	ICC Interpretation	CV (%) (95% CI)	SEM (95% CI)
PF (All)	1	1722.1 ± 716.1	0.97 (0.96 - 0.98)	Excellent	4.6 (3.8 - 5.3)	17.94 (16.15 - 19.74)
	2	1891.3 ± 706.7	0.98 (0.97 - 0.99)	Excellent	4.3 (3.5 - 5.1)	12.46 (11.21 - 13.70)
	3	1856.9 ± 730.3	0.97 (0.95 - 0.98)	Excellent	4.9 (3.9 - 5.9)	22.97 (20.67 - 25.26)
RFD50 (All)	1	1952.7 ± 2171.9	0.74 (0.63 - 0.82)	Moderate	53.4 (47.5 - 59.3)	562.18 (505.96 - 618.39)
	2	2455.0 ± 2039.2	0.55 (0.39 - 0.68)	Moderate	49.6 (42.3 - 57.0)	921.58 (829.42 - 1013.73)
	3	2714.5 ± 2162.0	0.35 (0.18 - 0.53)	Poor	49.1 (41.8 - 56.4)	1403.20 (1262.88 - 1543.52)
RFD250 (All)	1	2551.8 ± 1441.3	0.85 (0.78 - 0.90)	Good	19.4 (15.3 - 23.4)	218.14 (196.33 - 239.96)
	2	3075.9 ± 1551.8	0.86 (0.78 - 0.91)	Good	17.4 (13.2 - 21.7)	221.53 (199.37 - 243.68)
	3	3131.0 ± 1469.4	0.90 (0.85 - 0.94)	Excellent	14.5 (11.3 - 17.6)	140.38 (126.34 - 154.42)
PF (Pre)	1	978.4 ± 200.4	0.96 (0.92 - 0.98)	Excellent	3.5 (2.3 - 4.6)	6.98 (6.28 - 7.67)
	2	1101.9 ± 231.0	0.90 (0.80 - 0.96)	Excellent	5.1 (2.7 - 7.6)	22.22 (19.99 - 24.44)
	3	1038.0 ± 198.0	0.93 (0.83 - 0.97)	Excellent	4.3 (2.8 - 5.8)	14.56 (13.10 - 16.01)
RFD50 (Pre)	1	1024.9 ± 662.5	0.30 (0.04 - 0.59)	Poor	49.0 (40.7 - 57.4)	464.75 (418.27 - 511.22)
	2	1410.3 ± 1239.6	0.17 (0.00 - 0.51)	Poor	54.0 (38.9 - 69.2)	1015.08 (913.57 - 1116.58)
	3	1514.5 ± 956.1	0.18 (0.00 - 0.54)	Poor	55.6 (43.3 - 67.9)	791.76 (712.58 - 870.93)
RFD250 (Pre)	1	1352.3 ± 535.9	0.72 (0.52 - 0.87)	Moderate	18.5 (10.4 - 26.6)	146.61 (131.95 - 161.27)
	2	1682.1 ± 549.9	0.45 (0.13 - 0.72)	Poor	20.6 (10.8 - 30.4)	301.29 (271.16 - 331.41)
	3	1602.8 ± 510.0	0.61 (0.34 - 0.84)	Moderate	20.0 (11.5 - 28.6)	197.80 (178.02 - 217.58)
PF (Circa)	1	1775.8 ± 404.7	0.91 (0.84 - 0.96)	Excellent	4.9 (3.4 - 6.4)	34.50 (31.05 - 37.95)
	2	1911.9 ± 481.2	0.97 (0.95 - 0.99)	Excellent	3.6 (2.8 - 4.4)	13.68 (12.31 - 15.05)
	3	1861.3 ± 462.3	0.93 (0.86 - 0.97)	Excellent	5.7 (4.2 - 7.1)	33.97 (30.57 - 37.37)
RFD50 (Circa)	1	1580.4 ± 1186.6	0.39 (0.12 - 0.64)	Poor	57.8 (47.4 - 68.2)	717.67 (645.90 - 789.43)
	2	2523.5 ± 1630.5	0.35 (0.09 - 0.62)	Poor	51.1 (40.0 - 62.2)	1046.74 (942.07 - 1151.41)
	3	3233.7 ± 2380.5	0.33 (0.07 - 0.63)	Poor	41.2 (29.6 - 52.8)	1604.94 (1444.45 - 1765.43)
RFD250 (Circa)	1	2416.5 ± 874.4	0.53 (0.29 - 0.75)	Moderate	21.0 (14.2 - 27.7)	406.45 (365.81 - 447.10)
	2	3010.1 ± 979.3	0.64 (0.41 - 0.82)	Moderate	15.4 (8.6 - 22.3)	346.62 (311.96 - 381.28)
	3	3178.6 ± 915.2	0.83 (0.66 - 0.92)	Good	10.8 (7.2 - 14.3)	155.81 (140.23 - 171.39)
PF (Post)	1	2527.3 ± 464.6	0.88 (0.76 - 0.95)	Good	5.4 (3.9 - 6.9)	53.98 (48.58 - 59.38)
	2	2608.7 ± 383.5	0.90 (0.78 - 0.96)	Good	4.5 (3.4 - 5.5)	39.37 (35.43 - 43.30)
	3	2619.3 ± 404.7	0.81 (0.62 - 0.92)	Good	4.7 (2.2 - 7.1)	77.32 (69.58 - 85.05)
RFD50 (Post)	1	3525.9 ± 3242.7	0.73 (0.49 - 0.88)	Moderate	52.8 (39.0 - 66.5)	862.13 (775.92 - 948.35)
	2	3353.8 ± 2602.3	0.60 (0.31 - 0.80)	Moderate	43.7 (28.8 - 58.7)	1038.62 (934.76 - 1142.49)
	3	3222.9 ± 2289.4	0.19 (0.00 - 0.53)	Poor	52.3 (36.7 - 68.0)	1847.01 (1662.31 - 2031.71)
RFD250 (Post)	1	4138.2 ± 1289.1	0.67 (0.41 - 0.85)	Moderate	18.4 (11.0 - 25.8)	420.60 (378.54 - 462.66)
	2	4469.0 ± 1558.9	0.78 (0.58 - 0.90)	Good	17.0 (10.1 - 23.8)	334.61 (301.15 - 368.07)
	3	4507.1 ± 1196.0	0.73 (0.49 - 0.88)	Moderate	13.6 (9.0 - 18.2)	320.61 (288.55 - 352.67)

PF = peak force; RFD = rate of force development; SD = standard deviation; ICC = intraclass correlation coefficient; CI = confidence interval; CV = coefficient of variation; SEM = standard error of measurement; Pre = pre-PHV; Circa = circa-PHV; Post = post-PHV; PHV = peak height velocity.

Table 8. Between-day reliability for PF and RFD across maturity groups.

Category	Variable	Mean (\pm SD)	ICC (95%CI)	ICC Interpretation	CV (95%CI)	SEM (95%CI)
All						
	PF	1898.93 \pm 748.81	0.95 (0.92 - 0.97)	Excellent	7.6 (6.6 - 8.6)	39.01 (35.11 - 42.91)
	RFD50	3349.71 \pm 2411.45	0.48 (0.32 - 0.64)	Poor	39.3 (33.4 - 45.2)	1282.64 (1154.37 - 1410.90)
	RFD100	3555.87 \pm 2271.47	0.73 (0.62 - 0.83)	Moderate	27.8 (23.6 - 32.0)	614.53 (553.08 - 675.99)
	RFD150	3513.91 \pm 2025.33	0.79 (0.71 - 0.87)	Good	22.9 (19.5 - 26.4)	416.52 (374.87 - 458.17)
	RFD200	3501.99 \pm 1786.05	0.81 (0.75 - 0.89)	Good	19.6 (16.3 - 22.8)	338.10 (304.29 - 371.92)
	RFD250	3289.96 \pm 1531.18	0.87 (0.82 - 0.93)	Good	14.7 (12.4 - 17.1)	205.23 (184.71 - 225.75)
Pre						
	PF	1090.21 \pm 217.51	0.83 (0.74 - 0.95)	Good	7.4 (5.4 - 9.3)	36.65 (32.98 - 40.31)
	RFD50	2018.94 \pm 1182.92	0.30 (0.01 - 0.65)	Poor	40.5 (29.9 - 51.0)	840.63 (756.57 - 924.70)
	RFD100	2075.73 \pm 897.65	0.43 (0.13 - 0.73)	Poor	29.1 (20.1 - 38.0)	509.49 (458.54 - 560.44)
	RFD150	1964.72 \pm 690.06	0.43 (0.11 - 0.72)	Poor	24.5 (17.5 - 31.5)	394.03 (354.83 - 438.44)
	RFD200	1937.56 \pm 541.45	0.49 (0.20 - 0.77)	Poor	19.6 (14.8 - 24.4)	278.30 (250.47 - 306.13)
	RFD250	1825.43 \pm 454.49	0.60 (0.35 - 0.84)	Moderate	15.2 (11.5 - 18.9)	183.60 (165.24 - 201.96)
Circa						
	PF	1896.76 \pm 468.78	0.84 (0.73 - 0.94)	Good	8.3 (6.4 - 10.1)	75.20 (67.68 - 82.72)
	RFD50	3531.81 \pm 2298.92	0.09 (0.00 - 0.43)	Poor	43.9 (31.9 - 56.0)	2149.94 (1934.94 - 2364.93)
	RFD100	3595.28 \pm 1679.46	0.31 (0.06 - 0.62)	Poor	31.4 (23.7 - 39.0)	1174.87 (1057.38 - 1292.36)
	RFD150	3499.47 \pm 1427.77	0.42 (0.20 - 0.72)	Poor	25.2 (18.8 - 31.6)	837.06 (753.35 - 920.76)
	RFD200	3443.47 \pm 1191.70	0.41 (0.24 - 0.75)	Poor	22.9 (16.7 - 29.1)	732.96 (659.67 - 806.26)
	RFD250	3217.58 \pm 916.29	0.59 (0.49 - 0.86)	Moderate	16.0 (11.5 - 20.5)	384.93 (346.43 - 423.42)
Post						
	PF	2697.34 \pm 434.40	0.79 (0.58 - 0.91)	Good	6.8 (5.0 - 8.5)	91.08 (81.97 - 100.18)
	RFD50	4705.24 \pm 2809.73	0.64 (0.37 - 0.84)	Moderate	31.8 (23.1 - 40.5)	990.20 (891.18 - 1089.22)
	RFD100	5281.42 \pm 2769.23	0.80 (0.60 - 0.91)	Good	20.9 (14.8 - 27.1)	538.44 (484.59 - 592.28)
	RFD150	5270.82 \pm 2181.26	0.82 (0.63 - 0.92)	Good	17.3 (12.1 - 22.6)	388.80 (349.92 - 427.68)
	RFD200	5250.79 \pm 1619.35	0.77 (0.56 - 0.90)	Good	14.3 (8.4 - 20.1)	361.57 (325.41 - 397.73)
	RFD250	4922.64 \pm 1195.04	0.71 (0.47 - 0.88)	Moderate	11.4 (7.0 - 15.9)	340.80 (306.72 - 374.88)

PF = peak force; RFD = rate of force development; SD = standard deviation; ICC = intraclass correlation coefficient; CI = confidence interval; CV = coefficient of variation; SEM = standard error of measurement; Pre = pre-PHV; Circa = circa-PHV; Post = post-PHV; PHV = peak height velocity.

Notably, while the between-day SEM values for RFD at 250 ms (205.23 - 405.29 N·s⁻¹) were lower than those reported in previous studies on adults (645 N·s⁻¹) (García-Sánchez et al., 2025), this finding may be attributed to the smaller SD associated with the lower absolute strength levels of young athletes. Consequently, these consistently high CV values make it challenging to use the RFD as an individual monitoring metric under the current protocol. Our finding of lower RFD reliability is consistent with recent evidence highlighting that RFD is highly sensitive to testing protocols and data analysis choices (Guppy et al., 2022). To address these challenges, implementing a 1-s shortened IMTP protocol can mitigate pacing strategies often caused by traditional 3 - 5-s durations (Suarez et al., 2022). Furthermore, optimizing verbal cues to focus strictly on "explosive" intent (Maffioletti et al., 2016), providing visual force-time feedback (Stien et al., 2025), and increasing familiarization trials (Moeskops et al., 2018) may further facilitate motor learning in inexperienced youth. Future studies should investigate these combined strategies to ensure stable RFD measurements.

When comparing the age categories, the ICC values for RFD in the U12 and U15 categories were < 0.50. This suggests that the instability of neuromuscular control characteristics in early adolescence may contribute to the low reliability (Philippaerts et al., 2006). During this period, rapid increases in height and limb length temporarily reduce movement coordination and destabilize force production patterns (Philippaerts et al., 2006). The U18 athletes demonstrated higher ICC values than the other groups, which may be attributed to improved neural adaptations

and movement stability associated with their development and training experience (Granacher et al., 2016; Ozmun et al., 1994).

Evaluating RFD is inherently challenging in youths and elite adult athletes, which often necessitates multiple trials to achieve a reliable measure (Stevens et al., 2025). Therefore, the profound instability observed in developing youths is potentially a natural consequence of their developmental stages. Additionally, previous research on young athletes reported substantial variability for RFD (CV \leq 31.6%), which aligns closely with the low reliability observed in our study (Moeskops et al., 2018). Therefore, although averaging multiple trials can improve RFD reliability, prioritizing the PF, which can be robustly evaluated in a single trial, may be a practical option in a field setting.

Regarding between-day absolute values, a trend toward substantial changes from days 1 to 2 and 3 was observed, particularly in the U12 and U15 categories. This can be attributed to the learning effect (Moeskops et al., 2018). For young athletes with limited training experience, maximal rapid force production tasks such as IMTP are unfamiliar movements, and acquiring appropriate force generation strategies requires time (Moeskops et al., 2018). Although this study included a familiarization session and two practice trials immediately before each measurement, it is highly plausible that these procedures were insufficient to stabilize performance, particularly for younger and less-experienced participants. Therefore, to ensure accurate evaluation of youth populations, protocol modifications are recommended, including increasing the number of practice trials and implementing additional familiarization for first-

time assessments (Keogh et al., 2020; Moeskops et al., 2018).

Subsequently, the reliability differences between the PF and RFD demonstrated in this study have important implications for a Long-Term Athlete Development (LTAD) model (Lloyd and Oliver, 2012). Because PF is a stable indicator regardless of maturity status, it can be used long-term right from the initial stages of LTAD and can reliably track strength changes that accompany growth and development. In contrast, the interpretation of the RFD is limited owing to its low reliability in younger categories and persistently high intra-individual variability in the U18 category. Therefore, in developmental settings based on the LTAD model, monitoring should primarily focus on PF during the initial stages. RFD should be approached with caution, as it serves only as a supplementary metric once athletes have accumulated sufficient training experience and achieved high movement reproducibility.

While the primary analysis focused on chronological age categories, additional analyses by maturity group were conducted to confirm the validity of age-based evaluations from a biological maturation perspective. Consequently, consistent patterns were observed in both approaches. Maturity assessment requires anthropometric measurements and calculations, which can be burdensome in applied settings. However, the reliability patterns in simpler age categories, which are comparable to those in maturity groups, strongly support the practical applicability of IMTP measurements in the field.

The limitations of this study include the restriction of participants to young male basketball players and the cross-sectional design, which prevented the direct tracking of individual changes associated with growth. Additionally, the smaller sample sizes in the U12 and U18 categories, combined with observed ICCs slightly below 0.80, resulted in lower statistical power (57.9% and 56.3%, respectively) for between-day reliability. Furthermore, age, biological maturity, strength level, and resistance training experience were strongly interrelated; therefore, the specific independent influences of each factor on reliability could not be isolated.

Conclusion

PF is recommended as the primary metric for monitoring young athletes owing to its high reliability across all age groups. However, given that a learning effect was observed, ensuring sufficient familiarization prior to measurement is crucial for accurately evaluating strength changes resulting from growth and training. In contrast, the RFD should be interpreted with substantial caution, as its high variability makes it unsuitable for individual monitoring, particularly in younger or less-experienced athletes. Its use should be restricted to longer time windows (> 150 ms) and applied with experienced athletes only as supplementary references. Furthermore, adopting a shortened protocol combined with explosive verbal cues and visual feedback should be considered to improve RFD reliability.

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and approved by the University Ethics Committee for Research Involving Human Subjects. No external funding was received for this study. The datasets generated during the current study are not publicly available but are available from the corresponding author upon reasonable request. The authors declare that they have no conflict of interest. All experimental procedures were conducted in compliance with the relevant legal and ethical standards of the country where the study was carried out. The authors declare that no Generative AI or AI-assisted technologies were used in the writing of this manuscript.

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Key points

- Peak force (PF) during the isometric mid-thigh pull (IMTP) demonstrates excellent within-session and between-day reliability across all youth age categories (U12, U15, and U18) and maturity stages.
- Because a learning effect was observed, ensuring sufficient familiarization prior to measurement is crucial for accurately evaluating true strength changes.
- The rate of force development (RFD) exhibits high variability and should be interpreted with caution, as it is generally unsuitable for individual monitoring in younger or less-experienced athletes.
- The practical use of RFD should be restricted to longer time windows (> 150 ms) and applied only as a supplementary reference for experienced athletes.

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Supplementary Table 1. Within-session reliability for PF and All RFD across age categories.

Variable	Day	Mean ± SD	ICC (95% CI)	ICC Interpretation	CV (95% CI)	SEM (95% CI)
PF (All)	1	1722.1 ± 716.1	0.97 (0.96 - 0.98)	Excellent	4.6 (3.8 - 5.3)	17.94 (16.15 - 19.74)
	2	1891.3 ± 706.7	0.98 (0.97 - 0.99)	Excellent	4.3 (3.5 - 5.1)	12.46 (11.21 - 13.70)
	3	1856.9 ± 730.3	0.97 (0.95 - 0.98)	Excellent	4.9 (3.9 - 5.9)	22.97 (20.67 - 25.26)
RFD50 (All)	1	1952.7 ± 2171.9	0.74 (0.63 - 0.82)	Moderate	53.4 (47.5 - 59.3)	562.18 (505.96 - 618.39)
	2	2455.0 ± 2039.2	0.55 (0.39 - 0.68)	Moderate	49.6 (42.3 - 57.0)	921.58 (829.42 - 1013.73)
	3	2714.5 ± 2162.0	0.35 (0.18 - 0.53)	Poor	49.1 (41.8 - 56.4)	1403.20 (1262.88 - 1543.52)
RFD100 (All)	1	2369.4 ± 2199.0	0.82 (0.73 - 0.88)	Good	41.9 (35.6 - 48.2)	399.38 (359.44 - 439.31)
	2	2916.5 ± 2203.3	0.72 (0.60 - 0.81)	Moderate	39.4 (31.9 - 47.0)	617.00 (555.30 - 678.70)
	3	2973.5 ± 1967.1	0.60 (0.45 - 0.73)	Moderate	33.8 (27.7 - 39.9)	788.95 (710.05 - 867.84)
RFD150 (All)	1	2505.6 ± 1964.0	0.82 (0.74 - 0.88)	Good	33.0 (27.9 - 38.1)	346.71 (312.04 - 381.38)
	2	3003.3 ± 1957.6	0.81 (0.72 - 0.88)	Good	29.3 (24.1 - 34.6)	366.03 (329.43 - 402.64)
	3	3110.8 ± 1806.7	0.74 (0.62 - 0.83)	Moderate	25.1 (20.6 - 29.7)	473.96 (426.57 - 521.36)
RFD200 (All)	1	2547.7 ± 1670.5	0.82 (0.73 - 0.88)	Good	26.5 (21.6 - 31.5)	305.44 (274.89 - 335.98)
	2	3130.3 ± 1785.8	0.84 (0.76 - 0.89)	Good	23.4 (18.5 - 28.2)	290.74 (261.66 - 319.81)
	3	3300.9 ± 1683.3	0.84 (0.75 - 0.90)	Good	19.7 (15.7 - 23.7)	275.20 (247.68 - 302.72)
RFD250 (All)	1	2551.8 ± 1441.3	0.85 (0.78 - 0.90)	Good	19.4 (15.3 - 23.4)	218.14 (196.33 - 239.96)
	2	3075.9 ± 1551.8	0.86 (0.78 - 0.91)	Good	17.4 (13.2 - 21.7)	221.53 (199.37 - 243.68)
	3	3131.0 ± 1469.4	0.90 (0.85 - 0.94)	Excellent	14.5 (11.3 - 17.6)	140.38 (126.34 - 154.42)
PF (U12)	1	946.2 ± 176.5	0.96 (0.90 - 0.98)	Excellent	3.5 (2.3 - 4.7)	7.65 (6.88 - 8.41)
	2	1056.0 ± 191.7	0.85 (0.69 - 0.95)	Good	5.4 (2.6 - 8.2)	27.73 (24.96 - 30.51)
	3	994.7 ± 159.4	0.91 (0.79 - 0.97)	Excellent	4.2 (2.7 - 5.8)	14.24 (12.82 - 15.67)
RFD50 (U12)	1	1088.9 ± 673.8	0.41 (0.13 - 0.69)	Poor	45.2 (36.9 - 53.5)	394.38 (354.94 - 433.82)
	2	1381.8 ± 895.1	0.38 (0.06 - 0.70)	Poor	46.3 (30.6 - 62.1)	551.17 (496.05 - 606.29)
	3	1429.3 ± 868.9	0.15 (0.00 - 0.53)	Poor	53.9 (38.9 - 68.9)	730.37 (657.33 - 803.41)
RFD100 (U12)	1	1243.7 ± 731.4	0.59 (0.32 - 0.80)	Moderate	35.4 (25.2 - 45.6)	294.98 (265.48 - 324.48)
	2	1469.3 ± 871.6	0.48 (0.14 - 0.75)	Poor	44.8 (27.8 - 61.8)	450.97 (405.87 - 496.06)
	3	1497.4 ± 695.8	0.25 (0.00 - 0.61)	Poor	36.8 (21.1 - 52.4)	518.31 (466.48 - 570.14)
RFD150 (U12)	1	1364.9 ± 740.5	0.73 (0.51 - 0.88)	Moderate	30.2 (20.9 - 39.5)	196.96 (177.27 - 216.66)
	2	1597.1 ± 821.7	0.53 (0.20 - 0.79)	Moderate	34.5 (22.7 - 46.3)	382.10 (343.89 - 420.31)
	3	1542.3 ± 619.2	0.51 (0.18 - 0.79)	Moderate	23.3 (12.9 - 33.8)	302.10 (271.89 - 332.31)
RFD200 (U12)	1	1372.7 ± 626.3	0.74 (0.51 - 0.88)	Moderate	25.0 (13.6 - 36.3)	164.28 (147.85 - 180.71)
	2	1779.9 ± 732.3	0.52 (0.19 - 0.78)	Moderate	26.4 (14.6 - 38.2)	347.73 (312.96 - 382.50)
	3	1653.7 ± 648.9	0.65 (0.35 - 0.86)	Moderate	23.4 (12.6 - 34.1)	227.80 (205.02 - 250.58)
RFD250 (U12)	1	1298.0 ± 510.4	0.75 (0.53 - 0.88)	Moderate	18.0 (9.3 - 26.8)	128.49 (115.64 - 141.34)
	2	1726.2 ± 544.2	0.55 (0.23 - 0.80)	Moderate	17.7 (7.0 - 28.4)	242.08 (217.88 - 266.29)
	3	1591.7 ± 540.6	0.65 (0.35 - 0.86)	Moderate	20.5 (11.4 - 29.5)	187.04 (168.34 - 205.75)
PF (U15)	1	1788.4 ± 430.6	0.93 (0.87 - 0.96)	Excellent	4.7 (3.5 - 6.0)	29.71 (26.74 - 32.68)
	2	1941.7 ± 504.9	0.98 (0.96 - 0.99)	Excellent	3.4 (2.7 - 4.1)	11.68 (10.51 - 12.85)
	3	1875.5 ± 501.6	0.95 (0.90 - 0.98)	Excellent	5.2 (3.8 - 6.6)	27.25 (24.53 - 29.98)
RFD50 (U15)	1	1624.4 ± 1417.3	0.49 (0.26 - 0.70)	Poor	59.7 (51.1 - 68.3)	718.45 (646.61 - 790.30)
	2	2462.0 ± 1790.3	0.40 (0.15 - 0.63)	Poor	51.7 (41.1 - 62.4)	1069.01 (962.11 - 1175.91)
	3	3107.3 ± 2260.6	0.31 (0.08 - 0.59)	Poor	44.5 (34.5 - 54.4)	1570.90 (1413.81 - 1727.99)
RFD100 (U15)	1	2149.0 ± 1367.9	0.56 (0.34 - 0.74)	Moderate	45.8 (36.8 - 54.7)	594.35 (534.91 - 653.78)
	2	2819.7 ± 1538.8	0.39 (0.16 - 0.63)	Poor	40.1 (28.3 - 52.0)	943.57 (849.22 - 1037.93)
	3	3060.5 ± 1732.7	0.54 (0.31 - 0.76)	Moderate	31.4 (22.4 - 40.5)	797.54 (717.79 - 877.30)
RFD150 (U15)	1	2229.8 ± 1067.5	0.47 (0.23 - 0.68)	Poor	34.8 (26.8 - 42.8)	567.33 (510.60 - 624.07)
	2	2869.6 ± 1435.8	0.60 (0.39 - 0.78)	Moderate	29.3 (21.6 - 37.1)	567.13 (510.41 - 623.84)
	3	3117.1 ± 1486.4	0.58 (0.34 - 0.77)	Moderate	26.0 (18.7 - 33.3)	621.81 (559.63 - 683.99)
RFD200 (U15)	1	2322.8 ± 1003.4	0.52 (0.29 - 0.72)	Moderate	28.1 (21.0 - 35.1)	480.28 (432.25 - 528.30)
	2	2975.1 ± 1432.9	0.72 (0.54 - 0.85)	Moderate	23.8 (16.9 - 30.7)	393.86 (354.48 - 433.25)
	3	3358.3 ± 1282.2	0.70 (0.50 - 0.85)	Moderate	18.3 (12.5 - 24.1)	376.70 (339.03 - 414.37)
RFD250 (U15)	1	2491.3 ± 931.3	0.60 (0.39 - 0.77)	Moderate	20.6 (14.6 - 26.6)	368.73 (331.85 - 405.60)
	2	2954.5 ± 1129.4	0.69 (0.50 - 0.83)	Moderate	18.6 (12.5 - 24.6)	345.41 (310.87 - 379.95)
	3	3186.7 ± 1081.9	0.84 (0.70 - 0.92)	Good	11.9 (7.9 - 15.8)	175.49 (157.94 - 193.04)
PF (U18)	1	2591.7 ± 472.1	0.87 (0.73 - 0.95)	Good	5.6 (3.8 - 7.4)	59.23 (53.31 - 65.15)
	2	2632.8 ± 403.3	0.89 (0.75 - 0.96)	Good	5.0 (4.0 - 6.0)	44.26 (39.83 - 48.69)
	3	2626.8 ± 427.3	0.80 (0.59 - 0.92)	Good	5.2 (2.5 - 7.9)	83.31 (74.97 - 91.64)
RFD50 (U18)	1	3696.3 ± 3381.2	0.75 (0.50 - 0.90)	Moderate	51.7 (35.2 - 68.1)	846.19 (761.57 - 930.81)
	2	3515.4 ± 2679.1	0.54 (0.22 - 0.79)	Moderate	49.0 (32.2 - 65.8)	1209.39 (1088.45 - 1330.33)
	3	3262.5 ± 2381.9	0.22 (0.00 - 0.58)	Poor	52.2 (34.5 - 70.0)	1846.93 (1662.24 - 2031.62)
RFD100 (U18)	1	4241.5 ± 3325.6	0.83 (0.64 - 0.93)	Good	42.8 (25.2 - 60.4)	563.41 (507.07 - 619.76)
	2	4543.5 ± 2996.8	0.76 (0.51 - 0.90)	Good	32.7 (19.6 - 45.9)	721.65 (649.48 - 793.81)
	3	4201.3 ± 2237.2	0.40 (0.07 - 0.71)	Poor	34.9 (23.8 - 46.0)	1320.44 (1188.40 - 1452.49)
RFD150 (U18)	1	4504.2 ± 2769.5	0.80 (0.58 - 0.92)	Good	33.0 (21.1 - 44.9)	550.99 (495.89 - 606.09)
	2	4657.6 ± 2374.6	0.83 (0.63 - 0.93)	Good	24.2 (14.0 - 34.3)	400.03 (360.02 - 440.03)
	3	4557.0 ± 1833.2	0.58 (0.26 - 0.81)	Moderate	25.3 (17.0 - 33.7)	754.34 (678.90 - 829.77)
RFD200 (U18)	1	4492.1 ± 1927.6	0.70 (0.42 - 0.87)	Moderate	25.6 (15.9 - 35.3)	570.14 (513.13 - 627.16)
	2	4769.0 ± 1861.6	0.79 (0.56 - 0.92)	Good	19.6 (10.0 - 29.1)	382.08 (343.87 - 420.29)
	3	4736.1 ± 1576.1	0.70 (0.42 - 0.87)	Moderate	18.6 (11.8 - 25.3)	464.95 (418.45 - 511.44)
RFD250 (U18)	1	4280.6 ± 1322.5	0.66 (0.37 - 0.86)	Moderate	18.8 (10.5 - 27.0)	441.83 (397.65 - 486.01)
	2	4651.2 ± 1525.7	0.80 (0.58 - 0.92)	Good	15.1 (7.1 - 23.1)	310.25 (279.22 - 341.27)
	3	4468.7 ± 1241.8	0.78 (0.54 - 0.91)	Good	13.2 (8.2 - 18.1)	269.80 (242.82 - 296.78)

Supplementary Table 2. Within-session reliability for PF and All RFD across maturity groups.

Variable	Day	Mean ± SD	ICC (95% CI)	ICC Interpretation	CV (%) (95% CI)	SEM (95% CI)
PF (All)	1	1722.1 ± 716.1	0.97 (0.96 - 0.98)	Excellent	4.6 (3.8 - 5.3)	17.94 (16.15 - 19.74)
	2	1891.3 ± 706.7	0.98 (0.97 - 0.99)	Excellent	4.3 (3.5 - 5.1)	12.46 (11.21 - 13.70)
	3	1856.9 ± 730.3	0.97 (0.95 - 0.98)	Excellent	4.9 (3.9 - 5.9)	22.97 (20.67 - 25.26)
RFD50 (All)	1	1952.7 ± 2171.9	0.74 (0.63 - 0.82)	Moderate	53.4 (47.5 - 59.3)	562.18 (505.96 - 618.39)
	2	2455.0 ± 2039.2	0.55 (0.39 - 0.68)	Moderate	49.6 (42.3 - 57.0)	921.58 (829.42 - 1013.73)
	3	2714.5 ± 2162.0	0.35 (0.18 - 0.53)	Poor	49.1 (41.8 - 56.4)	1403.20 (1262.88 - 1543.52)
RFD100 (All)	1	2369.4 ± 2199.0	0.82 (0.73 - 0.88)	Good	41.9 (35.6 - 48.2)	399.38 (359.44 - 439.31)
	2	2916.5 ± 2203.3	0.72 (0.60 - 0.81)	Moderate	39.4 (31.9 - 47.0)	617.00 (555.30 - 678.70)
	3	2973.5 ± 1967.1	0.60 (0.45 - 0.73)	Moderate	33.8 (27.7 - 39.9)	788.95 (710.05 - 867.84)
RFD150 (All)	1	2505.6 ± 1964.0	0.82 (0.74 - 0.88)	Good	33.0 (27.9 - 38.1)	346.71 (312.04 - 381.38)
	2	3003.3 ± 1957.6	0.81 (0.72 - 0.88)	Good	29.3 (24.1 - 34.6)	366.03 (329.43 - 402.64)
	3	3110.8 ± 1806.7	0.74 (0.62 - 0.83)	Moderate	25.1 (20.6 - 29.7)	473.96 (426.57 - 521.36)
RFD200 (All)	1	2547.7 ± 1670.5	0.82 (0.73 - 0.88)	Good	26.5 (21.6 - 31.5)	305.44 (274.89 - 335.98)
	2	3130.3 ± 1785.8	0.84 (0.76 - 0.89)	Good	23.4 (18.5 - 28.2)	290.74 (261.66 - 319.81)
	3	3300.9 ± 1683.3	0.84 (0.75 - 0.90)	Good	19.7 (15.7 - 23.7)	275.20 (247.68 - 302.72)
RFD250 (All)	1	2551.8 ± 1441.3	0.85 (0.78 - 0.90)	Good	19.4 (15.3 - 23.4)	218.14 (196.33 - 239.96)
	2	3075.9 ± 1551.8	0.86 (0.78 - 0.91)	Good	17.4 (13.2 - 21.7)	221.53 (199.37 - 243.68)
	3	3131.0 ± 1469.4	0.90 (0.85 - 0.94)	Excellent	14.5 (11.3 - 17.6)	140.38 (126.34 - 154.42)
PF (Pre)	1	978.4 ± 200.4	0.96 (0.92 - 0.98)	Excellent	3.5 (2.3 - 4.6)	6.98 (6.28 - 7.67)
	2	1101.9 ± 231.0	0.90 (0.80 - 0.96)	Excellent	5.1 (2.7 - 7.6)	22.22 (19.99 - 24.44)
	3	1038.0 ± 198.0	0.93 (0.83 - 0.97)	Excellent	4.3 (2.8 - 5.8)	14.56 (13.10 - 16.01)
RFD50 (Pre)	1	1024.9 ± 662.5	0.30 (0.04 - 0.59)	Poor	49.0 (40.7 - 57.4)	464.75 (418.27 - 511.22)
	2	1410.3 ± 1239.6	0.17 (0.00 - 0.51)	Poor	54.0 (38.9 - 69.2)	1015.08 (913.57 - 1116.58)
	3	1514.5 ± 956.1	0.18 (0.00 - 0.54)	Poor	55.6 (43.3 - 67.9)	791.76 (712.58 - 870.93)
RFD100 (Pre)	1	1241.2 ± 768.2	0.55 (0.29 - 0.77)	Moderate	37.4 (27.9 - 46.8)	348.18 (313.37 - 383.00)
	2	1515.8 ± 1030.9	0.31 (0.02 - 0.63)	Poor	51.9 (36.5 - 67.4)	707.16 (636.44 - 777.87)
	3	1560.0 ± 762.9	0.18 (0.00 - 0.54)	Poor	39.6 (26.1 - 53.1)	623.72 (561.34 - 686.09)
RFD150 (Pre)	1	1355.4 ± 735.3	0.69 (0.49 - 0.86)	Moderate	30.8 (22.2 - 39.4)	224.37 (201.94 - 246.81)
	2	1545.1 ± 812.8	0.35 (0.04 - 0.65)	Poor	40.2 (28.6 - 51.7)	522.51 (470.26 - 574.77)
	3	1590.9 ± 658.7	0.39 (0.08 - 0.70)	Poor	25.9 (14.1 - 37.8)	396.67 (357.00 - 436.34)
RFD200 (Pre)	1	1374.6 ± 606.5	0.67 (0.44 - 0.84)	Moderate	25.3 (14.8 - 35.8)	197.44 (177.70 - 217.18)
	2	1662.1 ± 691.6	0.37 (0.06 - 0.66)	Poor	30.5 (19.6 - 41.3)	431.45 (388.31 - 474.60)
	3	1656.9 ± 614.6	0.52 (0.21 - 0.77)	Moderate	25.0 (14.5 - 35.6)	295.71 (266.14 - 325.29)
RFD250 (Pre)	1	1352.3 ± 535.9	0.72 (0.52 - 0.87)	Moderate	18.5 (10.4 - 26.6)	146.61 (131.95 - 161.27)
	2	1682.1 ± 549.9	0.45 (0.13 - 0.72)	Poor	20.6 (10.8 - 30.4)	301.29 (271.16 - 331.41)
	3	1602.8 ± 510.0	0.61 (0.34 - 0.84)	Moderate	20.0 (11.5 - 28.6)	197.80 (178.02 - 217.58)
PF (Circa)	1	1775.8 ± 404.7	0.91 (0.84 - 0.96)	Excellent	4.9 (3.4 - 6.4)	34.50 (31.05 - 37.95)
	2	1911.9 ± 481.2	0.97 (0.95 - 0.99)	Excellent	3.6 (2.8 - 4.4)	13.68 (12.31 - 15.05)
	3	1861.3 ± 462.3	0.93 (0.86 - 0.97)	Excellent	5.7 (4.2 - 7.1)	33.97 (30.57 - 37.37)
RFD50 (Circa)	1	1580.4 ± 1186.6	0.39 (0.12 - 0.64)	Poor	57.8 (47.4 - 68.2)	717.67 (645.90 - 789.43)
	2	2523.5 ± 1630.5	0.35 (0.09 - 0.62)	Poor	51.1 (40.0 - 62.2)	1046.74 (942.07 - 1151.41)
	3	3233.7 ± 2380.5	0.33 (0.07 - 0.63)	Poor	41.2 (29.6 - 52.8)	1604.94 (1444.45 - 1765.43)
RFD100 (Circa)	1	2085.5 ± 1268.0	0.49 (0.23 - 0.71)	Poor	46.4 (36.2 - 56.6)	646.01 (581.41 - 710.61)
	2	2897.8 ± 1449.0	0.32 (0.06 - 0.60)	Poor	36.2 (23.1 - 49.4)	979.34 (881.41 - 1077.28)
	3	3157.6 ± 1765.1	0.60 (0.35 - 0.80)	Moderate	28.3 (18.6 - 38.0)	707.97 (637.17 - 778.76)
RFD150 (Circa)	1	2208.4 ± 965.7	0.30 (0.05 - 0.58)	Poor	35.8 (26.5 - 45.0)	673.91 (606.52 - 741.30)
	2	2969.3 ± 1264.8	0.57 (0.32 - 0.77)	Moderate	23.7 (16.8 - 30.5)	536.99 (483.29 - 590.69)
	3	3193.7 ± 1508.1	0.61 (0.35 - 0.81)	Moderate	24.3 (18.0 - 30.6)	583.52 (525.17 - 641.87)
RFD200 (Circa)	1	2280.4 ± 906.6	0.37 (0.12 - 0.64)	Poor	28.8 (20.7 - 37.0)	567.77 (510.99 - 624.55)
	2	3121.3 ± 1256.6	0.74 (0.54 - 0.87)	Moderate	18.6 (11.7 - 25.4)	325.83 (293.25 - 358.41)
	3	3401.8 ± 1191.1	0.71 (0.49 - 0.86)	Moderate	16.1 (11.1 - 21.2)	343.55 (309.19 - 377.90)
RFD250 (Circa)	1	2416.5 ± 874.4	0.53 (0.29 - 0.75)	Moderate	21.0 (14.2 - 27.7)	406.45 (365.81 - 447.10)
	2	3010.1 ± 979.3	0.64 (0.41 - 0.82)	Moderate	15.4 (8.6 - 22.3)	346.62 (311.96 - 381.28)
	3	3178.6 ± 915.2	0.83 (0.66 - 0.92)	Good	10.8 (7.2 - 14.3)	155.81 (140.23 - 171.39)
PF (Post)	1	2527.3 ± 464.6	0.88 (0.76 - 0.95)	Good	5.4 (3.9 - 6.9)	53.98 (48.58 - 59.38)
	2	2608.7 ± 383.5	0.90 (0.78 - 0.96)	Good	4.5 (3.4 - 5.5)	39.37 (35.43 - 43.30)
	3	2619.3 ± 404.7	0.81 (0.62 - 0.92)	Good	4.7 (2.2 - 7.1)	77.32 (69.58 - 85.05)
RFD50 (Post)	1	3525.9 ± 3242.7	0.73 (0.49 - 0.88)	Moderate	52.8 (39.0 - 66.5)	862.13 (775.92 - 948.35)
	2	3353.8 ± 2602.3	0.60 (0.31 - 0.80)	Moderate	43.7 (28.8 - 58.7)	1038.62 (934.76 - 1142.49)
	3	3222.9 ± 2289.4	0.19 (0.00 - 0.53)	Poor	52.3 (36.7 - 68.0)	1847.01 (1662.31 - 2031.71)
RFD100 (Post)	1	4064.0 ± 3110.0	0.82 (0.65 - 0.92)	Good	41.3 (26.1 - 56.5)	541.80 (487.62 - 595.98)
	2	4257.8 ± 2882.6	0.77 (0.56 - 0.90)	Good	31.6 (20.5 - 42.8)	655.84 (590.25 - 721.42)
	3	4079.9 ± 2192.2	0.38 (0.08 - 0.68)	Poor	34.8 (24.3 - 45.4)	1339.11 (1205.20 - 1473.02)
RFD150 (Post)	1	4243.5 ± 2634.9	0.81 (0.62 - 0.92)	Good	32.0 (21.7 - 42.3)	505.12 (454.61 - 555.64)
	2	4417.6 ± 2377.5	0.81 (0.62 - 0.92)	Good	26.2 (17.1 - 35.3)	441.45 (397.31 - 485.60)
	3	4437.4 ± 1793.5	0.56 (0.26 - 0.79)	Moderate	25.3 (17.6 - 33.1)	780.00 (702.00 - 858.00)
RFD200 (Post)	1	4273.7 ± 1880.4	0.72 (0.49 - 0.87)	Moderate	25.0 (16.8 - 33.2)	515.14 (463.63 - 566.65)
	2	4523.2 ± 1952.6	0.77 (0.55 - 0.89)	Good	22.6 (13.9 - 31.3)	446.94 (402.25 - 491.64)
	3	4722.2 ± 1508.5	0.65 (0.37 - 0.84)	Moderate	18.9 (12.7 - 25.2)	528.57 (475.71 - 581.42)
RFD250 (Post)	1	4138.2 ± 1289.1	0.67 (0.41 - 0.85)	Moderate	18.4 (11.0 - 25.8)	420.60 (378.54 - 462.66)
	2	4469.0 ± 1558.9	0.78 (0.58 - 0.90)	Good	17.0 (10.1 - 23.8)	334.61 (301.15 - 368.07)
	3	4507.1 ± 1196.0	0.73 (0.49 - 0.88)	Moderate	13.6 (9.0 - 18.2)	320.61 (288.55 - 352.67)