International Journal of Strength and Conditioning

A Preliminary Investigation of the Relationship of Three Key Bar Positions on Weightlifting Performance

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ABSTRACT

Background: There are three fundamental bar positions in weightlifting: 1) Set-up (S), 2) Knee (K), and 3) Power Position (P). Currently, P is the primary position tested in continual monitoring. However, recommendations suggest assessing multiple positions. Purpose: To assess relationships between the three bar positions in an isometric pull with meet performance in regional to international level weightlifters. Methods: Data from twelve collegiate weightlifters (male: n = 6, age = 21.0 + 2.0; female: n = 6, age =19.7 + 1.1) weightlifters were analyzed. Pulls were performed from top-down (P → K → S). Absolute isometric peak force (IPF), allometrically scaled IPF (IPFa), and rate of force development from 0-250ms (RFD250) were derived from force-time curve analysis. Separate 2×3 linear mixed-effects models examined sex and position effects (α=0.05). Relationships between force characteristics at each position and weightlifting performance were assessed using Pearson's r. Results: Males produced greater IPF, IPFa, and RFD250 values compared to females at all positions ($p \leq 0.05$). IPF, IPFa, and RFD250 were greater at P than S and K ($p \leq 0.05$). RFD250 at K was greater than S ($p \leq 0.05$). Correlations with performance were moderate to strong for IPF, IPFa, and RFD250; correlations were generally weaker for females. Correlations for IPF were stronger at S than P. RFD250 correlations were generally stronger at P. Conclusion: Metrics from S and P correlate better with performance than K, with IPF and IPFa favoring S while RFD250 favors P, suggesting both may be useful as a continually monitoring performance in collegiate weightlifters.

Keywords: strength, technique, rate of force development

INTRODUCTION

In weightlifting, the pull phases of the snatch and clean are responsible for producing the net force impulse imparted to the barbell beginning at lift-off. The pull depends in large part upon the maximum strength and related characteristics (impulse, rate of force development, etc.) of the leg and hip extensors [1, 2, 3]. Although the pull is a continuous movement, there are three subphases: 1) *1st pull* (floor to the knee, just above the patella); 2) *Transition* (knee to the power position), in which the knees are re-bent and the hips extended and which the bar contacts the mid – upper thigh; and 3) *2nd pull* which ends in a "triple extension" with extension at the ankle , knee and hip and the shoulders are shrugged [2, 4, 5]. Proper positioning and force application at the start of each of these subphases is a key component determining successful attempts. Thus, monitoring strength changes and performance in weightlifters becomes important for continual training progress [3]. The isometric pull from the thigh (ITP) is a monitoring tool that can be used to measure force-time characteristics of weightlifters such as absolute isometric peak force

(IPF) and rate of force development (RFD). This position is used due to the greatest vertical ground reaction force and RFD occurring during this phase [6], and it corresponds with the peak of the strength curve [1, 3]. Additionally, evidence presents strong correlations between ITP derived variables (IPF, RFD) and weightlifting performance [1, 3, 8, 9]. Thus, information gathered from the ITP could be useful in identifying weightlifting potential [3].

The ITP protocol is, currently, the primary test used in continual monitoring of weightlifters' force-time characteristics [3, 9, 8, 10]. However, the force-time characteristics assessed by the ITP describe the last phase of the pull and could potentially miss specific deficits during the other two subphases of the pull that could be useful in guiding training. Recommendations from Stone et al. [3] state that isometric pulling assessment should be performed at multiple positions to determine the relationships between all the key positions and weightlifting performance. Recently, an isometric pull from the set position, representing the initiation of the pull from the floor, was demonstrated to have somewhat stronger correlations with performance in advanced weightlifters, suggesting that this type of isometric strength monitoring tool may also be used to measure force-time characteristics in weightlifters [8, 9, 10]. Despite the need for more research on this topic, only a few investigations exist that compare isometric pulling force-time metrics from different bar positions to weightlifting performance.
As of this writing, only one investigation has examined the relationship between knee position and weightlifting performance [10]. Additionally, only two studies have included rate of force development (RFD) in assessments [8, 10], and two have been investigations that included allometric scaling to partially account for differences in body mass [8,9], using the set and mid-thigh pull (P) positions. Assessments that incorporate multiple positions, RFD, and allometric scaling could, therefore, provide additional insight into the influence of these isometric metrics on weightlifting performance. Accordingly, the purpose of this investigation was to examine the relationships between isometric peak force (IPF), allometrically scaled IPF (IPFa), and rate of force development from 0–250 ms (RFD250), measured at three fundamental positions (set, knee, and thigh), and weightlifting performance in competitive weightlifters.

METHODS

Experimental Design

This study was an examination of the relationship between the three key positions with weightlifting competition performance in the snatch, clean & jerk, and total. Data were collected as part of a continual monitoring program for a collegiate weightlifting team and stored in a repository for retrospective analysis. All participants signed an informed consent form stating that the monitoring data collected for them could be used for analysis in research investigations. The form was approved by the East Tennessee State University IRB (# 06238sw-ETSU). Maximum effort isometric clean-grip pulls from three different positions were performed: 1) the set-up (start), 2) at the knee and in the 3) power position (thigh).

Subjects

Twelve weightlifters (males: n = 6, body mass = 85.9±17.2 kg, height = 174.7±7.3 cm, age = 21.0+ 2.0 yrs; females: n = 6, body mass = 61.7±5.8 kg, height = 157.4±5.0 cm, age = 19.7+1.1yrs) volunteered to participate in this study. The mean weightlifting experience of each athlete based on the time from their first competition to the day of testing was ~3.0±1.9 yrs. The sample consisted of national to international level athletes. Competition results were collected from a local meet. All isometric force-time data were collected two days following their participation at a local meet on September 30th, 2023.

Competition Results

Competition results used in analysis consisted of snatch, clean and jerk, and the total. Sinclair Coefficients were used to derive Sinclair totals for each weightlifter and used in the analysis. The Sinclair formula partially obviates body mass differences using a polynomial regression [11].

Isometric Testing

All athletes were familiar with basic testing procedures as this was part of their ongoing athlete monitoring process. Subjects completed a standard warm-up of 30 jumping jacks, 1x5 20kg clean pulls, and 3x5 weighted clean pulls (females = 40kg, males = 60kg) from the thigh position [1, 3, 8]. Additionally, participants were given two isometric warm-up pulls at 50% and 75% of perceived

Figure 1. Side (top) and front (bottom) views of the bar position at set-up (a), knee (b), and power (c) positions.

maximum effort for each position. Isometric pulls were performed in a custom-made power rack using dual force plates (Rice Lakes, Kingsport, Tn) with a sampling rate of 1000hz. For all maximum effort pulls, subjects received substantial encouragement by the investigators to ensure a maximal effort. Before each pull, subjects were instructed to "pull as fast and hard as possible" to maximize rate of force development and peak force [1]. Two maximum effort trials were average for the isometric tests [8]. However, if errors in pulling were observed (countermovement or a substantial change in body position) or if a ≥250N difference in peak force were measured, maximum effort attempts were repeated [1].

Three different clean-grip pulling positions were tested: set (S), knee (K) and power position (P). All positions represented the initiation of each subphase with S as the initiation of the first pull, K as the beginning of the transition (the mechanically weak point after which the bar typically decelerates), and P as the start of the second pull. For S, the isometric bar was placed the same distance (21 cm) from the floor as occurs with standard 10 kg plates (Figure 1a). For K, the bar was placed just anterior (≈1-2cm) to the center of the patella (Figure 1b). For P, the bar was placed touching the thigh with an internal knee angle of approximately 125-1450 and a hip angle of approximately 140- 1500 (Figure 1c) [3, 12]. IPF and RFD250 were derived from isometric force-time curve analysis (LabView, version 7.1, National Instruments). IPFa was calculated post data collection. Reliability in our laboratory for IPF has been consistently excellent: ICC = 0.95 or better with a CV of 1.9 – 3.4% [1, 3]. Reliability for RFD bands (i.e., 0-250ms) in our laboratory and others [6] has also been good to excellent [1, 3].

Statistical analysis

An a priori power analysis was performed in G*power with the following criteria: effect size f=0.25, α=0.05, Power=0.80, and Correlation=0.80. These criteria indicated that an n=12 was needed for this investigation. Separate 2 × 3 linear mixed-effects models (LMM) were fit for each force–time metric to examine the effects of sex and position while considering the random effects of

Table 1. Descriptive data and Hedge's g effect of sex from the isometric pulls and weightlifting meet.

Variable	All (n = 12)	F (n = 6)	M (n = 6)	Hedge's g ES	ES 95% CI
IPF-S	2015 ± 579	1524 ± 132	2506 ± 414	3.17	1.68-4.64
IPF-K	2242 ± 647	1681 ± 131	2804 ± 435	2.28	1.13-3.4
IPF-P	4464* ± 1467	3311* ± 353	5616* ± 1234	3.49	1.87-5.08
IPFa-S	111 ± 17	96 ± 6	124 ± 12	1.74	0.782-2.67
IPFa-K	124 ± 20	106 ± 7	139 ± 13	1.73	0.775-2.66
IPFa-P	245* ± 49	210* ± 24	275* ± 44	0.909	0.199-1.59
RFD250-S	2488 ± 1358	1637 ± 894	3340 ± 1199	0.72	0.055-1.36
RFD250-K	2849 ± 1347	1756 ± 748	3940 ± 827	1.01	0.274-1.71
RFD250-P	7656* ± 4056	4996* ± 1296	10317* ± 4132	0.702	0.041-1.34
Total	202.4 ± 66.8	154.1 ± 9.5	248 ± 44.8	2.89	0.810-4.98
Totala	11.4 ± 1.9	10.2 ± 1.5	12.4 ± 1.6	3.31	1.12-5.51
Sinclair	259.3 ± 58.2	205.7 ± 10.6	305.3 ± 40.2	4.43	1.92-6.94

*Means ± standard deviations; * significant difference from set-up and knee ($p < 0.05$); Hedge's g effect of sex small: 0.20, moderate: 0.50, large: 0.80; IPF: isometric peak force; IPFa: allometrically-scaled isometric peak force; RFD250: rate of force development 0-250ms; Totala: allometrically-scaled total; S: set-up position; K: knee position; P: power position*

individual differences. The alpha value was set at 0.05. Model assumptions were evaluated using graphical and diagnostic procedures. Residual normality was assessed using Q–Q plots of Pearson residuals. Homogeneity of variance was evaluated via residual–fitted value plots. Autocorrelation of residuals was examined using autocorrelation function plots of normalized residuals. Post hoc analysis was performed with a Scheffe adjustment. Independent t-tests were used to analyze sex differences in competition results (Total, Totala, Sinclair). Due to the relatively small sample size, an effect size (ES) was provided using Hedge's g [13]. Effect sizes were interpreted using the following criteria [14]: 0-0.2 trivial, 0.2-0.6 small, 0.6-1.2 moderate, 1.2-2.0 large, 2.0-4.0 very large, and >4.0 perfect. Pearson's r with 95% confidence intervals were calculated to illustrate relationships between isometric pulling parameters and weightlifting performance. Pearson's r values were averaged over weightlifting performance outcomes and presented in a spider plot to visually represent the most consistently strong relationships across performance. Statistical analysis was performed using R (version 4.4.0, R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Descriptive statistics (recorded as Mean ± SD) of isometric pull parameters and weightlifting performance results can be seen in Table 1. Hedge's g effect size of sex with 95% confidence intervals were recorded in Table 1 as well. Correlations between isometric pull measurements at different positions and weightlifting performance were recorded for the whole group (Table 2), females only (Table 3), and males only (Table 4). Correlations of IPF vs IPFa and IPF vs RFD250 at the same bar position are presented in Table 5.

IPF

IPF was statistically greater at P compared to the other two positions ($p < 0.05$). No differences were noted between K and S (Table 1). There was a very large main effect of sex at all three positions (ES: P = 3.49, K = 2.28, S = 3.17), with males producing substantially more absolute force than females.

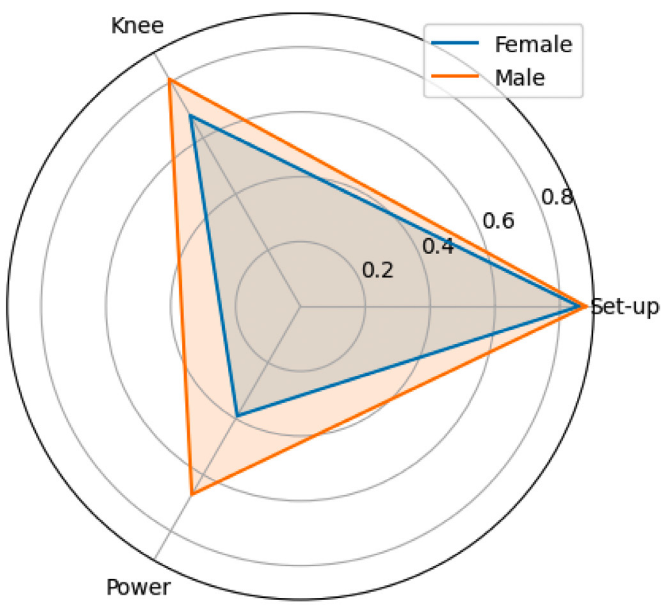

Figure 2. Average Pearson's r of IPF vs weightlifting performance outcomes differentiated by sex.

Table 2. Whole group correlation coefficients with 95% confidence intervals.

Weightlifting Performance	Isopull Parameter	Power		Knee		Set-Up	
		Pearson's r	95% CI	Pearson's r	95% CI	Pearson's r	95% CI
Snatch	IPF	0.89	0.64 - 0.97	0.94	0.81 - 0.98	0.96	0.85 - 0.99
	RFD250	0.92	0.73 - 0.98	0.86	0.56 - 0.96	0.72	0.24 - 0.91
	IPFa	0.72	0.24 - 0.91	0.80	0.41 - 0.94	0.83	0.49 - 0.95
Clean & Jerk	IPF	0.87	0.58 - 0.96	0.94	0.79 - 0.98	0.96	0.87 - 0.99
	RFD250	0.90	0.67 - 0.97	0.81	0.45 - 0.95	0.71	0.22 - 0.91
	IPFa	0.72	0.26 - 0.92	0.83	0.49 - 0.95	0.89	0.65 - 0.97
Total	IPF	0.88	0.62 - 0.97	0.94	0.81 - 0.98	0.97	0.88 - 0.99
	RFD250	0.91	0.71 - 0.98	0.84	0.51 - 0.95	0.71	0.24 - 0.91
	IPFa	0.72	0.26 - 0.92	0.82	0.47 - 0.95	0.87	0.58 - 0.96
Totala	IPF	0.74	0.29 - 0.92	0.84	0.53 - 0.96	0.87	0.6 - 0.96
	RFD250	0.77	0.34 - 0.93	0.71	0.23 - 0.91	0.69	0.18 - 0.9
	IPFa	0.67	0.16 - 0.9	0.83	0.49 - 0.95	0.90	0.67 - 0.97
Sinclair Total	IPF	0.81	0.45 - 0.95	0.90	0.67 - 0.97	0.92	0.73 - 0.98
	RFD250	0.81	0.45 - 0.95	0.78	0.38 - 0.94	0.71	0.23 - 0.91
	IPFa	0.73	0.27 - 0.92	0.87	0.59 - 0.96	0.92	0.74 - 0.98

IPF: isometric peak force; IPFa: allometrically-scaled isometric peak force; RFD250: rate of force development 0-250ms; Totala: allometrically-scaled total

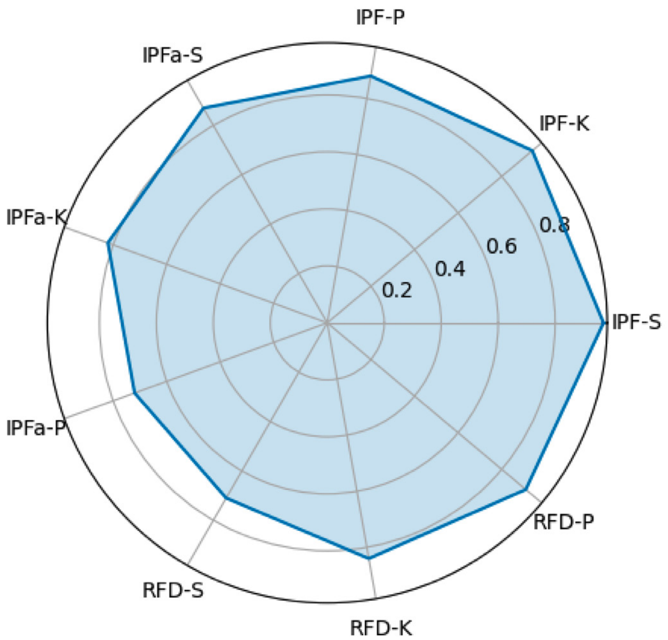

Figure 3. Average Pearson's r of position-specific force metrics vs weightlifting performance outcomes. IPF: isometric peak force; IPFa: allometrically-scaled isometric peak force; RFD250: rate of force development 0-250ms; S: set-up position; K: knee position; P: power position.

When examining the whole group correlations, moderate to strong correlations were noted for IPF at the three positions with weightlifting performance (Figure 3). Slightly stronger correlations were noted for S compared to P (0.87-0.96 vs 0.74-0.89 respectively). This was also noted when separating females (Table 3) and males (Table 4). Correlations appear to be somewhat stronger in males compared to females at all three positions (Figure 2).

IPFa

Similarly, IPFa was statistically larger at P compared to the other two positions ($p < 0.05$), and no statistically significant differences were noted between K and S (Table 1, Figure 3). Sex had a large to very large effect on IPFa results (ES: P = 0.909, K = 1.73, S = 1.74), with males having higher values than females in all three positions (Table 1). Trivial to weak correlations were noted between IPFa and weightlifting performance in males (-0.06-0.26) and females (0.02-0.29) at P (Figure 2). Weak correlations were noted at K in males (0.16-0.27) and trivial to moderate in females (0.03-0.49). Moderate correlations between IPFa and weightlifting performance were observed at S in males (0.40-0.58) and moderate to strong correlations in females (0.44-0.74). Slightly stronger correlations between IPF and IPFa were noted at P compared to S and K in males and females (Table 5).

RFD250

RFD250 was statistically higher at P compared to the other two positions ($p < 0.05$), with no differences noted between K and S (Table 1). The effect of sex on RFD250 was large at K (ES: 1.01), but moderate at S and P (ES: 0.72 and 0.702 respectively). Inverse to IPF and IPFa, RFD250 correlations with weightlifting performance parameters appear to be stronger at P compared to S in whole group (0.77-0.92 vs 0.69-0.72), males (0.43-0.83 vs 0.47-0.55),

Table 3. Female lifters correlation coefficients with 95% confidence intervals.

Weightlifting Performance	Isopull Parameter	Power		Knee		Set-Up	
		Pearson's r	95% CI	Pearson's r	95% CI	Pearson's r	95% CI
Snatch	IPF	0.53	-0.5 - 0.94	0.48	-0.54 - 0.93	0.70	-0.27 - 0.96
	RFD250	0.37	-0.63 - 0.91	0.46	-0.56 - 0.93	0.74	-0.17 - 0.97
	IPFa	0.25	-0.7 - 0.88	0.03	-0.8 - 0.82	0.44	-0.58 - 0.92
Clean & Jerk	IPF	0.25	-0.71 - 0.88	0.66	-0.32 - 0.96	0.79	-0.05 - 0.98
	RFD250	0.73	-0.2 - 0.97	0.14	-0.76 - 0.85	0.12	-0.76 - 0.85
	IPFa	0.02	-0.8 - 0.82	0.42	-0.59 - 0.92	0.74	-0.18 - 0.97
Total	IPF	0.39	-0.62 - 0.91	0.68	-0.3 - 0.96	0.86	0.16 - 0.98
	RFD250	0.69	-0.28 - 0.96	0.28	-0.69 - 0.89	0.38	-0.62 - 0.91
	IPFa	0.12	-0.77 - 0.85	0.33	-0.66 - 0.9	0.72	-0.22 - 0.97
Totala	IPF	0.11	-0.77 - 0.85	0.05	-0.79 - 0.83	0.17	-0.74 - 0.86
	RFD250	0.84	0.07 - 0.98	-0.22	-0.88 - 0.72	0.08	-0.78 - 0.84
	IPFa	0.29	-0.68 - 0.89	0.44	-0.58 - 0.92	0.63	-0.36 - 0.95
Sinclair Total	IPF	0.04	-0.8 - 0.82	0.16	-0.75 - 0.86	0.27	-0.69 - 0.89
	RFD250	0.83	0.05 - 0.98	-0.07	-0.84 - 0.78	0.16	-0.75 - 0.86
	IPFa	0.18	-0.74 - 0.87	0.49	-0.53 - 0.93	0.68	-0.29 - 0.96

IPF: isometric peak force; IPFa: allometrically-scaled isometric peak force; RFD250: rate of force development 0-250ms; Totala: allometrically-scaled total

Table 4. Male lifters correlation coefficients with 95% confidence intervals.

Weightlifting Performance	Isopull Parameter	Power		Knee		Set-Up	
		Pearson's r	95% CI	Pearson's r	95% CI	Pearson's r	95% CI
Snatch	IPF	0.69	-0.27 - 0.96	0.84	0.08 - 0.98	0.88	0.24 - 0.99
	RFD250	0.89	0.3 - 0.99	0.71	-0.24 - 0.97	0.47	-0.55 - 0.93
	IPFa	0.25	-0.7 - 0.88	0.27	-0.7 - 0.89	0.40	-0.61 - 0.92
Clean & Jerk	IPF	0.64	-0.36 - 0.96	0.77	-0.11 - 0.97	0.87	0.22 - 0.99
	RFD250	0.83	0.07 - 0.98	0.54	-0.49 - 0.94	0.52	-0.5 - 0.94
	IPFa	0.26	-0.7 - 0.88	0.27	-0.69 - 0.89	0.55	-0.47 - 0.94
Total	IPF	0.67	-0.31 - 0.96	0.81	-0.01 - 0.98	0.88	0.26 - 0.99
	RFD250	0.87	0.19 - 0.99	0.62	-0.38 - 0.95	0.50	-0.52 - 0.93
	IPFa	0.26	-0.7 - 0.88	0.27	-0.69 - 0.89	0.48	-0.54 - 0.93
Totala	IPF	0.20	-0.73 - 0.87	0.40	-0.61 - 0.91	0.56	-0.47 - 0.94
	RFD250	0.43	-0.58 - 0.92	0.09	-0.78 - 0.84	0.47	-0.56 - 0.93
	IPFa	-0.06	-0.83 - 0.79	0.16	-0.75 - 0.86	0.54	-0.49 - 0.94
Sinclair Total	IPF	0.40	-0.61 - 0.91	0.55	-0.48 - 0.94	0.71	-0.23 - 0.97
	RFD250	0.64	-0.36 - 0.96	0.25	-0.7 - 0.88	0.55	-0.48 - 0.94
	IPFa	0.09	-0.78 - 0.84	0.16	-0.75 - 0.86	0.58	-0.44 - 0.95

IPF: isometric peak force; IPFa: allometrically-scaled isometric peak force; RFD250: rate of force development 0-250ms; Totala: allometrically-scaled total

and females (0.69-0.84 vs 0.08-0.38), except for the snatch (0.74 vs 0.37). Similarly, correlations between IPF and RFD250 at the same bar positions tended to be stronger at P and K compared to S for the whole group and males, whereas females had stronger a stronger correlation at K (Table 5).

DISCUSSION

The primary purpose of this study was to compare the results of three different isometric pulling positions with weightlifting performance among a group of collegiate weightlifters. Based on this limited sample, it appears that absolute IPF values and RFD250 correlate somewhat better with absolute weightlifting performance versus scaled

Table 5. Correlations of IPF with IPFa and RFD250 at different isometric pull bar positions.

	IPFa	95%CI	RFD250	95%CI
IPF Whole Group				
Power	0.93	0.77 - 0.98	0.91	0.69 - 0.97
Knee	0.92	0.75 - 0.98	0.89	0.65 - 0.97
Set-up	0.92	0.75 - 0.98	0.73	0.27 - 0.92
IPF Females				
Power	0.89	0.27 - 0.99	0.11	-0.77 - 0.85
Knee	0.67	-0.3 - 0.96	0.42	-0.6 - 0.92
Set-up	0.76	-0.14 - 0.97	0.2	-0.73 - 0.87
IPF Males				
Power	0.85	0.11 - 0.98	0.87	0.21 - 0.99
Knee	0.68	-0.29 - 0.96	0.8	-0.04 - 0.98
Set-up	0.71	-0.24 - 0.97	0.58	-0.44 - 0.95

IPF: isometric peak force; IPFa: allometrically-scaled isometric peak force; RFD250: Rate of force Development 0-250ms

values in both males and females. This suggest that use of absolute values may be somewhat more valuable than scaled when assessing isometric testing for weightlifters. Agreeing with Joffe et al. [8] and Rochau et al. [9], the pull from S is somewhat superior to the other two positions for IPF assessment in comparison to weightlifting performance. This finding is consistent with evidence indicating that correlations of IPF with 1 RM's are somewhat greater at longer muscle lengths (i.e. S position), even though IPF and RFD were of a smaller magnitude [7, 8]. As Joffe et al. [8] point out, although the weightlifting lifts (snatch and clean) are ballistic in nature, the objective is a 1RM, thus greater correlations might be expected in the S position.

However, when considering RFD250, especially among the males, the strongest correlations were noted at P when compared to the absolute total and Sinclair total, suggesting that, if explosiveness is being considered, P may be somewhat superior. Interestingly, this indicates that perhaps RFD has the strongest correlations at shorter muscle lengths, which is supported by previous observations [15, 16]. Additionally, part of this finding may deal with the training program of the lifters. All of the lifters had been using similar training programs for several months before testing. Much of the training focused on pulling from the P position (2nd pull) and explosiveness was emphasized. Furthermore, it should be noted that the relationship between IPF-P and RFD250 was strongest among the males at P. Clearly, males and females did not show the same relative pattern of relationships among positions for all variables, agreeing with previous work [17].

Although Ben-Zeev et al [10] also investigated three similar positions, they did not examine scaled values (allometric and Sinclair). We calculated the Sinclair totals based on the mean body mass and totals provided by Ben-Zeev et al. [10]. The Sinclair totals between Ben-Zeev et al. [10] and the current study were 202.9 vs 205.7 for the women and 292.2 vs 305.3 the men. Based on the mean totals and estimated Sinclair totals, although similar, the Israeli lifters, particularly the males, do not appear to be quite as proficient as the lifters in the present study. Their correlations [10] did indicate that the start position IPF correlated better than the power position with the absolute total, agreeing with the results of the present study as well as Joffe et al. [8] and Rochau et al. [9]. However, unlike our result, they [10] also found that the knee position correlated better than the present result. We also found that RFD250 had stronger relationships with the power position which does not appear to be the case for the Israeli athletes [10].

LIMITATIONS

It should be acknowledged that sport science investigations are frequently limited by small sample sizes, which can reduce statistical power [18, 19]. Although an a priori power analysis indicated that 12 participants were sufficient for the primary outcomes, this remains at best a modest sample, additionally, subgroup analyses (male vs. female) were based on only six subjects per group.

Additionally, the sequential order of isometric testing (P, K, S) may have introduced residual fatigue from earlier pulls, potentially influencing performance in later trials. This sequence was maintained because it reflected a protocol used in our athlete monitoring program and in previous studies from this laboratory and others [8, 9, 10]. Retaining this order ensured consistency within the monitoring program, thus, standardizing potential fatigue effects across testing sessions. Subjective feedback from the athletes suggested that they did not perceive fatigue as a major influencing factor. However, future investigators may want to consider this potential fatiguing effect.

Based on the present data, isometric testing including these key positions may be quite important in "predicting" success in weightlifting performance. Indeed, longitudinal tracking of these positions over time could provide valuable information as to the athletes' progress and insights into position deficits which may translate into less than expected performance.

PRACTICAL APPLICATION

Based on this limited sample, we suggest using either S or P for isometric performance monitoring as these positions consistently showed somewhat better correlations with weightlifting performance. However, all three positions may be valuable as deviations at a given pull position may indicate weakness at one or more of these key positions.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

FUNDING

No funding was received in order for this research to be completed.

ETHICAL APPROVAL

All participants signed an informed consent form stating that the monitoring data collected for them could be used for analysis in research investigations. The form was approved by the East Tennessee State University IRB (# 06238sw-ETSU).

DATES OF REFERENCE

Submission - 03/02/2025
Acceptance - 12/02/2026
Publication - 06/06/2026

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