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Maximal isometric force in the start of the first pull exhibits greater correlations with weightlifting performance than in the mid-thigh position in national and international weightlifters

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ABSTRACT

This investigation compared the maximal isometric force capacity between the start position of the first pull (IPSP) and isometric mid-thigh pull (IMTP), and their relationship with weightlifting competition performance in twenty national and international, male and female weightlifters. Isometric strength assessment and competition performance data collected as part of the routine sport science services of a national weightlifting performance programme were used for this study. Differences in isometric peak force (PkF) and allometrically scaled peak force (PkFa) between the IPSP and IMTP were evaluated using a paired-samples t-test. The relationships between absolute and allometrically scaled IPSP, IMTP, Total (TOT), Snatch (SN) and Clean & Jerk (CJ) variables were analysed using Pearson's Product-Moment Correlation. Fisher's r-to-z transformation was used to statistically compare the correlation values between the IPSP and IMTP with weightlifting performance measures. The IMTP PkF and PkFa were significantly greater than the IPSP PkF and PkFa, respectively, across combined (COM), male (M) and female (F) groups ($p = < 0.001$). However, the IPSP PkF exhibited significantly greater correlations with SN ($r = 0.94$ vs. 0.83, $p < 0.05$) and TOT ($r = 0.95$ vs. 0.86, $p < 0.05$) than the IMTP PkF in the COM group. In addition, the IPSP PkFa exhibited a significantly greater correlation with allometrically scaled snatch (SNa) ($r = 0.83$ vs. 0.51, $p < 0.05$) than the IMTP PkFa in the COM group. No significant correlations were observed between the IPSP PkFa and IMTP PkFa across M, F and COM groups. These findings suggest that the maximal force capacity in the IPSP is a greater determinant of weightlifting performance than in the IMTP, however, each may be representative of independent neuromuscular qualities. Coaches and practitioners working with weightlifters may consider implementing the IPSP assessment in addition to the IMTP to evaluate the strength characteristics specific to the different phases of the pull.

1. Introduction

The snatch and the clean & jerk techniques are initiated with the 'pull' phase, where the bar is displaced from the floor to waist height; and vertical propulsive forces are applied to project the bar high enough to be caught in an overhead (Snatch) or front rack (Clean) position (Kipp & Giordanelli, 2018). The pull is comprised of three sub-phases: the first pull, transition and second pull, each exhibiting unique kinetic and kinematic characteristics (Gourgoulis, Aggeloussis, Garas, & Mavromatis, 2009). The first pull is integral to the efficiency of the lift, as precise barbell and joint mechanics can limit excessive external joint torque and preserve balance between the center of mass and base of support. This facilitates a more efficient transition phase and subsequently a greater application of vertical ground reaction forces (VGRF) in the second pull (Favre & Peterson, 2012).

The first pull occurs between the separation of the bar from the floor and the peak extension of the knee, finishing with the bar slightly above the patella. The lifter therefore must generate tension, overcome inertia, and accelerate the bar vertically by

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extending the legs whilst maintaining a constant torso angle relative to the floor (Chavda & Turner, 2020). This requires a large concentric knee extensor torque from a flexed knee angle, while resisting notable external joint torque around hip and lower back (Kipp, Redden, Sabick, & Harris, 2012).

Previous investigations have shown that peak VGRF during the first pull strongly correlate with the load lifted in the snatch and clean lifts (Baumann, Gross, Quade, Galbierz, & Schwirtz, 1988; Enoka, 1979; Souza, Shimada, & Koontz, 2002). Elite weightlifters also demonstrate greater relative peak VGRF during the first pull than their sub-elite counterparts (Kauhanen, Häkkinen, & Komi, 1984). In addition, smaller horizontal resultant acceleration vectors applied to the bar in the first pull are associated with greater technical efficiency and overall success rate in the snatch (Gourgoulis et al., 2009). These findings emphasize the importance of both the magnitude and vertical direction of force application during this phase and consequently, are critical considerations when evaluating phase-specific neuromuscular characteristics in weightlifters.

The existing dynamic and isometric assessments used to evaluate the neuromuscular characteristics in weightlifters are typically based upon their kinetic and kinematic specificity to the second pull (Carlock et al., 2004; Haff et al., 2005, 1997). The most widely investigated assessment is the isometric mid-thigh pull (IMTP), which evaluates the maximal VGRF and rate of force development (RFD) in an identical position to the start of the second pull (Comfort et al., 2019). This position was adopted because the greatest VGRF and RFD occurs during this phase (Haff et al., 1997). In addition, this position corresponds with the peak of the strength curve (Stone et al., 2019) which is proposed to be the optimal position for maximal isometric testing (Wilson & Murphey, 1996). Multiple investigations have demonstrated large correlations between the IMTP peak force (PkF) and RFD with weightlifting performance in sub-elite and elite male and female weightlifters ($r = 0.58$ to 0.84), reinforcing the importance of these qualities in the second pull (Beckham et al., 2013; Haff et al., 2005; Joffe & Tallent, 2020; Stone et al., 2005). However, differences in joint angles, external joint torque (Kipp et al., 2012) and temporal patterns of VGRF (Chavda et al., 2020) between the first and second pull gives rise to the supposition that the assessment of maximal force characteristics specific to the first pull may reveal additional information regarding the neuromuscular characteristics associated with superior weightlifting performance. In a recent review on the use of the IMTP in weightlifters, Stone et al. (2019) proposed conducting a maximal isometric assessment across multiple positions of the pull, including the start position of the clean or snatch lifts. It was suggested that this information could inform the prescription of training by addressing position-specific strength deficits in the pull. However, no investigations to date appear to have addressed this notion, therefore our understanding of the role of maximal force capacity in the start of the first pull is unclear.

However, several investigations have examined isometric testing across multiple positions of the corresponding dynamic exercise, including the deadlift (Bartolomei et al., 2019; Beckham et al., 2012; Malyszek et al., 2017; Miller, 2020), back squat (Bazyler, Beckham, & Sato, 2015; Marcora & Miller, 2000) and bench press (Murphy, Wilson, Pryor, & Newton, 1995). A common finding between these investigations was that the longer muscle length testing position elicited a comparatively smaller peak force than at the shorter muscle length position. This is likely attributed to each of these exercises being categorized as having ‘ascending strength curves’ (McMaster, Cronin, & McGuigan, 2009). Interestingly however, those investigations which examined the correlations between isometric PkF at different testing positions with the exercise 1-repetition maximum (1-RM), consistently revealed greater correlations between the peak force in the longer muscle length position (Bartolomei et al., 2019; Bazyler et al., 2015; Miller, 2020; Wilson & Murphey, 1996). These findings are perhaps expected, given that the weakest mechanical position is the theoretical limit for the maximal load that can be lifted in a dynamic movement. Although the snatch and clean are most appropriately categorized as ballistic tasks, rather than a maximal dynamic strength task, their shared objective is to lift a maximal weight. It is therefore plausible that this principle applies to these lifts as well. Like these previous reports, an isometric pull in the start position of the weightlifting movements may reveal greater correlations with weightlifting performance that the IMTP.

The purpose of this investigation is to compare the relationships between an isometric pull from the start position of the first pull (IPSP) and the IMTP with weightlifting competition performance in national and international male and female weightlifters. It is hypothesized that the IPSP will exhibit a lower maximal force output but will reveal a stronger correlation with weightlifting performance measures compared with the IMTP.

2. Methods

This investigation examined the relationship between the IPSP and IMTP with weightlifting competition performance including the Snatch (SN), Clean & Jerk (CJ) and Total (TOT) in national and international male and female weightlifters. Force-platform strength assessment and competition performance data collected as part of the routine sports science support services of a national weightlifting performance and talent development programme between 2014 and 2017 were utilised for this investigation. Testing took place during specific competition preparation camps at the beginning of training sessions. Testing data within four to eight weeks of a national or international competition were collected for analysis.

2.1. Participants

Twenty national and international male and female weightlifters (7 males; age: 24.2 years ± 3.0; weight: 85.5 kg ± 13.1; height: 1.76 m ± 0.06 and 13 females; age: 26.1 years ± 7.2; weight: 62.2 kg ± 8.5; height: 1.57 m ± 0.07) participated in this investigation. All participants were part of the national weightlifting performance programme or talent development programme at the time of data collection. All participants provided informed consent to the use of these data. Project approval was obtained from a University Ethics Committee.

2.2. Procedure

2.2.1. Isometric Pull Assessments

Isometric testing was performed using a ForceDecks bilateral force plate system (2 x 350 mm x 750 mm ForceDecks FD4000 Force Platforms, NMP Technologies, London, UK) inside a customised power rack with bar attachment points located at 2.5 cm intervals along the vertical bar supports. Force-time data were captured with a sampling frequency of 1000 hz using NMP ForceDecks software (Version 1.2.6322, NMP Technologies, London, UK). Testing took place at the beginning of training sessions following a standardised warm-up protocol which included dynamic movements (i.e., body weight squats and lunges), technical drills with an empty bar and a series of warm-up attempts in either the snatch or clean & jerk, depending on the athlete's training programme.

The set-up position for the IMTP test was established in accordance with previously described guidelines (Comfort et al., 2019). Knee and hip angles ranged between 125 to 145° and 140 to 150° respectively, and the bar held in a clean grip with the torso oriented vertically. The bar was positioned with slight contact on the upper thigh to ensure a kinematic similarity to the start of the second pull. Feet were positioned directly beneath the center of the bar and approximately hip-width apart. For the IPSP, the bar height was consistent for all participants as this was based on the height of a weightlifting bar when loaded with standard weightlifting disks of 45 cm diameter. Therefore, the center of the bar was positioned 22.5 cm from the floor. This meant that each participant's body position, such as knee and hip joint angles, might have varied slightly, depending on individual anthropometric and mobility characteristics. However, key technical criteria of the set-up position for the clean were adhered to, which included bar positioned directly above the metatarsophalangeal joint, center of the hip joint above the center of the knee joint, center of the shoulder joint above the center of the hip joint, center of the shoulder joint directly above or slightly in advance of the bar and the arms remained full extended (Figure 1) (Chavda et al., 2020). This was visually inspected by the administrator prior to the commencement of the test. Similarly, to the IMTP protocol, a clean grip was adopted for this assessment.

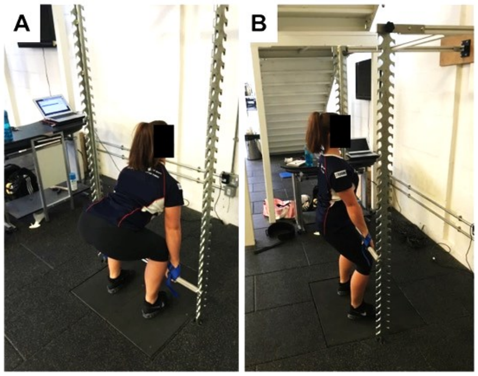

Figure 1: Example testing positions for the Isometric Pull from the Start Position (A) and the Isometric Mid-Thigh Pull (B).

Weightlifting shoes and lifting straps were utilized and standardized for both isometric tests. All participants were familiar with both testing protocols; therefore, a single warm-up attempt was performed before their first maximal attempt of each test. As these assessments formed part of a physical testing battery for the athletes, the order of the isometric assessments was standardized, so that the IMTP was performed before the IPSP. This was to avoid any confounding factors which may lead to greater error when trying to detect a meaningful change over time (McGuigan, 2020). Before each test, participants were instructed to "pull as hard and fast as possible" and "keep pulling until you are signaled to release" (Comfort et al., 2019). One second after the force trace either plateaued or continued to decline, a signal to cease the test was given. Each test lasted approximately 2 to 4 seconds. Three tests were performed for each athlete with 3 minutes rest between attempts. The net PkF was collected and the average value of all the three trials was used for the analysis. Test-retest reliability for IMTP and IPSP for PF was ICC = 0.97, CV 2.76% and ICC = 0.98, CV 1.3% respectively, and are consistent with previous reports (Beckham et al., 2012; Haff et al., 2005; Joffe & Tallent, 2020; Stone et al., 2005).

2.2.2. Competition Performance Data Collection

Competition performance data including SN, CJ and TOT were collected from national championship events, international IWF sanctioned events and the European Under 23s (A non-IWF sanctioned event) between 1st January 2014 and 31st December 2017. These competitions were chosen because it was typical for athletes to 'peak' for these competitions, and thus, it was reasoned that these performances reflected their optimal athletic performance. Competition performance data were obtained from the publicly available British Weight Lifting, International Weightlifting Federation and European Weightlifting Federation websites. Test-retest reliability of weightlifting performance in international male and female weightlifters has been reported as 2.5% (95% CI 2.2 to 2.9%) and 3.2% (95% CI 2.7 to 4.1%) respectively (McGuigan & Kane, 2004).

2.3. Statistical Approach

All data are presented as mean ± standard deviation. Strength assessment and competition performance data were tested for normal distribution using the Shapiro-Wilks test. All analyses were performed on absolute and allometrically scaled assessment (IPSP and IMTP, IPSPa and IMTPa, respectively) and competition data (SN, CJ, TOT and SNa, CJa, TOTa, respectively). Allometric scaling of isometric strength and weightlifting performance to body mass was performed using the power exponent of 0.67 (Jaric, Irkov, & Arkovic, 2005). A paired-samples t-test was used to analyze the difference between IPSP and IMTP and an independent-samples t-test was used analyze the differences between male and female groups, each with 95% confidence intervals and effect sizes. The relationship between all competition performance variables (SN, CJ, and TOT) with IPSP and IMTP was investigated using the Pearson's Correlation Coefficient. Correlation values are presented with 95% confidence intervals. Correlations were interpreted in accordance

Table 1: Mean ± SD of absolute and allometrically scaled weightlifting performance measures and isometric pull assessments.

Group	TOT (kg)	SN (kg)	CJ (kg)	IMTP PkF (N)	IPSP PkF (N)	TOTa (kg.kg$^{0.67}$)	SNa (kg.kg$^{0.67}$)	CJa (kg.kg$^{0.67}$)	IMTP PkFa (N.kg$^{0.67}$)	IPSP PkFa (N.kg$^{0.67}$)
M (7)	282 ± 46	128 ± 20	154 ± 27	3324 ± 664	1874 ± 357	14.58 ± 1.13	6.60 ± 0.47	7.78 ± 0.73	168.00 ± 20.59	94.78 ± 10.16
F (13)	165 ± 25	73 ± 11	92 ± 15	2272 ± 540	1211 ± 235	10.79 ± 1.16	4.75 ± 0.51	6.04 ± 0.69	142.50 ± 20.60	75.8 ± 10.20
COM (20)	206 ± 66	92 ± 30	114 ± 36	2640 ± 767	1443 ± 425	12.11 ± 2.17	5.40 ± 1.03	6.71 ± 1.17	151.40 ± 28.30	82.40 ± 13.10

TOT = Total; SN = Snatch; CJ = Clean & Jerk, TOTa = allometrically scaled Total; SNa = allometrically scaled Snatch; CJa = allometrically scaled Clean & Jerk; IPSP = Isometric Pull from Start Position; IMTP = Isometric Mid-Thigh Pull; PkF = Peak Force; PkFa = Allometrically Scaled Peak Force

with the following descriptive criteria: 0 = *trivial*, 0.1 = *small*, 0.3 = *moderate*, 0.5 = *large*, 0.7 = *very large*, 0.9 = *nearly perfect*, 1 = *perfect* (Hopkins, Marshall, Batterham, & Hanin, 2009). To evaluate the differences between correlations, all values were converted using Fishers r-to-z transformation. The comparison of correlations between independent groups (M vs. F) was done in accordance with the method described by Cohen, Cohen, West, and Aiken (2003). The comparison of correlations within groups (IPSP vs. IMTP) was done in accordance with the method described by Steiger (1980). Alpha was set at 0.05. All t-tests and correlation analyses were performed using SPSS (version 24.0). The analysis of comparisons between correlation values were performed in a customized Microsoft Excel spreadsheet (Version 2012).

3. Results

3.1. Comparisons between IPSP and IMTP

The mean ± SD for all strength assessment and performance variables are presented in Table 1. Significant differences were observed between the IPSP PkF and the IMTP PkF for the M (1449.2 ± 454.2 N, 95% CI = 1029.1 to 1869.3, t(6) = -8.442, $p < 0.001$, ES = 3.19), F (1060.5 ± 464.9 N, 95% CI = 779.6 to 1341.4, t(12) = -8.225, $p < 0.001$, ES = 2.06) and COM groups (1196.6 ± 487.7 N, 95% CI = 968.3 to 1424.8, t(19) = -10.973, $p < 0.001$, ES = 2.45) (Figure 2). Similarly, significant differences were observed between IPSP PkFa and IMTP PkFa for the M (73.22 ± 18.89 N.kg^{67}, 95% CI = 55.75 to 90.70, t(6) = -10.252, $p < 0.001$, ES = 3.88), F (66.69 ± 29.02 N.kg^{67}, 95% CI = 49.15 to 84.23, t(12) = -8.284, $p < 0.001$, ES = 2.30) and COM groups (69.98 ± 25.60 N.kg^{67}, 95% CI = 57.00 to 80.96 t(19) = -12.052, $p < 0.001$, ES = 2.69) (Figure 2). No significant differences were observed between the M and the F groups for the IPSP:IMTP ratio (1.94 ± 4.45 %, 95% CI = -11.30 to 7.40, t(18) = -10.973, $p = 0.204$, ES = 0.2) (Figure 3).

3.2. Correlations between IPSP, IMTP and weightlifting performance measures

All results from the correlation analysis are presented in Tables 2 and 3. The analysis between IPSP PkF and weightlifting performance variables revealed *nearly perfect*, *very large* to *nearly perfect*, and *very large* correlations for the COM, M and F groups, respectively. The analysis between IMTP PkF and weightlifting performance variables revealed *very large*, *very large* to *nearly perfect* and *large* correlations for the COM, M and F groups, respectively (Figure 4). The analysis between IPSP PkFa and allometrically scaled weightlifting performance variables revealed *very large, large* to *very large* and *large* correlations for the COM, M and F groups, respectively. The analysis between IMTP PkFa and allometrically scaled weightlifting performance variables revealed *large*, *moderate* to *very large* and *small* correlations for the COM, M and F groups, respectively (Figure 4). The correlation between the IPSP PkF and IMTP PkF in M and COM groups were *very large*. No significant correlation between IPSP PkF and IMTP PkF was observed in the F group. No significant correlations were observed between the IPSP PkFa with IMTP PkFa in either M, F or COM groups.

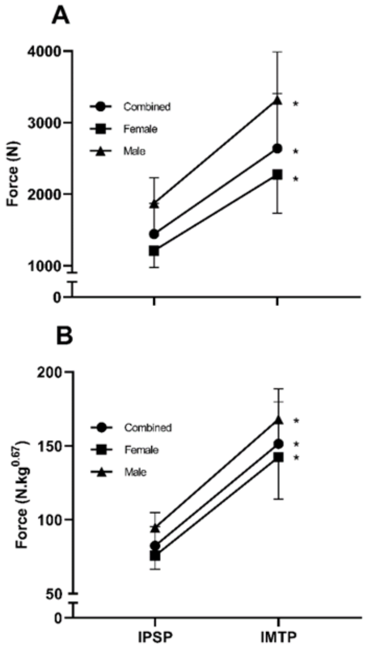

Figure 2: Absolute (A) and allometrically scaled (B) difference between IPSP and IMTP for male, female and combined male and female groups. IPSP = Isometric Pull from Start Position, IMTP = Isometric Mid-Thigh Pull. * denotes $p < 0.001$.

3.3. Comparison of correlations between IPSP and IMTP with weightlifting performance measures

A significantly greater correlation was observed between the IPSP PkF with SN and TOT compared with the IMTP PkF (Z = 2.16, *p* = 0.04 and Z = 2.05, *p* = 0.03, respectively). Furthermore, a significantly greater correlation was observed between IPSP PkFa with SNa compared with the IMTP PkFa (Z = 2.08, *p* = 0.04).

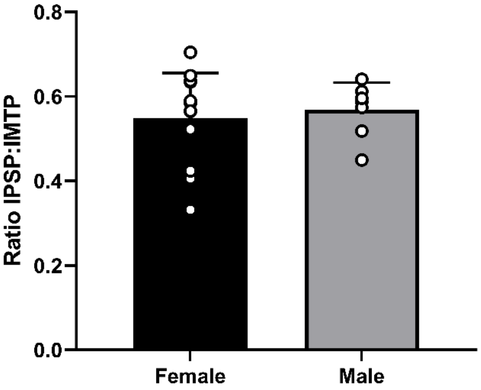

Figure 3: Group average and individual ratio between IPSP: IMTP for males and females. IPSP = Isometric Pull from Start Position, IMTP = Isometric Mid-Thigh Pull. Ratio IPSP: IMTP = IPSP ÷ IMTP. White circles denote individual data.

4. Discussion

The aim of this investigation was to compare the relationships between the IPSP and IMTP with weightlifting competition performance in national and international weightlifters. A critical finding of this investigation was that despite the IPSP exhibiting a comparably smaller PkF than the IMTP, IPSP PkF demonstrated a stronger relationship with SN and TOT in the COM group. Furthermore, when allometrically scaled to body mass, the IPSP PkFa also showed a stronger relationship with SNa in the COM group. These findings suggest that the maximal isometric force capacity in the start position of the first pull is a greater determinant of weightlifting performance than at the start of the second pull.

To date, no empirical investigations have examined the relationship between the IPSP with measures of weightlifting performance. However, several investigations have reported similar *large* to *nearly perfect* correlation values between IMTP PkF with SN, CJ and TOT (*r* = 0.82 to 0.93, *r* = 0.81 to 0.83, *r* = 0.80 to 0.82, respectively) (Beckham et al., 2013; Haff et al., 2005; Joffe & Tallent, 2020; Stone et al., 2005). A number of these investigations also examined the relationship between allometrically scaled IMTP PkFa and SNa, CJa and TOTa, reporting *moderate* to *very large* correlations (*r* = 0.50 to 0.79, *r* = 0.50 to 0.77, *r* = 0.78, respectively), which are generally higher than those reported in the present investigation (Beckham et al., 2013; Stone et al., 2005). However, the correlations between IPSP PkFa with allometrically scaled performance measures were similar to or greater than previous reports in the IMTP PkFa, ranging between *large* to *very large* correlations. To the best of the author's knowledge, the correlations between IPSP with weightlifting performance in the present investigation are the highest reported between a maximal isometric assessment and SN, CJ and TOT in the literature to date, bringing forth a potentially more accurate surrogate measure to of weightlifting performance potential.

Our findings support the already extensive evidence for the use of maximal isometric strength testing in multi-joint, biomechanically specific positions, as they elicit high correlations with corresponding dynamic sporting movements (Comfort et al., 2019; Lum, Haff, & Barbosa, 2020; Wilson & Murphey, 1996). However, these findings appear to conflict with the recommendation that maximal isometric testing should be conducted at the peak of the strength curve (Wilson & Murphey, 1996). The rationale for this is based on the notion that this standardised position should reduce the variability in force output associated with the error in determining specific joint angles for testing (Wilson & Murphey, 1996) and that it coincides with the region where VGRF and RFD are optimised in the corresponding dynamic movement (Haff et al., 1997; Wilson & Murphey, 1996). The latter point implies that this position would exhibit a greater correlation with dynamic performances compared with testing at other joint angles.

Interestingly however, in the present investigation the weakest pull position (IPSP) elicited greater correlations with weightlifting performance. Similar findings were reported by Bazyler et al. (2015) who investigated the relationship between maximal isometric squat PkF at 90° and 120° knee angles with the back squat 1-RM. Despite showing a significantly greater PkF in the 120° knee angle, the isometric PkF in the 90° knee angle demonstrated a *very large* and a considerably greater correlation with back squat 1-RM (*r* = 0.86 vs. 0.60). Several investigations have reported similar findings showing isometric PkF to be greater in the shorter muscle length conditions, yet a greater correlation observed between PkF in the longer muscle length condition with the corresponding exercise 1-RM (Bartolomei et al., 2019; Miller, 2020; Murphy et al., 1995).

On the contrary, Marcora and Miller (2000) examined the relationship between isometric PkF and peak RFD in the back squat at 90° and 120° knee angles with countermovement jump (CMJ) and squat jump (SJ) height. No correlations were observed between PkF at 90° or 120° knee angle with either jump, however peak RFD in the 120° knee angle exhibited *large* to *very large* correlations with CMJ and SJ height (*r* = 0.69 and 0.71, respectively). Moreover, no correlations were reported with peak RFD in the 90° knee angle, indicating that the peak RFD at comparatively shorter muscle lengths exhibit greater correlations with similar ballistic dynamic performance compared with peak RFD at longer muscle lengths. Similar findings were reported by Rousanoglou, Georgiadis, and Konstantinos (2008), showing RFD at shorter muscle length in the isometric leg extension exhibited greater correlations with jumping performance, compared with longer muscle lengths.

Table 2: Correlations with 95% CI's, between absolute and allometrically scaled IPSP, IMTP and Weightlifting Performance Measures

		IPSP PkF			IMTP PkF	
	r value	95% CI	Descriptor	*r* value	95% CI	Descriptor
SN COM	0.94 ** #	0.85 - 0.98	*nearly perfect*	0.83 **	0.61 - 0.93	*very large*
CJ COM	0.95 **	0.88 - 0.98	*nearly perfect*	0.88 **	0.72 - 0.95	*very large*
TOT COM	0.95 ** #	0.88 - 0.98	*nearly perfect*	0.86 **	0.67 - 0.94	*very large*
SN M	0.96 **	0.75 - 0.99	*nearly perfect*	0.77 *	0.04 - 0.96	*very large*
CJ M	0.89 **	0.42 - 0.98	*very large*	0.91 **	0.50 - 0.99	*nearly perfect*
TOT M	0.93 **	0.59 - 0.99	*nearly perfect*	0.87 *	0.34 - 0.98	*very large*
SN F	0.81 **	0.47 - 0.94	*very large*	0.60 *	0.07 - 0.87	*large*
CJ F	0.85 **	0.56 - 0.95	*very large*	0.69 **	0.22 - 0.90	*large*
TOT F	0.85 **	0.56 - 0.95	*very large*	0.66 **	0.17 - 0.89	*large*
		IPSP PkFa			IMTP PkFa	
	r value	95% CI	Descriptor	*r* value	95% CI	Descriptor
SNa COM	0.83** #	0.61 - 0.93	*very large*	0.51*	0.09 - 0.78	*large*
CJa COM	0.85**	0.65 - 0.94	*very large*	0.65**	0.29 - 0.85	*large*
TOTa COM	0.85**	0.65 - 0.94	*very large*	0.59**	0.20 - 0.82	*large*
SNa M	0.81*	0.15 - 0.97	*very large*	0.33	-0.56 - 0.87	*moderate*
CJa M	0.69	-0.13 - 0.95	*large*	0.79*	0.09 - 0.97	*very large*
TOTa M	0.78*	0.78 - 0.97	*very large*	0.64	-0.22 - 0.94	*large*
SNa F	0.52	-0.04 - 0.83	*large*	0.28	-0.32 - 0.72	*small*
CJa F	0.65**	0.15 - 0.88	*large*	0.47	-0.11 - 0.81	*small*
TOTa F	0.62**	0.10 - 0.87	*large*	0.40	-0.19 - 0.78	*small*

IPSP = Isometric Pull from Start Position, IMTP = Isometric Mid-Thigh Pull, PkF = Peak Force, PkFa = Allometrically Scaled Peak Force, SN = Snatch, CJ = Clean & Jerk, TOT = Total, SNa = Allometrically Scaled Snatch, CJa = Allometrically Scaled Clean & Jerk, TOTa = Allometrically Scaled Total, COM = Combined Male and Female group, M = Male group, F = Female group. * = $p < 0.05$; ** = $p < 0.01$ denotes statistically significant correlations. # = $p < 0.05$ denotes statistically significant difference between IPSP and IMTP correlation.

Table 3: Correlations with 95% CI's, between absolute and allometrically scaled IPSP and IMTP variables for male, female and combined male and female groups.

		IPSP PkF			IMTP PkF	
	r value	95% CI	Descriptor	*r* value	95% CI	Descriptor
IPSP PkF COM	-	-	-	0.82 **	0.59 - 0.93	*very large*
IPSP PkF M	-	-	-	0.76 *	0.02 - 0.96	*very large*
IPSP PkF F	-	-	-	0.51	-0.06 - 0.83	*large*
IMTP PkF COM	0.82 **	0.59 - 0.93	*very large*	-	-	-
IPSP PkF M	0.76 *	0.02 - 0.96	*very large*	-	-	-
IPSP PkF F	0.51	-0.06 - 0.83	*large*	-	-	-
		IPSP PkFa			IMTP PkFa	
	r value	95% CI	Descriptor	*r* value	95% CI	Descriptor
IPSP PkFa COM	-	-	-	0.43	-0.02 - 0.73	*moderate*
IPSP PkFa M	-	-	-	0.41	-0.50 - 0.89	*moderate*
IPSP PkFa F	-	-	-	0.10	-0.48 - 0.62	*small*
IMTP PkFa COM	0.43	-0.02 - 0.73	*moderate*	-	-	-
IPSP PkFa M	0.41	-0.50 - 0.89	*moderate*	-	-	-
IPSP PkFa F	0.10	-0.48 - 0.62	*small*	-	-	-

IPSP = Isometric Pull from Start Position, IMTP = Isometric Mid-Thigh Pull, PkF = Peak Force, PkFa = Allometrically Scaled Peak Force, COM = Combined Male and Female group, M = Male group, F = Female group. * = $p < 0.05$; ** = $p < 0.01$ denotes statistically significant correlations.

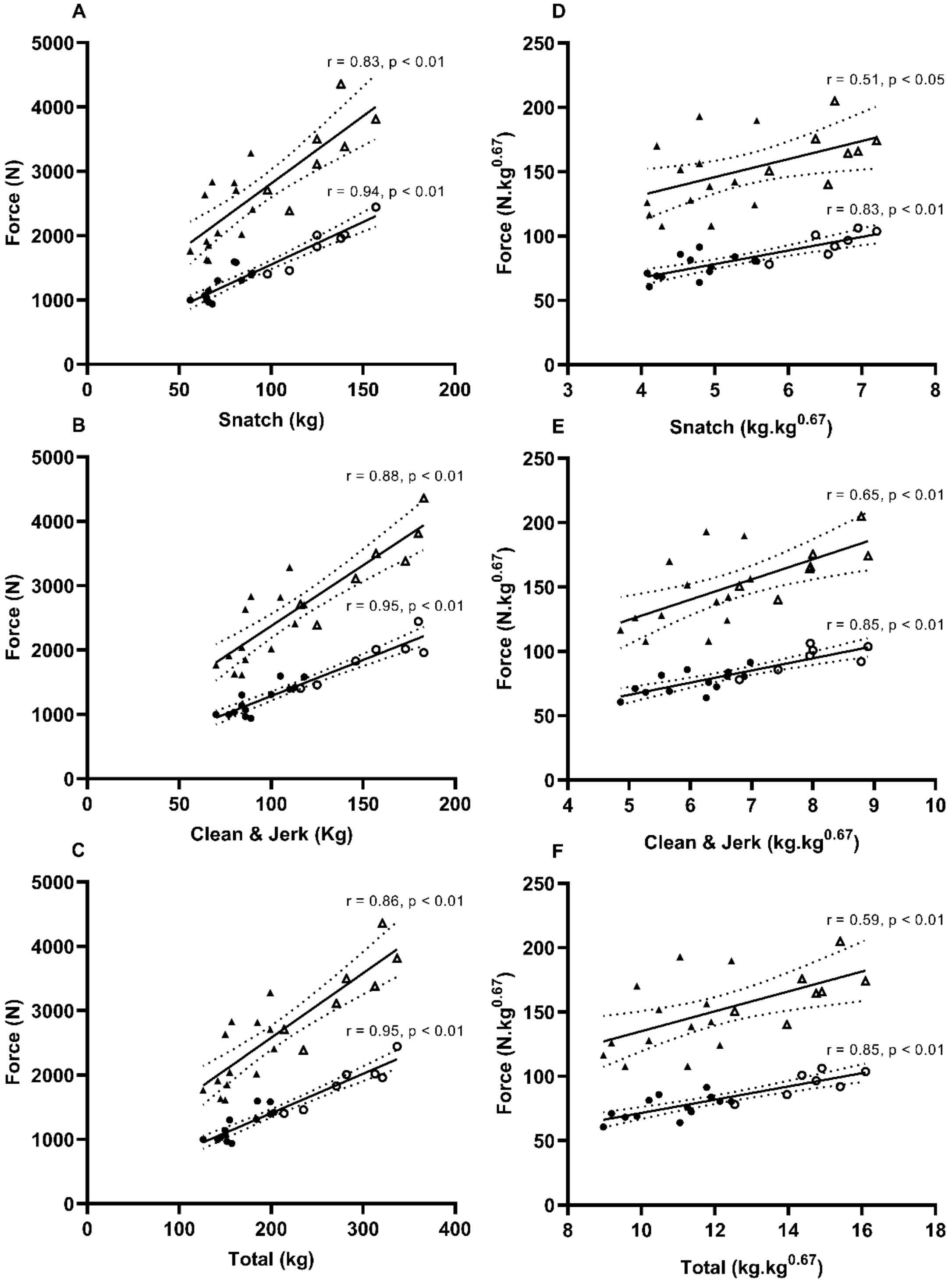

Figure 4: Correlations between absolute and allometrically scaled IPSP, IMTP variables and weightlifting performance measures of the combined male and female group, with 95% Confidence Intervals. (A) Snatch, (B) Clean & Jerk, (C) Total, (D) Allometrically scaled Snatch, (E) Allometrically scaled Clean & Jerk, (F) Allometrically scaled Total. Triangles denote IMTP, circles denote IPSP. Solid symbols denote females, hollow symbols denote males. IPSP = Isometric Pull from Start Position, IMTP = Isometric Mid-Thigh Pull.

A possible explanation for the apparent conflict in research findings might relate to differences in the force-velocity characteristics and intended movement outcomes of the dynamic tasks. It is plausible that these may influence their correlations with isometric tests at varying joint angles or the PkF and RFD variables. For example, in plyometric and ballistic tasks, the intention is to maximise take-off or release velocity at the end of the concentric phase to project one's body mass or an external object into a flight phase (Hubbard, De Mestre, & Scott, 2001; Linthorne, 2001). These tasks may be more limited by the isometric RFD capacity at the position where the maximum force capacity is optimised, as this is where the greatest mechanical advantage occurs and the region of greatest filament cross-bridge cycle transition rate (Fitts, McDonald, & Schluter, 1991). Several investigations have shown that in bilateral triple-extension isometric assessments (isometric squat, isometric mid-thigh pull and isometric leg press) the greatest RFD coincided with the region where maximum force is optimised (knee angles between 120 to 150°) (Bazyler et al., 2015; Bogdanis et al., 2019; Comfort, Jones, McMahon, & Newton, 2015; Palmer, Pineda, & Durham, 2018). This may explain why several investigations report that isometric RFD in shorter muscle lengths exhibits greater correlations with vertical jump performance compared with isometric RFD at longer muscle lengths, and all isometric positions examining PkF (Marcora & Miller, 2000; Rousanoglou et al., 2008). Consequently, for these types of athletic skills, it may be most appropriate to assess isometric RFD within a mechanically specific position to the corresponding dynamic task and at the position where peak force is optimised. On the contrary, in a maximal dynamic strength exercise where the objective is to lift the heaviest weight possible over a relatively constant displacement, the primary limiting factor is the weakest mechanical position across the range of motion. Exercises with linear strength curves such as the back squat, bench press and deadlift, the weakest mechanical position is in the start of the concentric phase (McMaster et al., 2009). It therefore may be necessary to evaluate isometric PkF in a mechanically specific position, however at the position where PkF is the lowest.

The pull phase of the SN and CJ arguably possess characteristics of both maximal dynamic strength and ballistic movements, as the objective is to lift and project a maximal weight high enough to be caught in the overhead or front rack position. However, the sub-phases of the pull, namely the first and second pull exhibit unique positional and temporal force and velocity characteristics (Baumann et al., 1988; Gourgoulis et al., 2009; Harbili, 2012) and function across different end of the muscles force-length curve. The first pull is considered a more strength-oriented phase as it occurs within a comparatively weaker mechanical position and subsequently is a slower movement and requires the lifter to overcome the inertia of the bar (Chavda & Turner, 2020; Garhammer, 1991). Conversely, the second pull is considered a power-oriented movement as it occurs within a stronger mechanical position, is much shorter in duration and exhibits the greatest force, velocity, power, and RFD (Baumann et al., 1988; Gourgoulis et al., 2009). The implementation of both the IPSP and IMTP may therefore be necessary to evaluate the position specific neuromuscular qualities for each of these phases, however this concept warrants further investigation.

In the present investigation, when allometrically scaled to body mass, the IPSP PkFa and IMTP PkFa were poorly correlated with each other across M, F and COM groups, supporting the notion that the maximal force capacity specific to the first and second pull are independent neuromuscular qualities. The evaluation of each of these pull positions may help to identify deficits in the athlete's phase specific strength characteristics and subsequently lead to more directed training prescription. There is also a considerable amount of evidence to suggest that these two positions of the pull may experience specific adaptations in response to muscle length specific training (Bogdanis et al., 2019; Kubo et al., 2006; Noorkõiv, Nosaka, & Blazevich, 2014; Thepaut-Mathieu, Van Hoecke, & Maton, 1988; Ullrich, Kleinöder, & Brüggemann, 2009; Weiss, Fry, Wood, Relyea, & Melton, 2000), however, this is beyond the scope of this investigation.

No differences were observed between M and F groups in correlations between IPSP or IMTP with SN, CJ or TOT, or in correlations between IPSP PkFa or IMTP PkFa with SNa, CJa or TOTa. Furthermore, no differences were observed between M and F groups for the IPSP:IMTP ratio. There was some indication of greater correlations between the two isometric pulling positions with weightlifting performance in the M group compared with the F group and this was observed in both absolute and allometrically scaled values. However, the lack of statistical significance suggests no difference exist between male and female weightlifters in the pulling strength characteristics which relate to weightlifting performance. Therefore, it is evident from our results that male and female weightlifters should train these qualities similarly.

It should be acknowledged that these data are cross-sectional and do not indicate a causal relationship between the IPSP, IMTP and weightlifting performance. However, a recent investigation showed a *large* correlation between the change in IMTP PkF and change in SN, CJ and TOT across two consecutive years in international female weightlifters (r = 0.64 to 0.65) (Joffe & Tallent, 2020) indicating a causal relationship. Based upon the present and previous findings, it is recommendation that future investigations examine the alterations in both isometric pulling positions across an extensive period of specific training to determine the impact of changes in these qualities on weightlifting performance.

In conclusion, these findings suggest that the maximal force capacity in the start position of the first pull has a greater correlation with weightlifting performance measures than maximal force capacity in the start of the second pull. However, when the effects of body mass are controlled for through allometric scaling, these assessments are poorly correlated with each other indicating that each are reflective of independent neuromuscular qualities. Therefore, coaches and practitioners working with competitive weightlifters may consider implementing both the IMTP and IPSP assessments to assess the position-specific neuromuscular characteristics of the pull.

Conflict of Interest

The authors declare no conflict of interest

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