ASSOCIATIONS BETWEEN STRENGTH AND POWER WITH THROWING PERFORMANCE IN HIGH LEVEL MALE AND FEMALE JAVELIN THROWERS

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This study investigated the associations between strength and power measures and estimated javelin throwing performance. Thirteen male (personal best: 77.0 ± 5.7 m) and thirteen female (55.8 ± 5.8 m) javelin throwers underwent various lower and upper body power and strength tests, along with a javelin throwing test. Associations with throwing performance were observed for lower body power measures in males and upper and lower body maximal strength in females, suggesting sex-specific differences in important physical characteristics for throwing.

KEYWORDS: kinematics, jumps, overarm, velocity, shoulder, athletics

INTRODUCTION: In the javelin throw, the aim is to throw the javelin as far as possible. The throw distance is influenced by several factors, such as release velocity, angle, and height (Bartlett et al., 1996; Hubbard & Alaways, 1987; Komi & Mero, 1985). Studies in various throwing sports link throwing performance to upper and lower body force production characteristics. For example, correlations have been found between pitch velocity and shoulder isokinetic and isometric torques in male adolescent and collegiate baseball players (Clements et al., 2001; Cross et al., 2022), and lower extremity power assessed by vertical jump tests in male professional baseball pitchers (Wong et al., 2023). In females, handball research suggests correlations between throwing velocity and maximal upper body strength in amateurs, and upper and lower body power characteristics at submaximal loads in elite athletes (Granados et al. 2007, 2013). However, investigating the physical characteristics required in javelin throwing is needed. Despite many parallels to other throwing sports, the javelin throw has some unique characteristics, such as the heavier and differently shaped implement, and the aim to not only maximize throwing velocity but also throw at an optimal release angle. Moreover, physiological differences and differences in javelin weight between males and females mean that optimal throwing characteristics may be sex-dependent. Therefore, this study aimed to investigate the associations between strength and power measures with javelin throwing performance in high level male and female athletes.

METHODS: In this cross-sectional study, thirteen male (mean ± SD, age: 24 ± 3 years, personal best: 77.0 ± 5.7 m) and thirteen female (age: 25 ± 5 years, personal best: 55.8 ± 5.8 m) participants provided written consent and underwent three testing sessions over two days. All test sessions included a standardised warm-up including light aerobic exercise, dynamic stretching, and submaximal strength exercises. In the first afternoon session, mobility, strength, and power were assessed. The following tests were then performed: bilateral countermovement jump (CMJ) and drop jump (BLDRJ40, 40-cm box), unilateral drop jump (ULDRJ20, 20-cm box), depth jump (ULDEJ20, 20-cm box), and leg press (ULLP), and clinical maximal isometric strength (CMIS) for both the upper and lower body. In the second morning session, body composition and health-related assessments were performed. Javelin throwing assessments and standing overhead medicine ball throw (SOMBT) were conducted after a self-selected warm-up in the third session, which took place at midday in an indoor athletics facility.

Two submaximal practice trials were performed, followed by three maximal trials for the vertical jumps and leg press, and two maximal trials for CMIS. The best trial for analysis was determined using jump height for CMJ and ULDEJ20, reactive strength index for BLDRJ40 and ULDRJ20, and maximal strength for CMIS. Rest periods of 60 seconds were allowed between trials in CMIS, bilateral jumps, and ULLP, and 30 seconds in unilateral jumps. The test leg was alternated between trials in ULDEJ20, ULDRJ20, and ULLP.

CMJ was performed and analysed as in McMahon et al. (2018). Participants rapidly squatted to their preferred depth and immediately jumped as fast and as high as possible. Jump height and RSImod ($\frac{Jump\ height\ [m]}{Time\ to\ take{-}off\ [s]}$) were calculated. In drop jumps, participants stepped off a box, landed with both legs (BLDRJ40) or one leg (ULDRJ20) knees and hips as straight as possible and then jumped as fast and high as possible. In ULDEJ20, participants stepped off a box, landed with one leg in a squat of ~60 degrees of knee flexion and then jumped as high as possible. Jump height, RSI ($\frac{Jump\ height\ [m]}{Contact\ time\ [s]}$), peak landing force, mean and peak power in the braking and propulsion phases, and vertical stiffness were calculated as described in McMahon et al. (2021).

For the leg press, participants sat leaning against a backrest, and rested their foot on an instrumented platform (knee angle: 107 degrees). Upon receiving the start cue, they pushed as fast and as hard as possible for ~3 seconds until a force plateau was achieved. Maximum force was determined as the difference between the zero-level and the highest recorded force, and the peak rate of force development within a 100-millisecond window was computed.

In CMIS, participants first gradually built tension on the force transducer, and then exerted maximal force for ~3 seconds until a force plateau was achieved. A portable EasyForce dynamometer assessed strength in shoulder internal and external rotation, and hip abduction, adduction, and extension. For shoulder tests, participants were secured in a prone position with the testing arm at 90 degrees of abduction and 10 degrees horizontal adduction, elbow at 90 degrees flexion, and forearm in pronation. In the hip strength assessments, the ankle was secured to the dynamometer. Hip abduction and adduction tests involved lying on the side with the measured limb in a horizontal position, while hip extension tests required a prone position. Ankle plantarflexion was assessed using a PeakForce dynamometer. Participants sat with their back against a wall and the dynamometer affixed to the foot while in a 90-degree dorsiflexed position. Joint moments were calculated by multiplying force with the corresponding lever arm length. Grip strength was evaluated using a custom force transducer. The participant was seated with 90 degrees of shoulder abduction and elbow flexion, forearm in supination, and the wrist in a neutral position.

In SOMBT, participants stood with their feet shoulder-width apart, raised the medicine ball (1 kg for females, 2 kg for males) above their heads and swung it forward. Two submaximal trials followed by three maximal trials were performed with 60-second rest intervals. Highest velocity recorded using a radar gun was analysed.

In the javelin throwing assessments, six maximal throws were performed. A slightly overweight javelin was used due to tip paddings, black paint and reflective tapes near the front tip, rear tip, and in front of the grip to allow for throwing against a tarp and accurate motion analysis. Four to five minutes of rest was allowed between throws. Two high-speed video cameras, placed 18 m behind and to the side of the thrower, captured the throws at 240 Hz and were synchronised using a custom LED light device. Recordings were processed using SIMI Motion. The reflective tapes on the javelin were manually digitised from four frames before up to four frames after release. A calibration process involved digitizing eight points with known 3D real-world coordinates in each 2D camera view, followed by applying the Direct Linear Transformation (Abdel-Aziz & Karara, 1971). The release velocity, angle, and height of the javelin were determined using the positions of reflective tapes in the final frame when the javelin was gripped. The standard projectile motion equation was used to estimate throw distance considering release velocity, angle, height, and gravity.

The data's distribution was assessed via the Shapiro-Wilk test, employing transformations when necessary. Pearson correlations were computed between estimated throw distance (TD_{est}) and strength and power measures. In unilateral tests, both lower body sides and the throwing arm side for the upper body are reported. R (version 4.3.1, https://www.R-project.org/) was used for statistical analyses, with significance at $p \leq 0.05$.

RESULTS AND DISCUSSION: Males demonstrated associations between some lower body power measures and throwing performance (Table 1), while females showed associations between upper and lower body maximal strength and throwing performance (Table 2), suggesting sex-specific differences in important physical characteristics for throwing. In males, these findings align with a study in high level pitchers (Wong et al. 2023) which reported correlations between lower body power assessed by vertical jumps and baseball pitch velocity. The absence of a correlation between upper body maximal strength measures and throwing performance in males, previously observed in adolescent and collegiate baseball players (Clements et al., 2001; Cross et al., 2022), could be explained by potentially higher performance levels. In females, the results align with studies on amateur handball players that showed correlations between maximal upper body strength and throwing velocity (Granados et al. 2007, 2013). Speculatively, female throwers in this study may not have reached the same elite performance level as males, given that those studies (Granados et al. 2007, 2013) found associations between lower and upper body power and throwing performance in elite athletes.

Table 1. Variables with significant correlations in males and their descriptive values.

Test	Variable	n	Mean ± SD	R with TD_{est} [95% CI]	P
BLDRJ40	Jump height	13	35.22 ± 5.48 cm	.61 [.09 to .87]	.026
	P_{avg} propulsive	13	4629 ± 655 W	.56 [.01 to .85]	.047
ULDEJ20, NTAS	Jump height	12	20.91 ± 4.82 cm	.59 [.02 to .87]	.045
	P_{avg} braking	12	-1726 ± 275 W	-.68 [-.90 to -.17]	.015
			-17.78 ± 2.93 W/kg	-.65 [-.89 to -.11]	.023
	RSI	12	0.47 ± 0.16 m/s	.59 [.03 to .87]	.042
	Vertical stiffness	12	0.000060 ± 0.000019 N/m*	-.62 [-.88 to -.07]	.033
ULDEJ20, TAS	Vertical stiffness	12	17.1 ± 6.5 kN/m	.61 [.06 to .88]	.035
ULDRJ20, NTAS	P_{avg} braking	13	-2023 ± 359 W	-.71 [-.91 to -.27]	.006
			-21.28 ± 3.98 W/kg	-.64 [-.88 to -.13]	.019
	Peak landing force	13	401 ± 41 %BM	.59 [.05 to .86]	.036

SD standard deviation, CI confidence interval, TAS throwing arm side, NTAS non-throwing arm side, P_{avg} average power, P_{peak} peak power, BM body mass, TAS throwing arm side, NTAS non-throwing arm side, BLDRJ bilateral drop jump, ULDEJ unilateral depth jump, ULDRJ unilateral drop jump, * inverse transformation employed (original 15.4 ± 5.7 kN/m)

Table 2. Variables with significant correlations in females and their descriptive values.

Test	n	Mean ± SD	R with TD_{est} [95% CI]	P
Ankle plantarflexion torque, NTAS	13	180 ± 43 Nm	.73 [.31 to .91]	.004
		2.25 ± 0.56 Nm/kg	.68 [.21 to .90]	.010
Ankle plantarflexion torque, TAS	13	185 ± 47 Nm	.58 [.04 to .86]	.040
Hip abduction torque, NTAS	13	143 ± 31 Nm	.63 [.12 to .88]	.022
		1.78 ± 0.35 Nm/kg	.67 [.20 to .89]	.012
Hip abduction torque, TAS	13	139 ± 36 Nm	.64 [.14 to .88]	.018
		1.73 ± 0.43 Nm/kg	.65 [.15 to .88]	.016
Grip strength, TAS	13	433 ± 60 N	.56 [.02 to .85]	.045
Shoulder internal rotation torque, TAS	13	50 ± 11 Nm	.64 [.14 to .88]	.019
		0.63 ± 0.14 Nm/kg	.61 [.09 to .87]	.026

SD standard deviation, CI confidence interval, TAS throwing arm side, NTAS non-throwing arm side

Several factors may contribute to the observed differences. Despite similar body mass-normalized strength between females and males, females may exhibit lower rates of force development (Häkkinen, 1991). Implements with different weight may also require distinct optimal techniques between sexes and, consequently, different strength and power. In particular, body segment timing patterns have been reported to vary between sexes among high level javelin throwers (Liu et al., 2014) and with varying ball weights in handball throwing (van den Tillaar & Ettema, 2011).

This study has limitations. The throw distance estimation assumes the javelin as a point-like object, potentially affecting accuracy. However, considering release angle and height provides a more realistic estimate of throwing performance compared to focusing solely on release velocity (Bartlett et al., 1996; Hubbard & Alaways, 1987; Komi & Mero, 1985). Additionally, data were collected from February to March, when some participants had done few high-intensity throwing sessions, potentially affecting their preparedness.

CONCLUSION: Coaches and strength and conditioning practitioners should be aware of the distinct most important force production characteristics in male and female javelin throwers. Our results suggest that throwing performance is generally correlated with lower body power variables in males, and with maximal strength in females. It is also worth considering whether the difference in javelin weight contributes to the strength and power requirements between sexes.

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