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Original Article

Rate of force development, lean body mass and throwing performance in female shot-put athletes

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Abstract:

Aim of the study was to investigate the relationship between lower body rate of force development and lean body mass, with competitive shot-put throwing performance in female shot-putters using the linear style. Seven female shot-put athletes (age: 24.4 ± 4.2yrs, body height: 172.8 ± 5.2cm, body mass: 93.3 ± 10.5kg, 4.4 ± 2.0 years of competition experience), who qualified for the final of the shot-put event of the national indoor championship, participated in the study. Three days after the national event, they visited the laboratory to perform maximal isometric leg press for the measurement of the rate of force development (RFD), and maximal countermovement jumps (CMJ), while body composition (dual x-ray absorptiometry) was also evaluated. Shot-put performance was recorded from the official results during the national event. Close correlations were found between shot-put performance during competition and RFD between 100-250ms, maximum leg press isometric force, and CMJ power (r: 0.766 - 0.913, $p < 0.05$). Close correlations were also found between shot-put performance and total (r: 0.932, $p < 0.005$) and trunk (r: 0.885, $p < 0.005$) lean body mass (LBM). Lower extremities' LBM was correlated with CMJ max power and RFD between 0-250ms from the onset of muscle contraction (r: 0.834 - 0.905, $p < 0.05$). These results suggest that monitoring leg press rate of force development, lean body mass and countermovement jumping power may provide important information about performance in female shot-putters who compete with the lineal style.

Key words: Power performance, track and field throws, body composition, female athletes.

Introduction

Shot-put is an explosive track and field event (Zatsiorsky et al., 1981). The delivery phase and the final thrust of the shot-put throw, which contributes mostly to the throwing performance, may be developed between 180-250ms after assuming the power position (Zatsiorsky et al., 1981). Consequently, an increased rate of force development (RFD), i.e. the force/torque-time curve during an explosive muscle contraction (Aagaard et al. 2002; Maffiuletti et al., 2016), may be of great importance for shot-put performance as revealed in other power-demanding activities (Bogdanis et al., *in print*; Cross et al., 2016; Maffiuletti et al., 2010; Methenitis et al., 2016a; Zaras et al., 2016). Previous data in young track and field throwers indicated that lower extremities' RFD during a multi-joint exercise such as the leg press, is related with performance in standard throwing exercises (Zaras et al., 2016). In addition, training-induced increases in RFD are associated with increases in track and field throwing performance (Zaras et al., 2014; Zaras et al., 2016). However, there is no direct evidence for a link between competitive shot-put performance and RFD in shot-putters.

RFD after the initial 100msec of an explosive muscle contraction, seems to be at least partly affected by the lean body mass (LBM, Maffiuletti et al. 2016). LBM has been shown to be moderately associated with shot-put performance (Kyriazis et al. 2010). Although data for the LBM of female shot-putters are lacking, it is generally accepted that females have lower lean body mass compared to males. However, there is no scientific evidence for a possible link between RFD, LBM and performance in female shot putters. Both RFD and lean body mass can be readily and non-invasively evaluated. Therefore, their possible link with competitive performance might provide important information to the coach and athlete about the effectiveness of the chronic training intervention. However, to our knowledge, there is no evidence to support a relationship between RFD, LBM, and competitive performance in female shot-put athletes.

Lower body power production during the countermovement jump (CMJ), a field or laboratory test wildly used to assess explosive performance, has been shown to correlate well with performance in male shot-putters (Kyriazis et al. 2009). However, it remains unknown whether CMJ performance is linked to shot-put competitive performance in female shot-putters, the latter having lower competitive performance and

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presumably lower lean body mass compared to male shot-put athletes. Therefore, the purpose of the present study was to investigate the relationship between RFD, LBM, and CMJ performance with the linear style shot-put throwing performance achieved during competition in female shot-putters. It was hypothesized that RFD, LBM, and CMJ performance would be at least partly associated with competitive shot-put performance in female shot-putters.

Material And Methods

Participants

Seven female shot-put athletes (age: 24.4 ± 4.2yrs, body height: 172.8 ± 5.2cm, body mass: 93.3 ± 10.5kg, 4.4 ± 2 years of competition experience), who qualified for the final of the shot-put event of the national indoors championship, participated in the present study. They ranked between the first and the ninth place during this shot-put event. All procedures were in accordance with the Declaration of Helsinki and approved by the local university ethics committee, while all participants signed an informed consent before entering in the research procedure.

Experimental Design And Procedures

This was a correlational study. After performing two familiarization sessions on two different occasions separated by one week, seven female shot-putters performed CMJs and isometric leg press, three days after the national indoor track and field championship. Body composition analysis was performed with dual x-ray absorptiometry 5 days after the competition. Shot-put performance was recorded from the official results of the national event.

Measures

Countermovement jumping

Athletes started with 5 min warm-up on a stationary bicycle with 50 Watt and then performed 3 countermovement jumps (CMJs) with submaximal intensity. Subsequently, they performed 3 maximal CMJs jumps with 2 min rest between each jump, on a force platform as previously described (Methenitis et al., 2016a; Methenitis et al., 2016b, Zaras et al., 2014, Zaras et al., 2016). The signal was filtered using a secondary low-pass Butterworth filter with a cutoff frequency of 20 Hz. Data from the force platform were recorded to calculate the jump height and the maximum Power (10, 14). The best jumping height attempt was used for further analysis. The ICCs for jump height and power were 0.87, (95% CI: Lower = 0.83, Upper = 0.95) and 0.91 (95% CI: Lower = 0.90, Upper = 0.99), respectively, n = 13 (Zaras et al., 2014).

Isometric Force and Rate of Force Development

Ten minutes after the CMJs, participants seated on a custom-made steel leg press chair and placed both their feet on the force platform (Applied Measurements Ltd Co. UK, WP800, 1000kg weighting platform, 80x80 cm, sampling frequency 1000 Hz) which was positioned perpendicular on a concrete laboratory wall. Knee angle was set at 120° and hip angle was set at 100º (Marcora and Miller, 2000; Methenitis et al., 2016a; Terzis et al., 2016; Zaras et al., 2016). Athletes were instructed to apply their maximum force as fast as possible for 3 seconds. Three maximum trials were performed with 2 minutes interval. Athletes were vocally encouraged to perform their best. Variables calculated from the force-time curve included the maximum isometric force (MIF) and RFD as previously described (Aagaard et al., 2002; Methenitis et al., 2016a, Methenitis et al., 2016b; Terzis et al., 2016, Zaras et al., 2014; Zaras et al., 2016). RFD was calculated according to the following equation: RFD ($N\cdot s^{-1}$) = $\Delta Force \cdot \Delta Time^{-1}$ (Aagaard et al., 2002; Methenitis et al., 2016a, Methenitis et al., 2016b; Terzis et al., 2016, Zaras et al., 2014; Zaras et al., 2016). The best performance, between the three efforts of each participant, was determined according to the RFD performance at 150ms, and this curve was further used in statistics (Methenitis et al, 2016a; Zaras et al., 2016). The selection of the 150ms RFD performance was used according to a previous study on male throwers, reporting the highest correlations between throwing performance and RFD (30). The ICC for MIF and RFD were: ICC = 0.90, (95% CI: Lower = 0.86, Upper = 0.96) and ICC = 0.92, (95% CI: Lower = 0.80, Upper = 0.98), n=13 (Zaras et al., 2014).

Body Composition

A total body scan was performed with dual energy x-ray absorptiometry (DPX-L; LUNAR Radiation, Madison, WI, USA). All measurements were analysed using the LUNAR radiation body composition program, as previously described (Methenitis et al., 2016c, Zaras et al., 2016). Fat mass and lean body mass (LBM) were determined for the total body as well as for the lower extremities. ICC for lower extremities LBM = 0.98, (95% CI: Lower = 0.95, Upper = 0.99), total LBM = 0.93, (95% CI: Lower = 0.89, Upper = 0.97), total % fat 0.90, (95% CI: Lower = 0.85, Upper = 0.96) and lower extremities % fat= 0.94, (95% CI: Lower = 0.88, Upper = 0.98), $p < 0.0001$; n = 13 (Zaras et al., 2014).

Statistical Analysis

Descriptive statistics are presented as means and standard deviation (± SD). Pearson's product moment correlation coefficient was used to explore correlations between variables. The interpretation of the observed correlations was performed according to Hopkins' ranking: correlation coefficients between 0.3 - 0.5 were considered moderate, between 0.51 - 0.70 large, between 0.71 - 0.90 very large, and > 0.91 almost perfect (Kyriazis et al., 2009). Statistical analyses were performed with SPSS Statistics Ver. 20 (IBM Corporation, Chicago, IL, USA). Two-tails significance was accepted at $P \leq 0.05$.

Results

The average shot-put performance during the finals of the national championship event was 13.90 ± 1.96 m. Total, lower extremities', upper extremities', and trunk lean body mass were 55.87 ± 3.84 kg, 20.70 ± 1.12 kg, 7.43 ± 1.20 kg and 25.08 ± 2.71 kg, respectively. CMJ height, max power, and max power per kg of body mass were 0.29 ± 0.01 m, 1105 ± 161 W and 11.89 ± 0.88 W·kg body weight^{-1}, respectively. RFD at 50ms from the onset of muscle contraction was 8351 ± 4949 N·s^{-1}, while at 100ms it was 11890 ± 5647 N·s^{-1}, at 150 ms 11077 ± 4464 N·s^{-1}, at 200ms 9960 ± 3566 N·s^{-1} and at 250ms it was 9004 ± 2810 N·s^{-1}. Finally, maximum leg press isometric force was 3403 ± 639 N.

Very large to almost perfect correlations (characterized according to Hopkins' ranking, 8) were found between shot-put performance and total (r: 0.932, p <0.005) and trunk (r: 0.885, p <0.005) lean body mass. In contrast, shot-put performance was not correlated with lower or upper extremities' lean body mass. Very large to almost perfect correlations were found between shot-put performance and CMJ max and relative max power, maximum leg press isometric force and RFD between 100-250ms (r: 0.766 - 0.913, p <0.05, Table 1, Figure 1). Total lean body mass was correlated with CMJ height, max power and relative max power (r: 0.781 - 0.897, p <0.05), as well as with RFD performance at 200ms and 250ms (r: 0.792 – 0.853, p <0.05). Lean body mass of the lower extremities was correlated with CMJ max power and RFD between 0-250ms (r: 0.834 - 0.905, p <0.05).

Table 1. Correlation coefficients between competitive shot-put performance, countermovement jumping, leg press maximum isometric force and leg press rate of force development, and lean body mass, in seven female shot-putters of national level (only significant correlations are presented).

	Countermovement jump		Leg press	Leg press rate of force development			
	Power	Power·kg-1	Isometric force	100ms	150ms	200ms	250ms
Shot-put	0.834	0.808	0.766	0.767	0.832	0.877	0.913
LBM leg	0.833			0.895	0.885	0.871	0.856

LBM leg = Lean body mass of the lower extremities, all correlations were significant at p < 0.05.

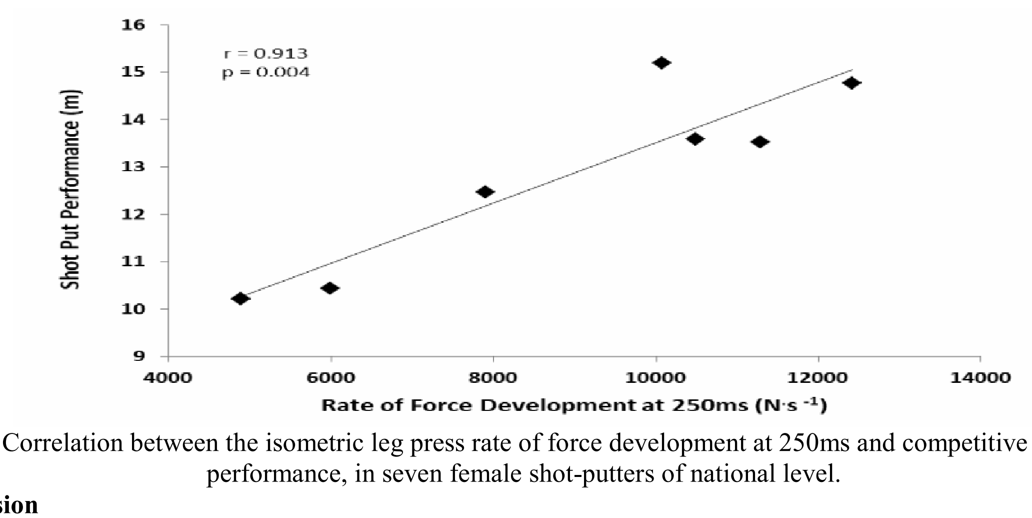

Fig. 1. Correlation between the isometric leg press rate of force development at 250ms and competitive shot-put performance, in seven female shot-putters of national level.

Discussion

The main finding of the present study was that RFD of the lower extremities was closely correlated with the linear shot-put performance during competition in female shot-put throwers. RFD may be readily evaluated in the laboratory, thus providing valuable information for the coach and athlete about the training outcome. Although RFD is frequently used to characterize explosive power performance (Maffiuletti et al., 2010), there is only scarce data regarding its relationship with track and field throwing performance. The present study, for the first time indicates a direct link between leg press RFD and shot-put performance in female shot-putters. According to the present results, leg press RFD may explain about 50% to 80% of the shot-put performance during an official throwing event. Specifically, it seems that the RFD at 250ms after the initiation of the explosive leg press contraction may be of importance linking this laboratory test performance with field shot-put performance. Interestingly, this time-frame coincides with the time to complete the final thrust during the shot-put (Zatsiorsky et al., 1981).

Previous studies reported significant correlations between leg press RFD at 50-250ms, and performance in various field throwing tests, however not with competitive track and field throwing performance (Zaras et al., 2014; Zaras et al., 2016). In a another previous study it was reported that midthigh pull RFD and shot-put performance were not correlated after 8 weeks of strength and power training (Stone et al., 2003). The kinesiological nature of the midthigh pull differs from that of shot-put since the upper extremities are actually pulling (in midthigh pull) and not pushing the external resistance (shot put). This may partly explain the lack of correlation between RFD and shot performance in the earlier study (Stone et al., 2003). In contrast, both in the present study, as well as in a previous report (Zaras et al., 2016), isometric leg press exercise was used, where the lower-body musculature is recruited in a biomechanically similar manner as the final thrust during the shot-put (Kyriazis et al., 2009; Peng and Huang, 2006; Zatsiorsky et al., 1981). Therefore, the current data suggest that leg press RFD, especially at the 250ms, may be a useful tool to assess performance in female shot-put throwers competing with the linear style. Nevertheless. it would be of interest to investigate this relationship in experienced shot-putters using the rotational style which is even more explosive after taking the final thrusting position (Coh et al., 2005). The present data also reinforces previous reports about the significant relationship among muscle power, lean body mass and throwing performance (Kyriazis et al., 2009, Methenitis et al., 2016c; Terzis et al., 2003; Terzis et al., 2012; Terzis et al., 2008; Zaras et al., 2016). Both increased CMJ power and total lean body mass is important for elite linear shot-put performance (Methenitis et al., 2016; Terzis et al., 2003; Terzis et al., 2008; Zaras et al., 2016). Lean body mass is closely associated with maximum muscular strength and power, which also seem to correlate with linear shot-put performance (Morrow et al., 1982; Terzis et al., 2007).

An unexpected finding of the present study was the absence of a relationship between lean body mass of the lower extremities and shot-put performance. It is generally accepted that lower extremities are of substantial importance for shot-put performance with several studies reporting significant correlations between legs' LBM and shot-put performance (Kyriazis et al., 2009; Methenitis et al., 2016a, Peng and Huang, 2006; Terzis et al., 2007; Zaras et al., 2016; Zatsiorsky et al., 1981). However, most of these studies included male athletes. The muscle mass distribution may differ between male and female individuals and this might have influenced the current results in female athletes. Future studies should address this interesting and important issue.

The high correlation coefficients found in the current study may have been influenced by the large range of performance abilities of the participating athletes (see Figure 1). The current data suggest that a high level of leg press RFD may predict a high level of competitive shot-put performance in female athletes. However, this notion needs further verification with more participants having a smaller range of shot put performance. Moreover, it should not escape the reader's attention that competitive shot-put performance depends on several factors other than RFD and lean body mass, such as technique and psychological determinants. Concurrent evaluation of these factors may provide a better insight into shot-put performance.

In conclusion, the current data indicate that leg press rate of force development is linked with shot-put performance during competition in female throwers using the linear style. Close correlations were also found between shot-put performance and total and trunk lean body mass. Therefore, regular monitoring of the lower body rate of force development and lean body mass may provide important information about performance in female shot-putters competing with the lineal style.

Conclusions

According to the current results it may be proposed that for higher linear shot-put performance, coaches should aim to increase the lower body rate of force development and total lean body mass in female shot-put throwers. In addition, evaluation of the leg press rate of force development might be a useful tool for monitoring the training induced changes in throwing performance and perhaps prediction of shot-put performance. Regular evaluation of leg press rate of force development may be preferred in contrast to other evaluations of muscle strength and power.

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