Rate of force development, muscle architecture and performance in young competitive track and field throwers

ABSTRACT

The rate of force development (RFD) is an essential component for performance in explosive activities, while it has been proposed that muscle architectural characteristics might be linked with RFD and power performance. The purpose of the study was to investigate the relationship between RFD, muscle architecture and performance in young track and field throwers. Twelve young track and field throwers completed 10 weeks of periodized training. Before (T1) and after (T2) training performance was evaluated in competitive track and field throws, commonly used shot put tests, isometric leg press RFD, 1-RM strength as well as vastus lateralis (VL) architecture and body composition. Performance in competitive track and field throwing and the shot put test from the power position increased by 6.76±4.31%, ($p<0.001$), and 3.58±4.97%, ($p=0.019$), respectively. RFD and 1-RM strength also increased ($p<0.05$). VL thickness and fascicle length increased by 5.95±7.13% ($p=0.012$), and 13.41±16.15% ($p=0.016$), respectively. Significant correlations were found at T1 and T2, between performance in the shot put tests and both RFD and fascicle length ($p<0.05$). Close correlations were found between RFD, muscle thickness and fascicle length ($p<0.05$). Significant correlations were found between the % changes in lean body mass and the % increases in RFD. When calculated together the % increase in muscle thickness and RFD could predict the % increase in shot put throw test from the power position ($p=0.019$). These results suggest that leg press RFD may predict performance in shot put tests which are commonly used by track and field throwers.

Keywords: resistance training, shot put, force-time curve, muscle thickness, fascicle length

INTRODUCTION

Track and field throwing events are explosive activities with complex technical characteristics requiring rapid force production. The delivery phase and the final thrust of the throw are powerful movements with short duration roughly 150-240ms (4, 5, 18, 35). Therefore, the ability to produce large amounts of force rapidly, i.e. the rate of force development (RFD), should be essential for throwing performance. Strength and power are directly related to RFD, at least in strength trained individuals (19, 22, 23). However, data regarding the relationship among these variables in track and field throwers are rare (28). Stone et al. (28), showed that midthigh pull RFD increased after 8 weeks of training by 19.6% while no significant correlation was found with shot put throwing performance or with any other strength and power variables in collegiate throwers. To the best of our knowledge no other investigation has examined the relationship between the RFD and the performance in track and field throwing events.

Muscle strength and power are influenced by a number of neuromuscular and morphological characteristics including muscle thickness, fascicle angle and fascicle length (1, 7, 11, 29). Previous studies revealed that heavy resistance and power training may alter muscle architectural characteristics. For instance, periodized resistance training induces increases in muscle thickness, fascicle angle and length in well trained athletes (6, 27). Track and field throwers spend a large part of their preparation using resistance training programs in order to increase strength and power, however, the effect of these training routines on their muscle architectural characteristics and RFD has not been addressed yet. Moreover, it has been suggested that fascicle length may influence the RFD. Data from Edman & Josephson, (15), suggests that longer fibers tend to produce force slower than shorter fibers in the early force production (< 30ms) in frog muscles, perhaps because longer fascicles need longer time to stretch the intramuscular series elastic elements. Blazevich et al., (10), found that after 5 weeks of strength training, subjects with initially longer fascicles had the least improvement or even a reduction in force in the first few milliseconds of force production. Earp et al., (14), showed a positive relationship between RFD (10-30ms) and gastrocnemius fascicle length in drop jumps and a negative relationship (0-10ms) in countermovement jumps. Thus, it remains debated whether fascicle length and RFD are related, especially later in the force-time curve, at 100-250ms, which is more relevant in sports and especially in track and field throwing events.

The purpose of the present study was to investigate the relationship between RFD, muscle architecture and throwing performance and the potential changes in these relationships after long term periodized training in a group of young competitive track and field throwers.

METHODS

Experimental Approach to the Problem

The relationship between the RFD, muscle architecture and track and field throwing performance remains largely unclear. The correlation among these variables was evaluated in twelve young competitive throwers (6 males and 6 females). Because systematic exercise training induces significant neuromuscular adaptations, the relationship between the aforementioned variables was evaluated at two different time-points during the athletic year round training: before (T1) and after (T2) 10-wk of periodized training aiming at the summer national track and field competition period. Training was designed according to the principles of periodization and was separated into two 5-wk mesocycles aiming to enhance maximum strength and strength-power, respectively. Changes in performance were statistically compared with ANOVA for repeated measures. The relationships between variables were determined using Pearson's product moment correlation.

Athletes

Six male (21.3 ± 7.5 years, 1.78 ± 0.07 m, 90.4 ± 20.8 kg) and 6 female (18.0 ± 2.8 years, 1.66 ± 0.06 cm, 73.7 ± 17.5 kg) young throwers gave their written consent to participate in the study after being informed about the experimental procedures. Written parental consent was also obtained in participants under 18 years of age. Five of the participants were discus throwers (3 males, 2 females), 4 hammer throwers (2 males, 2 females), 2 shot put throwers (1 male, 1 female) and 1 javelin thrower (1 female). Ten of the participants were officially qualified for the national championship and their performance was among the top 15 of the nation. All throwers were in good health and received no medication or nutritional supplements during the training period. All procedures were performed in accordance with the principles outlined in the Declaration of Helsinki and were approved by the local ethics committee.

Procedures

Training

Before the initiation of the 10-wk summer training period related to the present study, all athletes completed 15 weeks of winter preparation aiming to increase performance for the winter competition. That winter training program was similar to the 10-wk program used in this study (Table 1), but it was 5 weeks longer due to the preceded summer transition phase. By the end of the winter phase, all athletes participated in a winter competition with throwers from other track and field clubs. Two weeks transition phase followed and then athletes were trained as described in Table 1, aiming for the summer national event. Training was designed into two, five wk mesocycles according to the principles of periodization (17, 33). During the first mesocycle hypertrophy and maximum strength were the main targets of resistance training while during the second mesocycle maximum strength and power development were the main targets. The acute training variables are presented in Table 1. The training program was designed to each individual needs according to the demands of the throwing event of each athlete. About 5% of all the planned training sessions were not completed due to small injuries. All efforts were performed with maximum possible movement velocity especially during the second mesocycle when strength-power was developed. Training also included plyometrics with various jumping bounds, agility exercises and short-distance sprinting with maximum velocity.

Track and Field throws

Shot put, javelin, hammer and discus throwing performance was measured outdoors (each athlete performed his/her own specialty) following the official rules of the International Amateur Athletics Federation. Ambient temperature was always 20-24°C while weather was calm and sunny during all throwing measurements. Briefly, after a short warm up (jogging, stretching, 2-4 near maximum-effort throws) athletes performed 6 throws with maximum effort (13). After each attempt, technical feedback was provided by a certified coach. The best throwing performance was used in further analysis.

Shot put tests

The next day, all athletes performed three different shot put tests: a) the backward overhead shot throw, b) the front shot put throw and c) the shot put throw from the power position (12, 16). All athletes were very well familiar with these shot put tests as they all used them regularly during training over the years. Athletes performed 4 attempts of each test with maximum effort with 2 minutes rest between each attempt. The best performance for each test was used in statistical analysis. The intra-class correlations (ICC) for the shot put tests were: backward overhead shot throw ICC = 0.98 (95% CI: Lower = 0.92, Upper = 0.99, n = 13), front shot put throw ICC = 0.93 (95% CI: Lower = 0.80, Upper = 0.99, n = 13), and shot put throw from the power position ICC = 0.94 (95% CI: Lower = 0.83, Upper = 0.98, n = 13).

[Table 1, About Here]

Rate of Force Development

All athletes performed at least 3 familiarization sessions with multiple submaximal and maximal isometric leg press efforts in the laboratory set up used for testing, during the month before the initial measurements (T1). The day after the shot throw tests, athletes came to the laboratory for the assessment of maximum isometric force and rate of force development during leg press. Throwers were seated on a custom made steel leg press chair and placed both their feet on the force platform (Applied Measurements Ltd Co. UK, WP800, 1000 kg weighting platform, 80 x 80 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 (25, 34). Athletes were instructed to apply their maximum force as fast as possible for 3 seconds. Two maximum trials were performed with 3 minutes interval. Throwers were vocally encouraged to perform their best effort during the measurement. Data from the force platform were recorded (Kyowa sensor interface PCD- 320A) and analyzed. The signal was filtered using a secondary low pass Butterworth filter with a cutoff frequency of 20 Hz. Variables calculated from the force-time curve included the maximum isometric peak force (IPF), the rate of force development (RFD) and the impulse. Maximum isometric peak force was calculated as the greater force generated from the force-time curve. RFD was calculated as the mean tangential slope of the force-time curve in specific time windows of 0-50, 0-100, 0-150, 0-200, and 0-250ms (RFD = ΔForce / ΔTime). These time intervals were chosen because of the potential relationship to force production during throwing (5, 35). Impulse was calculated as the area under the force-time curve which represents the total force-time integral in a given time period [$Impulse_{0\text{-}k} = \Sigma F_{0\text{-}k} * \Delta Time_k$, (k = 50, 100, 150, 200, 250ms)] (2, 34). The best performance according to overall RFD was used for statistical analysis. The ICC for the isometric peak force, the RFD (overall) and the impulse were: ICC = 0.90, (95% CI: Lower = 0.86, Upper = 0.96), ICC = 0.92, (95% CI: Lower = 0.80, Upper = 0.98) and ICC = 0.93, (95% CI: Lower = 0.85, Upper = 0.98), respectively (n = 13).

1-RM Strength Test

Thirty minutes after the isometric RFD leg press test, throwers performed the 1-RM strength test on a 45^o incline leg press machine. After a 5-min warm-up on a stationary bicycle and static stretching exercises, athletes performed incremental efforts until they were unable to lift a heavier load. Ten repetitions with moderate resistance were performed in the first warm up set, and 3-5 repetitions in the next two sets with approximately 10% load increment in each of these sets. Then single-repetition sets were performed with 2.5-5% load increments until athletes were unable to lift a heavier load (6-7 multiple-repetition and single-repetition sets in total). Three minutes of rest was allowed between sets. In all cases two of the researchers were present and vocally encourage all throwers. The ICC for 1-RM leg press strength test was ICC = 0.98, (95% CI: Lower = 0.94, Upper = 0.99), n=13.

The following day athletes reported to the gym in order to perform 1-RM strength tests for the hang power clean and the back squat. All measurements were performed on a weightlifting plateau using an Olympic bar. Athletes were familiar with Olympic style weight lifts since they used them regularly during training over the years. After a short warm up (5-min running and static stretching exercises) athletes begun the testing session with the hang power clean. Three warm up sets of 8, 4 and 2 repetitions with 50%, 75% and 90% of 1-RM, respectively, were given to the athletes. Then 3 trials were given until the athletes were unable to lift the bar. The hang power clean was initiated from the standing position with the athlete holding the bar using hand straps. The movement begun by lowering the bar to midthigh above the knees and then lifted the bar explosively upward with the effort to place the bar on the shoulders with a quarter squat position (21). In addition, back squat was initiated from the standing position with the bar placed on the trapezoids and the shoulders. Then, the athlete begun to bend the knees and squat until the deepest point of the movement was reached. From this position the athlete lifted the bar upward to the starting position. At all times, two researchers were present to evaluate the technique of the lifts and vocally encourage the athletes. The ICC for 1-RM hang power clean and back squat tests in our laboratory are ICC = 0.97, (95% CI: Lower = 0.77, Upper = 0.94), and ICC = 0.96, (95% CI: Lower = 0.81, Upper = 0.94), respectively, n=13.

Ultrasonography

On a separate day, B-mode ultrasound images (6.5 MHz, MicroMaxx Ultrasound System, Sonosite, Bothel, USA) were recorded from the right vastus lateralis (VL) using a 45-mm linear probe in order to determine its architectural characteristics. Throwers laid supine with their knees fully extended and their muscles relaxed. Sonographs were taken in the middle of the muscle at 50% of the distance from the central palpable point of the greater trochanter to the lateral condyle of the femur (8). A water-soluble gel was applied to the transducer to aid acoustic coupling. The transducer was placed longitudinal at femur oriented in parallel to the muscle fascicles and perpendicular to the skin. The transducer's alignment was considered appropriate when several fascicles could be easily outlined without interruption across the image (8). Images were analyzed for muscle thickness, fascicle angle and fascicle length with image analysis software (Motic Images Plus, 2.0). Muscle thickness was defined as the mean of the distances between the superficial and deep aponeurosis measured at the ends of each 45-mm wide sonograph, fascicle angle as the angle of insertion of muscle fascicles onto the deep aponeurosis, and fascicle length as the fascicular path between the insertions of the fascicle onto the upper and deeper aponeurosis. When the fascicle extended off the image, the length of the missing portion of the fascicle was estimated by linear extrapolation of both the fascicular path and the aponeurosis (9). The reliability for the measurement of muscle thickness [ICC = 0.976 (95% CI: Lower = 0.954, Upper = 0.988), p = 0.000], fascicle angle [ICC = 0.862 (95% CI: Lower = 0.746, Upper = 0.928), p = 0.000], and fascicle length [ICC = 0.834 (95% CI: Lower = 0.700, Upper = 0.911), p = 0.000] was determined on another occasion, on two consecutive days by the same investigator (n = 36).

Body Composition Analysis

After the ultrasound evaluation a total body scan was performed with Dual X-Ray Absorptiometry (model DPX-L; LUNAR Radiation, Madison, WI, USA) in order to evaluate lean body mass. All measurements were analyzed using the LUNAR radiation body composition program. Analysis include fat mass, bone mineral density (BMD) and lean body mass (LBM) for total body, arms, trunk and legs. The ICC for body composition analysis was determined from two different researchers ICC = 0.98, (95% CI: Lower = 0.95, Upper = 0.99), n = 13.

Statistical Analyses

All data are represented as mean ± SD. Analysis of variance for repeated measures was used to test differences between T1 and T2 in all raw data. Bonferroni confidence interval adjustment was used to compare the main effects between T1 and T2. Effect sizes were calculated using the eta-squared statistic while statistical power was also calculated to obtain the power of the test. Pearson's r product moment correlation coefficient was used to explore the relationships between performance in shot put tests and RFD, 1-RM strength, muscle architecture, and LBM. Performance in track and field throws was transformed into Z scores in order to examine possible correlations with the rest of the variables at T1 and T2. Standard multiple regression analysis was performed for the % change of variables between T1 and T2. Because of the small sample size (n = 12) adjusted R squared was used for the interpretation of the multiple regression analysis results (30). Within subject's variation and reliability was determined for all variables by calculating the confidence limits (CI 95%) and intra class correlation (ICC) coefficient as described before (20). Significance was accepted at $p \leq 0.05$. All statistical analyses were performed using SPSS version 17.0 software (SPSS inc. Chicago, IL, USA).

RESULTS

There were no statistically significant differences between male and female athletes in training-induced performance and morphological changes (e.g. for track and field throws: p = 0.565, and for muscle fascicle length: p = 0.498). Thus, data are presented as one group.

Training: Performance in track and field throws (hammer, discus, javelin and shot put) was increased from T1 to T2 by 6.76 ± 4.31 % (p = 0.000, $eta^2 = 0.705$, power = 0.996). Shot put test from the power position increased from T1 to T2 by 3.58 ± 4.97 % (p = 0.019, $eta^2 =$ 0.408), while no significant alternations were observed for the backward and the front shot put tests. In addition, 1-RM strength in leg press, hang power clean and back squat increased from T1 to T2 by 8.01 ± 6.01 % (p = 0.008, $eta^2 = 0.492$), 4.72 ± 5.28 % (p = 0.006, $eta^2 =$ 0.516), and 4.68 ± 2.98 % (p = 0.000, $eta^2 = 0.731$), respectively, (Table 2). Leg press isometric peak force (IPF) was also increased from T1 to T2 by 22.65 ± 20.12 % (p = 0.009, $eta^2 = 0.475$, Table 2).

[Table 2, Table 3 and Table 4, About Here]

Rate of force development and impulse were increased between T1 and T2 in all time frames (Figure 1 A, B, Table 2). Vastus lateralis thickness increased between T1 and T2 by 5.95 ± 7.13 % (from 2.57 ± 0.32 cm to 2.71 ± 0.29 cm, p = 0.049, $eta^2 = 0.452$, power = 0.783). Fascicle angle remained unaltered between T1 and T2 (from 19.05 ± 2.82º to 18.42 ± 1.85º, p = 0.531, $eta^2 = 0.037$, power = 0.091), while fascicle length was increased from T1 to T2 by 13.41 ± 16.15% (from 7.85 ± 0.89 cm to 8.84 ± 1.16 cm, p = 0.016, $eta^2 = 0.425$, power = 0.738). Total lean mass remained unaltered after training while legs lean mass tended to increased from T1 to T2 by 3.72 ± 5.75% (p = 0.057, $eta^2 = 0.347$, Table 2). No significant alternations were observed for arms and trunk lean mass or for fat and BMD.

[Table 5, About Here]

Correlations: Track and field throws (Z scores) were significant correlated with fascicle length only at T2 (r = 0.59, p < 0.05) and with 1-RM strength in clean at T1 and T2 (r = 0.61 and 0.59, respectively, p < 0.05). Performance in shot put tests was significantly correlated with 1-RM strength at T1 and T2 (Table 3). Furthermore, shot put tests and 1-RM together were significant correlated with RFD at both T1 and T2 in almost all RFD time frames (Table 4). Shot put tests and 1-RM strength were also correlated with muscle thickness and fascicle length (Table 5). In addition, shot put tests and 1-RM strength were correlated with lean body mass both at T1 and T2 (Table 5). Significant correlations were found between RFD and muscle thickness and fascicle length both at T1 and T2 (Table 6). Significant correlation was found between the % increase in VL thickness and % increase in shot put test from the power position (r = -0.607, p = 0.048). In accordance, strong correlations were found between the % change in lean body mass variables and % increase in isometric peak force, RFD and Impulse (Table 7).

[Figure 1 A, B, About Here]
[Table 6, About Here]

Multiple regression analysis: Standard multiple regression analysis revealed a significant regression model between the % increase in shot put test from the power position and the linear combination of the % increase in VL muscle thickness and the % increase in RFD50ms (adjusted R squared = 0.533, p = 0.019, Thickness Beta = -0.637, p = 0.019 and RFD50ms Beta = 0.509, p = 0.046). Interestingly, the linear combination of the % increase in VL fascicle length and the % increase in VL muscle thickness tended to explain 33% of the % increase in track and field throws (adjusted R squared = 0.338, p = 0.06, Length Beta = 0.703, p = 0.028, Thickness Beta = 0.511, p = 0.09). Also, the linear combination of the % increase in VL fascicle length and the % change in VL fascicle angle had the tendency to explain 33% of the % increase in track and field throws (adjusted R squared = 0.335, p = 0.06, Length Beta = 1.605, p = 0.034, Angle Beta = 1.206, p = 0.092).

[Table 7, About Here]

DISCUSSION

The main finding of the study was that shot put tests were significantly correlated with isometric leg press RFD in young track and field throwers both at the beginning and at the end of a 10-wk training period aiming to increase performance for the summer national competition. This close link was revealed in all RFD time frames starting from the first 50ms up to 250ms of the isometric leg press test. Shot put tests are explosive activities with simple technical characteristics requiring rapid force production especially of the lower limbs. These tests are commonly used by all track and field throwers regardless of their competitive event, while performance in these tests has been shown to correlate well with top level track and field throwing performance (31). The present data suggest that the rate of force production of the lower extremities may predict performance of a shot put test in experienced throwers, regardless of the training period. Nevertheless, no significant correlation was observed between the % change in any of the shot put tests and the % increase in RFD after the 10 week training period. This might be due to the fact that the participants were competing in different track and field throwing events, with small but important differences in performance demands and training stimuli. These differences are expected to induce different training adaptations. For example, athletes competing in javelin throw use lower absolute loads and higher movement velocities in training compared to athletes competing in hammer throw. Moreover, there is a different use of the upper body during training in these different throwing events. These training differences might have induced different neuromuscular adaptations leading to an uncoupling between changes in performance and RFD.

Besides muscular power, performance in track and field throws depends also on technical and psychological characteristics of each athlete. Thus, it is expected that the RFD and muscle architecture may only partly predict performance in track and field throws. Interestingly, only when track and field throws was calculated as Z scores, it was significantly correlated with vastus lateralis fascicle length, especially at T2. Likewise, the % increase in track and field throws between T1 and T2 was not correlated with the % changes either in muscle architecture or 1-RM strength and RFD. Nevertheless, the linear combination of the % increase in fascicle length with the % increase in muscle thickness could explain approximately 34% of the variation of the % increase in track and field throws (p = 0.06). Also, the linear combination of the % increase in fascicle length with the % change in fascicle angle could explain approximately 33% of the variation of the % increase in track and field throws ($p = 0.06$). These results should be interpreted with caution due to the small sample size and the lack of statistical significance in training induced fascicle angle increase.

Although RFD is thought to be a major contributor to power performance, there is only scarce data regarding its relationship with track and field throwing performance. Stone et al., (28), showed that after 8 weeks of strength and power training no significant correlation was observed between midthigh pulls RFD and shot put throwing or 1-RM strength. In the present study, a close relationship was found between shot put testing from the power position and isometric leg press RFD while strong relationships were also observed with 1-RM strength. Close correlations were also found between leg press RFD and the backward shot put throw test as well as the front shot put throw test. We can speculate that the discrepancy between the two studies might be due to the differences in the exercise used for the evaluation of RFD: both lower and upper leg muscles are recruited during isometric midthigh pulls while the upper body musculature is attempting to pull a mass from a low position which is biomechanically more similar to the hammer throw. Instead, the isometric leg press used here recruited only the lower musculature in a manner biomechanically similar to all four track and field throwing events. Our results are also in agreement with other studies showing that strength and power are directly related to RFD at least in strength trained individuals (19, 22, 23). The present data suggest that isometric leg press $RFD_{100-200}$ may be used to evaluate shot put testing performance in throwers regardless of the training period, and it is closely linked with strength and power capacity in young track and field throwers. Moreover, performance in shot put tests was significantly correlated with lean body mass, as shown before (26, 31), although the % changes in shot put tests and lean mass were not correlated. However, significant relationships were found between the % changes in lean body mass and RFD for the time frames 100-250ms. This suggests that lean body mass is important for rapid force development in young track and field throwers.

Vastus lateralis thickness increased significantly after training suggesting gains in muscle mass and strength. In concert, lower extremities' lean mass tended to increase after training ($p = 0.057$) while strength increased significantly in all performance tests. Performance in shot put tests was closely linked with vastus lateralis thickness while a strong relationship was found between the % increase in muscle thickness and shot put throw test from the power position, suggesting that gains in muscle mass may explain approximately 37 % of the variation in shot put test performance change after training. Fascicle length was also correlated with performance in shot put tests both pre and post training. Previous studies have also reported significant correlations between fascicle length and sprinting and jumping (3, 13, 24, 27). In the present study, the correlation coefficients between shot put tests and fascicle length were larger at T2 compared to T1 implying that increased fascicle length contribute to increases in muscle power and thus increases in performance during the shot put tests. Although attractive, the current results might be interpreted with caution since no other data exists regarding the relationship between throwing performance and muscle architecture.

Earp et al., (14), showed a positive relationship between RFD (10-30ms) and gastrocnemius fascicle length in drop jumps and a negative relationship (0-10ms) in countermovement jumps. However, most of the sports activities require the force application later in the force-time curve: 100-250ms. In particular, in track and field throws it has been calculated that the force application at the power position of all 4 Olympic events extends between 150-250ms (4, 18, 32, 35). The present results suggest that longer fascicle may produce higher power later in the isometric leg press force-time curve (e.g. 200ms). Nevertheless, no link was found between the % increase in isometric leg press RFD and vastus lateralis fascicle length due to the training intervention. The RFD may be altered due to a number of neuromuscular adaptations to resistance training such as the synchronization of neural activation or changes in muscle fiber types/area (2), thus blurring the connection between changes in RFD and fascicle length.

Data analysis revealed that the linear combination of % increase in RFD_{50} with % increase in vastus lateralis thickness may explain 53% of the variation of shot put throw test from the power position. This relationship shows a connection between RFD and muscle architecture with performance in shot put tests, as performed here. Thus, when the appropriate instruments are available to coaches, an increase in leg press RFD and gains in vastus lateralis thickness might predict increases in overall throwing performance as tested here with the shot put tests.

All of the performance measures as well as the RFD were significantly increased with training which underpins the effectiveness of the training program. Unfortunately, we were not able to evaluate possible neural or intramuscular training adaptations which would have provided a better insight of the performance results. Moreover, the number of athletes, their performance level and the fact that they were competing in different track and field throwing events might limit the generalization of the present data. Year-round data in elite athletes are needed in order to make certain conclusions about the relationship between RFD and throwing performance.

CONCLUSIONS

The present data suggest that performance in commonly used shot put tests is closely linked with isometric leg press RFD in young track and field throwers. In addition, leg press RFD appears to be an appropriate functional performance test for throwers since it is linked with muscle strength and power in throwers. Moreover, vastus lateralis fascicle length and thickness are related with shot put tests in young throwers.

RECOMMENDATIONS

The training stimulus as described in Table 1 induced significant increases in sports performance, strength, and the RFD, in young track and field throwers, thus it may be a useful training approach for track and field coaches. The present results also show a significant correlation between leg press RFD and muscle architecture with commonly used shot put tests which are used by all throwers in training and are well correlated with competitive throwing performance. It seems that positive changes in the RFD, muscle thickness and fascicle length would be linked with improvements in shot put throwing tests. Therefore, increases in performance in shot put tests may reveal increases in leg RFD which provide feedback about the effectiveness of the training stimulus. Alternatively, when the appropriate instruments are available to coaches, an increase in leg press RFD and gains in vastus lateralis thickness might predict increases in overall throwing performance, as tested here with the shot put tests. Additionally, training programs should focus on the development of rapid force production especially when approaching the competition period. Also, isometric leg press RFD at 100-250ms may be used as a simple laboratory test to monitor performance in track and field throws in young track and field throwers as well as to evaluate the athlete’s swiftness before a competition and/or after every training mesocycle. When ultrasound equipment is available, regular examination of muscle architecture characteristics might provide insights into training adaptation induced by strength/power training programs.