

Original Article

Muscular strength, neuromuscular activation and performance in discus throwers

GIORGOS KARAMPATOS¹, GERASIMOS TERZIS², GIORGOS GEORGIADIS³

^{1,2,3} *Athletics Laboratory, School of Physical Education and Sport Science, National and Kapodistrian University of Athens, Athens, GREECE*

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Abstract

The aim of the study was to investigate muscular strength and neuromuscular activation of the lower extremities during discus throwing. Six experienced, right-handed, discus throwers, performed three maximal attempts from the power position and three maximal attempts with the full rotational style. They also performed a maximum squat and incline bench press test. Electromyographic (EMG) signals were recorded from quadriceps and gastrocnemius of the right and the left lower extremities during all efforts. Average EMG signals (aEMG) during discus throwing were normalized relatively to the EMG signals measured during 1RM squat strength test. Discus throwing performance, was significantly correlated with 1RM in incline bench press ($r=0.96$, $p<0.01$) as well as with aEMG from right quadriceps, at the delivery phase ($r=0.81$, $p<0.05$). Discus throwing performance was significantly, negatively, correlated with the duration of the activation of quadriceps and gastrocnemius of right lower extremity ($r=-0.94$, $p<0.01$, and $r=-0.88$, $p<0.05$, respectively). These results suggest that discus throwing performance is strongly linked with absolute muscular strength during incline bench press but not with max squat strength. Furthermore, discus throwing performance seems to be strongly linked with an enhanced activation of the right quadriceps, as well as with a short activation of right quadriceps and gastrocnemius, during delivery.

Key words athletic throws, track and field, electromyography, muscular strength

Introduction

Discus throwing is an explosive track and field event which demands the production of high muscular power. Human muscle power is mainly determined by three biological attributes: muscle fiber type composition (namely fast twitch fibers), muscular strength, and neuromuscular activation during movement (Moritani 2003). Muscle fiber type composition in humans is thought to be determined, to a large part, by hereditary factors (Komi and Karlsson 1979), hence, it seems unlikely to be altered significantly with athletic training. Therefore, discus throwers aim to enhance the other two parameters, namely their muscular strength and neuromuscular activation, in order to increase their performance (besides improving their technical skills). Specifically, these athletes follow intense resistance training programs in order to increase their muscular strength/power as well as neuromuscular activation level (Häkkinen et al. 1985).

Maximal strength of the upper body, seems to play an important role for discus throwing. An earlier study revealed a close correlation between maximal strength in incline bench press and discus throwing performance in moderately trained throwers (Morrow et al. 1982). This close relationship might be a valuable tool for the discus throwing coach. Since there are only limited data on this issue, one of the aims of the present study was to corroborate this relationship. Furthermore, Morrow et al. (1982) found that maximal squat strength was not related significantly with discus throwing performance, although a significant part of the discus throwers' training preparation is devoted to lower body strength training. Thus, we also aimed to reexamine the relationship between the squat strength and discus throwing performance.

The third parameter which influences power production, is the level of muscular activation during the throwing action. Sports coaches have linked this biological parameter with the concept of specific strength, which can be defined as the strength produced by a certain muscle group during the actual sport performance (Terzis et al. 2007). Muscular activation during movement can be evaluated with the surface electromyography (EMG, De Luca 1997). In an earlier doctoral thesis (Finanger 1964, cited in Bartlett 1992), the electromyographic activity of various upper body muscles was recorded in discus throwers, although there was no attempt to correlate the amplitude of this activity with performance. In a similar study, Peng et al. (2005) compared the activation of various upper body muscles during discus throwing with different weights. In another recent study, Dinu et al. (2008) reported a similar pattern of activation of the upper body muscles when throwing a discus of 1.7kg or 2kg. However, the activation of the lower body muscles during discus throwing has not been investigated yet.

A recent study, revealed that in well-trained shot putters, the level of activation (EMG amplitude) of the right quadriceps and pectoralis muscles after taking the power position, was closely related with linear shot put performance (Terzis et al. 2007). Similar results were found more recently in experienced shot putters performing with the rotational style, both at the beginning of the training season as well as during the competition period (Kyriazis et al. 2009). However, it remains unknown whether this relationship applies also for the protagonist muscles during discus throwing. Furthermore, it is well accepted between the track and field coaches and specialists involved in throwing events, that the left leg (in right-handed discus throwers) plays an important role during the delivery phase of the throw (Silvester 2003). However, the activation pattern of the left lower extremity (namely the quadriceps and the gastrocnemius muscles) in right handed athletes during discus throwing has not been explored before.

The purpose of the present study was to investigate muscular strength and neuromuscular activation of the lower extremities during discus throwing, in skilled athletes. Based on previous studies we hypothesized that there would be a strong correlation between the activation of the right quadriceps during the delivery phase of discus throwing and performance.

Methods

Subjects

Six male discus throwers (age 24.5 ± 2 yrs, body height 190.6 ± 5 cm, body mass 113 ± 5 kg, right-hand dominance), gave their written consent to participate in the study, after being thoroughly informed about all procedures. All athletes had more than five years of specific discus-throwing training and competing experience. Each athlete was trained under the supervision of a different coach. Measurements were performed at the end of the winter preparation phase, three weeks before the first event of that specific year. All tests for each athlete were performed on a single day during the morning hours. Research design and procedures were approved by the ethics committee of the SPESS of the University of Athens.

Discus throwing performance and EMG recording

Discus throwing was performed outdoors on a standard circle. The ambient temperature was 22°C . After 30 min of individual warm-up, EMG bipolar electrodes (Ag/AgCl, center to center distance of 20 mm), were placed between the innervation zone and the distal tendon of quadriceps (vastus lateralis) and gastrocnemius (medial head) of the right and the left lower extremity, according to standard procedures (De Luca 1997). The choice of quadriceps and gastrocnemius was based on previously collected electromyography data during shot-putting revealing a high correlation between the activation level or timing of activation of these muscles with shot put performance (Terzis et al. 2007). Electromyography electrodes were connected with a pre-amplifier unit (set at $\times 1000$) of an MP100 acquisition system (BIOPAC Systems Inc., CA, USA) which was firmly strapped on the lower back of each subject. Raw EMG signals were A/D converted at 16-bit resolution and recorded (sampling frequency 1 kHz) in a Centris 660 Macintosh computer. Subjects performed three attempts from the power position followed by three attempts with the full rotational style. Three minutes rest was allowed between attempts. The best performance of each subject for each throwing style was used in further analysis.

Strength tests

Twenty minutes after discus throwing, the athletes performed the strength testing indoors. They warmed up for 15 minutes, with the EMG electrodes fixed on their bodies. They performed an 1RM squat test, as previously described (Beachle et al. 2000). Briefly, they started with a comfortable weight (approx. 60-70% of predicted 1RM). The weight was further increased (5 kg minimum increment each time) according to the subjects' wish, until he was unable to lift any more. All subjects attained their 1RM in 5-6 sets. Three minutes rest was allowed between each attempt. A wooden stool was placed behind the athlete at a position which allowed a knee angle of approximately 90° at the lowest squat position. This restriction was applied because during discus throwing, after assuming the power position, the knee angle never drops lower than 90° (kinematic analysis of the athletes participated in the study). EMG from quadriceps and gastrocnemius muscles, was recorded as described in the previous paragraph.

Ten minutes rest was allowed after the squat test. Subsequently, the 1RM incline bench press test was performed on a 25° incline bench using the same loading procedures as described for the squat test. After a short warm up (stretching and bench-pressing with light weights), subjects laid down on a bench so that the barbell was at the level of their nipples. The distance between the two palms was such that allowed a 90° elbow angle when the upper arms were parallel to the ground.

EMG analysis

Electromyographic signals were analyzed as previously described (Terzis et al. 2007). All EMG signals were low cut-off filtered (10Hz) and full wave rectified. For the analysis of the EMG amplitude during the discus throwing attempts, the signal was divided into 40 msec intervals, and the average value (aEMG) for each one of these intervals was calculated in mV (AcqKnowledge 3.5.2, BIOPAC Systems Inc., CA, USA). The highest value of the aEMG for each muscle contraction was used in further analysis.

Full wave rectified EMG signals during the strength tests were also divided into 40 msec intervals and the aEMG for these intervals was calculated. The highest of these aEMG values (in mV) was used in further analysis in order to normalize the aEMG values of the respective muscle which were recorded during discus throwing. In a recent study, it was reported that the time between the initiation of activation of different muscles was correlated with linear shot put performance (Terzis et al. 2007). Thus, in the present investigation we also analyzed the time between the initiation of activation of the right and left quadriceps and gastrocnemius muscles, after taking the power position in order to investigate whether these parameters were associated with discus throwing performance.

Statistics

Mean and standard deviation were used to describe each variable. Pearson's r product moment correlation coefficients were used to explore the linear relationships between different variables. The significance level was set at $p \leq 0.05$.

Results

Discus throwing and strength tests

Discus throwing performance from the power position was 42.77 ± 2.9 m, while discus throwing performance with full rotation was 49.64 ± 4.3 m. One RM squat strength was 252 ± 13 kg. Incline bench press 1RM strength was 127.5 ± 16 kg. Correlation coefficients between discus throwing from the power position and 1RM squat and 1RM incline bench press strength were $r=0.66$ (ns), and $r=0.97$ ($p<0.01$), respectively. Correlation coefficients between discus throwing performance with full rotation and 1RM squat and incline bench press strength were $r=0.61$ (ns), and $r=0.96$ ($p<0.01$, Figure 1), respectively. Correlation coefficient between 1RM incline bench press and 1RM squat strength was $r=0.66$ (ns).

Figure Captions

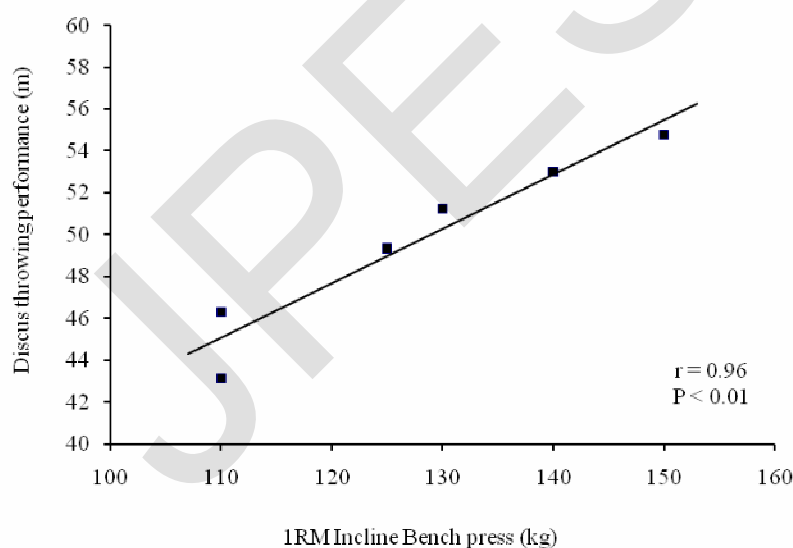


Fig. 1. Correlation between discus throwing performance and maximum strength (1RM) in incline bench press in six skilled discus throwers.

Electromyographic signals

Discus throwing performance from the power position was significantly correlated with the aEMG of the right quadriceps during the delivery phase ($r=0.80$, $p<0.05$). Similarly, discus throwing performance with full rotation was significantly correlated with the aEMG of the right quadriceps during the delivery phase ($r=0.81$, $p<0.05$, Figure 2). Furthermore, when all three attempts which were performed by each athlete with the full rotational style included in the calculation (i.e. 6 athletes $\times$ 3 attempts = 18 attempts), the correlation coefficient between the aEMG of quadriceps and discus performance was strong ($r=0.89$, $p<0.01$). In contrast, discus throwing performance was not related with the activation of either right or left gastrocnemius nor with the activation of left quadriceps.

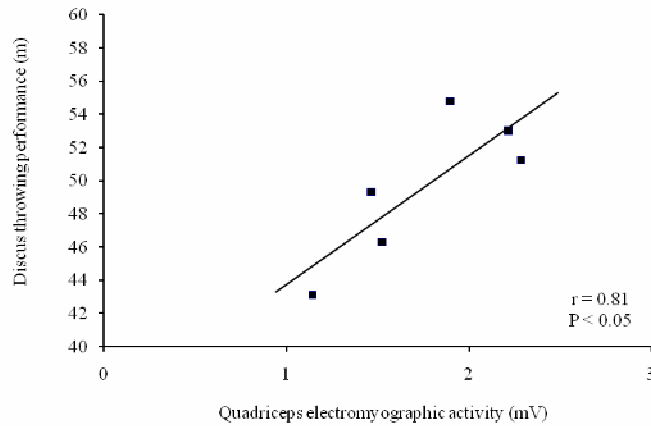


Fig. 2. Correlation between discus throwing performance and activation of right quadriceps during the delivery phase in six experienced discus throwers. Average electromyographic activity during discus throwing is expressed relative to electromyographic activity during the 1RM squat test.

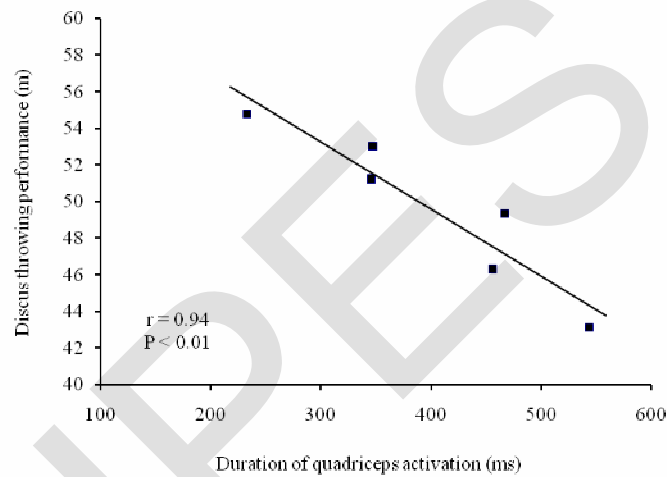


Fig. 3. Correlation between discus throwing performance and the duration of the activation of the right quadriceps during the delivery phase of discus throwing, in skilled athletes (n=6).

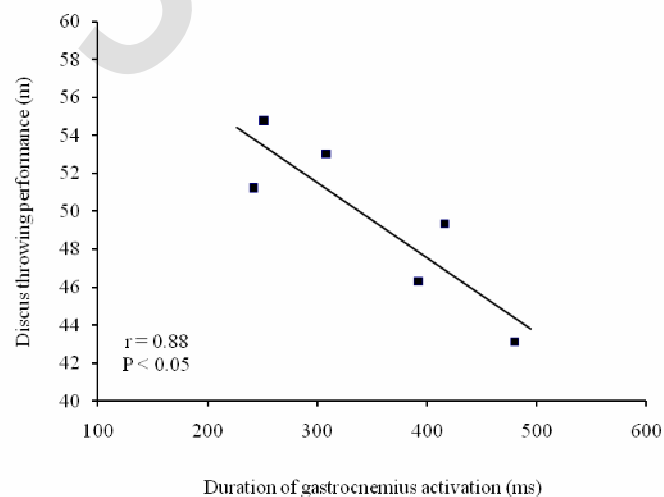


Fig. 4. Correlation between discus throwing performance and the duration of the activation of the right gastrocnemius during the delivery phase of discus throwing, in skilled athletes (n=6).

The duration of the activation of right quadriceps during the delivery phase was significantly, negatively, correlated with full rotational discus performance ($r=-0.94$, $p<0.01$, Figure 3). A similarly close,

negative, relationship was revealed between the duration of the activation of right gastrocnemius and discus throwing performance ($r=-0.88$, $p<0.05$, Figure 4). In contrast, the duration of activation of the muscles of the left lower extremity were not related significantly with performance (Table 1). Furthermore, analysis of the correlations between discus throwing performance and the time difference in the activation of the different muscle measured revealed low and non-significant correlations (Table 1).

Table 1. Correlation coefficients between discus throwing performance, muscular strength and electromyographic activity in six skilled discus throwers.

	Full rotation	Power position
<i>Activation (aEMG, mV)</i>		
Quadriceps right	0.81*	0.80*
Gastrocnemius right	0.21	0.11
Quadriceps left	0.41	0.37
Gastrocnemius left	0.11	0.07
<i>Duration of Activation (ms)</i>		
Quadriceps right	-0.94**	-0.59
Gastrocnemius right	-0.88*	-0.48
Quadriceps left	0.11	0.12
Gastrocnemius left	0.24	0.25
Gastrocnemius right - right	0.52	0.35
Gastrocnemius right - left	0.62	0.31
<i>1RM (kg)</i>		
Squat	0.61	0.66
Incline Bench Press	0.96**	0.97**

1RM: one repetition maximum. * $P<0.05$; ** $P<0.01$.

Discussion

The main result of the present study was that the amplitude of the electromyographic (aEMG) signal recorded from the right quadriceps at the delivery phase during discus throwing, was closely related with discus throwing performance both from the power position as well as during the full rotational style. A high aEMG can be related with either an increased number of active motor units or with an increase in the number of type II motor units which are activated (Sale 2003). Both mechanisms can result in increased power production by the respective muscles. Thus, this close relationship suggests that the best discus throwers can activate their right quadriceps more effectively during the delivery phase, (irrespective of the specific physiological mechanism) therefore, achieving a better performance. Similar correlation coefficients have been reported between the neuromuscular activation of the quadriceps muscles during shot put performance with the linear style (Terzis et al. 2007) as well as with the rotational style (Kyriazis et al. 2009). Moreover, it seems that this relationship is not affected by the training period. In the study of Kyriazis et al. (2009), the correlation coefficient between the activation of the quadriceps and shot put performance was identical to the one found in the present study, and it was the same both at the beginning of the training season as well as during the competition period. These data taken together seem to reveal that the electromyographic activity of the thigh muscles during discus throwing and shot put, might be associated with the concept of specific strength, that is the muscular strength produced by a certain muscle group during the actual sport performance. In a practical sense, the electromyographic activity of the thigh muscles might be used to reveal whether the level of strength which an athlete is producing during discus throwing is sufficient or other parameters besides strength (e.g. kinesiological faults) need more attention by the coach.

An interesting result of the present study was that discus throwing performance with full rotation was not related significantly with 1RM squat strength. This is in concert with previous results (Morrow et al. 1982). This suggests that the absolute level of muscular strength of the lower extremities is less important for discus throwing performance, while it seems that strength produced the same muscular group during throwing is much more important for performance (see above paragraph). However, this result is in contrast to the results regarding the linear shot put where a significant relationship was found between squat strength and performance (Terzis et al. 2007). The difference between these results may have been influenced by the higher movement velocity during discus throwing compared with shot put (Bartlett 1992). Higher levels of muscular strength can be applied during a slower movement (according to the force-velocity relationship). It seems that a certain (yet unknown) high level of absolute muscular strength of the lower extremities acts as a base upon which muscular power and specific strength are developed: further increases in 1RM strength of the lower extremities might not induce further increases in discus throwing performance.

In contrast, the correlation coefficient between the incline bench press and discus performance was rather high ($r=0.97$, $p<0.01$). A similar high correlation coefficient was also shown in a previous study (Morrow et al. 1982). The same close relationship was revealed when discus throwing was performed from the power position ($r=0.97$, $p<0.01$). This result is indicative of the importance of the absolute strength of the upper body in discus throwing and of the significance for the implementation of strength training for discus throwers. An increased focus on the development of muscular strength/power on the incline bench press (and perhaps other related resistance exercises) might induce further enhancements in discus throwing performance. Furthermore, the moderate correlation found between 1RM incline bench-press and 1RM squat strength suggests that the training for discus throwers might aim differently between the strength development of the upper and lower body. It seems that athletic preparation for discus throwers should aim at increasing the absolute muscular strength of the upper body (i.e. incline bench press) and the specific strength of the lower body, as long as a certain (yet unknown) level of lower body muscular strength has been attained.

A close, negative, relationship was found between the duration of the activation of the right vastus lateralis as well as of the right gastrocnemius muscles during the delivery phase, and discus throwing performance. A short time of activation of these muscles reveals a faster movement which should be related with faster discus release velocities and better performance. It is worth noting that a close, negative but non-significant relationship was also found between the duration of activation of the right vastus lateralis and the aEMG of the same muscle during the power position ($r=0.78$, $p=0.06$). Thus, there was a tendency to record higher aEMG from vastus lateralis in the faster (and better) performers, which again shows the importance of the activation of the right quadriceps during discus throwing.

The activation of the right gastrocnemius during the delivery phase was not correlated with performance. The same result has been reported for the shot put performance (Terzis et al. 2007). This might be due to either a weak activation of this muscle during the squat test or to a more supportive role of this muscle during the delivery phase of discus throwing. Furthermore, the activation of the left quadriceps and the left gastrocnemius during the delivery phase, was not related with performance. This was true both for the full rotational style as well as for the performance starting from the power position. These data suggest that the action of the left lower extremity in right-handed athletes is not directly influencing discus throwing performance. This result is in contrast to the results of Yu et al. (2002) which they reported a close correlation between discus throwing performance and ground reaction force of the left leg. This discrepancy might be related to the lower performance level of the athletes which participated in the present study compared with the study of Yu et al. (2002). Moreover, in the present investigation, there was no correlation between discus throwing performance and individual differences in the timing of activation of different muscles. This might be linked with kinesiological differences between our athletes. Unfortunately, only four EMG channels were available so we were not able to record the electromyographic signal from other, probably, significant muscles such as the muscles of the upper body. Thus, the issue of individual differences in the timing of muscular activation in discus throwing requires further investigation.

Conclusion

The present results suggest that discus throwing performance is strongly related with the absolute muscular strength during incline bench press but not with squat strength. Thus, coaches should focus on the improvement of the absolute strength in incline bench press. It seems that after attaining a specific (yet unknown) level of muscular strength in squat, further increase in strength will probably not lead to improvement in discus throwing performance. A special emphasis should be stressed on the quick activation of the right lower leg (in right-handed athletes), while it seems that the level of activation of the left lower extremity is not so important for discus throwing performance. In contrast, the activation level of the quadriceps of the right leg during the delivery phase of the throw is directly proportional to performance. It seems that the electromyographic activity of the thigh muscles might be used to reveal whether the level of strength which an athlete is producing during discus throwing is adequate, or other parameters besides muscular strength (e.g. kinesiological faults) need more attention by the coach.

References

- Bartlett, R.M. (1992). The biomechanics of the discus throw: a review. *Journal of Sports Sciences*, 10, 467-510.
- Beachle, T.R., Earle, R.W., and Wathen, D. (2000). Resistance training. In: T.R. Beachle, and R.W. Earle (Eds.), *Essentials of strength training and conditioning* (pp. 395-425). Champaign, IL: Human Kinetics.
- Costill, D.L., Daniels, J., Evans, W., Krahenbuhl, G., and Saltin, B. (1976). Skeletal muscle enzymes and fiber composition in male and female track athletes. *Journal of Applied Physiology*, 40, 149-154.
- De Luca, C.J. (1997). The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics*, 13(2), 135-163.

- Dinu, D., Natta, F., Portero, P., and Vandewalle H. (2008). Does the use of a light discus modify the throwing pattern? A study of kinematical and electromyographic data of the throwing arm. In M. Estivalet, and P. Brisson (Eds.), *The engineering of sport 7* (pp. 689-694). Springer.
- Finanger, K.E. (1969). An EMG study of the function of selected muscles involved in the throwing of the discus. *Unpublished doctoral dissertation*, University of Iowa.
- Häkkinen, K., Alen, M., and Komi, P.V. (1985). Changes in isometric force and relaxation time, electromyographic and muscle fiber characteristics of human skeletal muscle during strength training and detraining. *Acta Physiologica Scandinavica*, 125, 573-585.
- Komi, P.V., and Karlsson, J. (1979). Physical Performance, skeletal muscle enzyme activities and fiber types in monozygous and dizygous twins in both sexes. *Acta Physiologica Scandinavica*, 450, 211-215.
- Kyriazis, T., Terzis, G., Boudolos, K., Georgiadis, G. (2009). Muscular power, neuromuscular activation, and performance in shot put athletes at preseason and at competition period. *Journal of Strength and Conditioning Research*, 23, 1773-1779.
- Moritani, T. (2003). Motor unit and motoneurone excitability during explosive movement. In: P.V. Komi (Ed.), *Strength and power in sport*. Oxford (pp. 27-49). Oxford: Blackwell Scientific Publications.
- Morrow, J.R., Disch, J.G., Ward, P.E., Donovan, T.J., Katch, F.I., Katch, V.L., Weltman, A.L., and Tellez, T. (1982). Anthropometric, strength and performance characteristics of american world class throwers. *Journal of Sports Medicine*, 22, 73-79.
- Peng, H., Huang, C., and Peng, H. (2005). Electromyographic analysis of the discus standing throw. *International Symposium on Biomechanics in Sport*, (pp.151-155), Beijing, China.
- Sale, D.G. (2003). Neural adaptation to strength training. In: P.V. Komi (Ed.), *Strength and power in sport*. Oxford (pp. 281-314). Oxford: Blackwell Scientific Publications.
- Silvester, J. (2003). *Complete book of throws*. Human Kinetics: Champaign, IL,.
- Terzis, G., Karampatsos, G., and Georgiadis, G. (2007). Neuromuscular control and performance in shot put athletes. *Journal of Sports Medicine and Physical Fitness*, 47, 284-290.
- Terzis, G., Georgiadis, G., Vassiliadou, E., and Manta, P. (2003). Relationship between shot put performance and triceps brachii fiber type composition and power production. *European Journal of Applied Physiology*, 90, 10-15.
- Yu, B., Broker, J., and Silvester J. (2002). A kinetic analysis of discus throwing techniques. *Sports Biomechanics*, 1, 25-46.