

## THE EFFECT OF STRENGTH TRAINING ON TENNIS SERVICE PERFORMANCE OF JUNIOR TENNIS PLAYERS

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### Abstract

The purpose of the present study was to evaluate the effect of a 7-week shoulder specific strength training program additional to tennis training sessions on the service velocity of junior tennis players. Initially 60 junior tennis players (29 boys and 31 girls) with at least 2 years of tennis experience and never followed a routine strength program, volunteered to participate in the study. All the subjects followed a regular tennis training session (75 min). The subjects were randomly assigned into three groups: i) group-A, which practiced in addition 15 min service after the tennis session, ii) group-B which practiced a 7-week strength training program (15 min per session, 3 times per week) after the tennis session, and iii) a group-C, control group, which did not follow any extra programs after the tennis session. Two-way repeated measures analysis of variance was performed to detect differences in each group before and after the experimental period. The independent variable was the group (two experimental groups with different training protocol and the control group with only tennis training), and the repeated factor was the “test” (pre and post test, before and after the training period). Statistical significance was accepted at  $p < .05$ . It was measured an overall significant quantitative improvement on service performance while, the qualitative findings showed significant improvement in service technique only in group A.

**Keywords:** tennis, shoulder strength program, service, service velocity

### Introduction

Tennis skills are composed by complex movements. One of these skills, service performance, is a result of the effective transfer of torque production that depends on technique, muscle strength and flexibility (Cohen, Mont, Campbell, Vogelstein, & Loewy, 1994; Mont,

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Coen, Campbell, Gravare, & Mathur, 1994). An important factor for tennis service is the ability to exert high muscular force and power to the racquet. Therefore, the ball speed in tennis service is generated by the speed of the racquet immediately before the impact (Gordon, & Dapena, 2006). Gordon and Dapena (2006) measured the contributions of the motion of body segments to the racquet head speed during the tennis service and suggested that among the main contributors were the external shoulder rotation, wrist extension and twist rotation of the lower trunk, twist rotation of the upper trunk relative to the lower trunk, shoulder abduction, and wrist flexion. Also, Gordon and Dapena (2006) suggested that there was a positive contribution of shoulder internal rotation shortly before the impact with the ball.

In addition, it has been shown that the internal rotators of the dominant shoulder in tennis players produce greater torque than those who don't play tennis (Ng, & Kramer, 1991). The internal rotators of the dominant shoulder are typically stronger of the non-dominant shoulder in tennis players (Chandler, Kibler, Stracener, Ziegler, & Pace, 1992). Also, tennis players tend to have muscle strength imbalance of internal versus external rotators (Mont et al. 1994; Chandler et al. 1992; Ellenbecker, Davies, & Rowinski, 1988). Although muscle strength plays a key role to the overheads sports performance (Wooden, Greenfield, Johansonm, Litzelman, Mundrane, & Donatelli, 1992; Bartlett, Storey, & Simons, 1989; Perry, 1983) there are only a few studies evaluating the effect of strength training on shoulder rotators muscles and the related functional performance (Treiber, Lott, Duncan, Slavens, & Davis, 1998; Mont et al. 1994). It has been suggested that the upper and lower strength in a tennis player can be extremely useful not only in the enhancement of athletic performance but also in the prevention and rehabilitation of injuries (Ellenbecker, & Roetert, 2004). More specific Treiber et al. (1998) showed that strength training for four weeks with Therabands and light weight dumbbells appears to increase service velocity of college tennis players.

The purpose of the present study was to evaluate whether an additional 7-week shoulder specific strength training program would significantly increase service velocity of junior tennis players compared to the group which practice only service in addition to tennis training sessions.

## Method

### **Experimental Approach to Problem**

Service in tennis is based on complex motor movement and depends on technique, muscle strength and flexibility. The purpose of the present study was to evaluate the effect of shoulder specific strength training program additional to tennis training sessions on the service velocity of junior tennis players in order to define the need of strength exercise for junior tennis players.

### **Subjects**

Initially 60 junior tennis players (29 boys and 31 girls) from three different Greek tennis clubs volunteered to serve as subjects. All subjects practiced tennis with a coach for at least 2 years (two to three times per week), and never followed a routine strength. All the subjects participated in a regular tennis practice session (75 min). Each session included warm-up, drills practicing ground strokes and volley, as well as drills practicing tactics of the games for 60 min and 15min practicing service. The subjects were randomly assigned into three groups: i) group-A, which practice in addition 15 min service after the tennis session, ii) group-B which practice a 7-week strength training program (15 min per session, 3 times per week) after the tennis session, and iii) a group-C, control group, which did not follow any extra programs after the tennis session.

Four of the subjects failed to complete the study: three (two experimental and one control subject) participated in less than 75% the sessions, and one subject could not complete the study because of an injury. The data from these four subjects were dropped from the study.

The subjects ranged from 13 to 14 years old (group-A  $13.3 \pm 1$ , group-B  $14.2 \pm 0.8$ , and group-C  $14.4 \pm 0.7$ ,  $M \pm SD$  respectively), had an average weight for group-A  $45.75 \pm 7.74$  kg, group-B  $38.33 \pm 8.14$  kg, and group-C  $41.83 \pm 7.16$  kg,  $M \pm SD$  respectively and an average height for group-A  $153.25 \pm 7.2$  cm, and group-B  $144.4 \pm 9.6$ cm, and group-C  $145.3 \pm 5.8$  cm,  $M \pm SD$  respectively.

All players were right handed-dominant. Subjects were evaluated pre and post training program for service performance: a) ball speed (quantitative evaluation) and b) technique of the service (qualitative evaluation). In addition, the range of motion and the strength of the internal and external rotation of the shoulder were evaluated.

### **Quantitative service evaluation**

The service performance was conducted on an indoor tennis court. Each subject was instructed to perform service from the baseline (0-40 m to the right of the center mark) with new Wilson USA Open balls, with maximal velocity and control until a total of five balls landed in the left service box. No limit was placed on the number of the attempts. If the player did not succeed after 10 efforts had a rest break for 3-4 min. The average velocity of service was the mean of the best three. Ball velocity was assessed in (km/h) with a calibrated radar gun (Jug Company, 2000). The radar gun was positioned 5 meters behind the baseline, opposite to the subject, at a height 2 meters (Jug Company, 2000). Before the evaluation the subjects played tennis for 10-12 min and had 10-15 service from the baseline for warm-up.

### **Qualitative service performance evaluation**

The subjects underwent service technique evaluation by three experienced tennis coaches. Before the beginning of the procedure, the coaches were informed about the procedure and the goals of the study. A pilot procedure has been followed, where the three coaches watched (2 times in 10 days) a videotape with service skills in similar conditions with the present study. The correlation coefficients between the coaches ( $r = .92$ ) and between the trials ( $r = .91$ ) were high. No player was found to have faulty technique and thus no player was excluded from the participation in the study. There were observed six technical elements in service motion: 1) the basic position, 2) the grip, 3) the body orientation, 4) the back swing 5) the touch with the ball, 6) the follow through (Eason, Smith, & Plaisance, 1989; Magill, 1985). When one of those elements was missing, the score was 0, while it was 1 when it was appeared (Mcpherson, & Thomas, 1989). Ten trials were assessed and the sum of the score for each element was recorded. The score for the technique evaluation was computed by adding the scores for all the technical elements for 10 trials.

### **Shoulder rotator strength assessment**

The subjects underwent shoulder rotator strength evaluation that is usually used by exercisers and is also accepted by many authors uses the (Brzycki, 1993; Mayhew, Ware, & Rinster, 1993) equations. This is an indirect method of assessing maximal strength that is based on the maximal number of repetitions that the exerciser accomplishes. The testing procedure that was followed by Giannakopoulos, Beneka, & Malliou (2004). is now described. Each participant is positioned supine holding a dumbbell with stabilization straps secured at the pelvis and midthoracic levels. The assessed extremity is positioned on a table with stabilization straps also secured at humeral level. The test is initiated with the arm in  $90^\circ$  of external rotation. To test the internal rotation movement, the trial is initiated with the arm in  $90^\circ$  of external rotation.

Respectively, when the external rotation is tested, the trial is initiated with the arm in 90° of internal rotation. The participants try to complete the maximal number of repetitions (e.g., 12 repetitions) with a dumbbell of their choice (e.g., 2.5kg). According to Brzycki's and Mayhew's equations, the maximal number of repetitions for a given weight corresponds to a specific coefficient (e.g., 0.75). Dividing the dumbbell's weight (2.5kg) by that coefficient results in a number indicating maximal strength (e.g.,  $2.5/0.25 = 3.33$ ). The result, in this case 3.33, is considered to be the maximal strength of the muscle group tested. Similarly, the maximal strength of the other muscle group is assessed (Beneka, Malliou, Giannakopoulos, Kyrialanis, & Godolias, 2002; Giannakopoulos et al. 2004; Kibler, Chandler, & Livingston, 1996).

### **Range of motion evaluation of shoulders rotator cuff**

The testing position of the participant for the internal rotation was supine with the arm abducted to 90degrees, the elbow flexed to 90degrees and the forearm pronated and perpendicular to the table. A towel was placed under the humerus to bring the arm into the scapula plane. The goniometer was aligned along the ulnar styloid process and perpendicular to the table.

The testing position of the participant for the external rotation was supine, with the arm abducted to 90deg, the elbow flexed to 90deg and the forearm pronated and perpendicular to the table. A towel was placed under the humerus to bring the arm into the scapula plane. The goniometer was aligned along the ulna to the ulnar styloid process and perpendicular to the table (Andrews, Harrelson, & W. K., 2004).

### **Service training program (group-A)**

The participants in group-A followed a service training session (15 min per session, 3 times per week) after the tennis practice. The service session included a) toss practice, and b) serve practice with 2 targets ("T" and diagonal) from both sides (deuce and advantage).

### **Shoulder strength intervention programs (group-B)**

The subjects from group B participated in a strength training program, 6 exercises for both shoulders (left and right), 15 min, 3 times per week for 7 weeks. (From 0 to the 3<sup>rd</sup> week performed 2 sets of 10-15 repetitions with 0.5-1.0 kg free weights. After the 3<sup>rd</sup> week the program progressed to 3 sets with the same repetitions and increase in the free weights by 0.5 kg (Table 1). There was at least one day rest between practice days.

The subjects were instructed to breathe normally. The subjects from both groups were given detailed written, verbal and physical instructions by the trainer for the various exercises. Before the beginning of the intervention period each subject had to demonstrate proper technique to the trainer.

### **Post assessments**

Within 2 days, after the completion of the 7 –week intervention period, the follow up assessment for all groups was begun (serving velocity and technique).

### **Statistical Analyses**

Means and standard deviations were calculated for all depended variables. Two-way repeated measures analysis of variance (ANOVA) (2X3, tests by different training protocol) was performed on depended variables to detect differences in each group before and after the

experimental period. The independent variable was the group (two experimental groups with different training protocol and the control group with only tennis training), and the repeated factor was the “test” (pre and post test, before and after the training period). Statistical significance was accepted at  $p < .05$ .

## Results

Two-way repeated measures analysis of variance was used to test the differences in all depended variables before and after training period for each group. The independent variable was the group (two experimental groups and one control group), and the repeated factor was the test (before and after the training period). Tables 1 and 2 illustrate the means and standard deviations for external and internal rotation range of motion values for all the groups.

Table 1

*Means and standard deviations for external rotation range of motion values for all the groups*

Groups	Range of motion / External Rotation				F
	PreTest		PostTest		
	M	SD	M	SD	
Control	68.92	10.6	71.83	7.71	.706
Service	61.50	15.5	86.75	17.2	52.9***
Strength/Service	73.5	14.5	79.08	13.3	2.58
F	14.17***				

\* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$

Table 2

*Means and standard deviations for internal rotation range of motion values for all the groups*

Groups	Range of motion / Internal Rotation				F
	PreTest		PostTest		
	M	SD	M	SD	
Control	49.58	16.03	58.25	22.61	3.172
Service	50.75	8.27	82.75	19.25	43.242***
Strength/Service	44.25	8.92	54.83	14.11	4.730*
F	7.086**				

\* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$

For external rotation range of motion test, the results showed (Table 1) that all the groups improved their performance between the two tests but this improvement was significant only for the “Service Group”  $F(1,33)=43.24$ ,  $p < .001$

For internal rotation range of motion test, statistical analysis showed that all the groups improved their performance between pre and post test but in a different way ( $F(2, 33) = 7.086$ ,  $p < .05$ ). Sidak Multiple Comparison test was performed to test the differences in performance for

each group. The results showed that there was a significant performance improvement in the internal rotation range of motion test only for the experimental groups, and not for the control group (Table 2).

Tables 3 and 4 illustrate the means and standard deviations for external and internal rotation strength values for all the groups. For strength performance in external rotation movement statistical analysis showed that all the groups improved their performance between pre and post test but in a different way  $F(2, 33) = 8.012, p < .05$ . Sidak Multiple Comparison test was performed to test the differences in performance for each group. The results showed that there was a significant performance improvement in the external rotation strength performance only for the “Service Group”  $F(1, 33) = 19.79$  the “Strength Service Group”  $F(1, 33) = 38.009$  and not for the control group.

For strength performance in internal rotation movement (Table 4) statistical analysis showed that all the groups improved their performance between pre and post test but in a different way  $F(2,33)=7.98, p < .05$ . Sidak Multiple Comparison test was performed to test the differences in performance for each group. The results showed that there was a significant performance improvement in the internal rotation strength performance only for the “Strength Service Group”  $F(1, 33) = 15.96$  and the “Service Group”  $F(1, 33) = 4.25$  and not for the others.

Table 3

*Means and standard deviations for external rotation strength values for all the groups*

Groups	Strength / External Rotation				F
	PreTest		PostTest		
	M	SD	M	SD	
Control	4.20	.57	4.45	.57	5.93
Service	4.47	.55	4.85	.69	19.79**
Strength/Service	3.98	.66	4.50	.65	38.009***
F	8.012*				

\* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$

Table 4

*Means and standard deviations for internal rotation strength values for all the groups*

Groups	Strength / Internal Rotation				F
	PreTest		PostTest		
	M	SD	M	SD	
Control	4.90	.79	5.10	.95	2.33
Service	6.01	1.36	6.27	1.52	4.25
Strength/Service	4.54	.98	5.06	1.09	15.96***
F	7.98*				

\* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$

Tables 5 and 6 illustrate the means and standard deviations for quantitative and qualitative service evaluation test for all the groups.

Table 5

*Means and standard deviations for quantitative service evaluation test for all the groups*

Quantitative service evaluation test					
Groups	PreTest		PostTest		F
	M	SD	M	SD	
Control	47	12.5	48.17	12.23	.943
Service	53	9.31	60.83	10.89	42.512***
Strength/Service	44.33	14.63	52.08	17.35	41.612***
F					10.137***

\*p<.05, \*\*p<.01, \*\*\*p<.001

Table 6

*Means and standard deviations for qualitative service evaluation test for all the groups*

Qualitative service evaluation test					
Groups	PreTest		PostTest		F
	M	SD	M	SD	
Control	41.66	6.14	39.16	5.1	1.40
Service	48.33	4.34	55.00	3.74	10.1*
Strength/Service	45.83	7.4	49.16	5.96	2.50
F					4.848**

\*p<.05, \*\*p<.01, \*\*\*p<.001

For the Quantitative service evaluation test (Table 5), results showed that all groups improved their performance between pre and post test but in a different way ( $F(2, 33) = 10.137$ ;  $p < .001$ ). Sidak Multiple Comparison test was performed to test the differences in performance for each group. The results showed that there was a significant performance improvement in the quantitative service evaluation test for the experimental groups between pre and post tests, but no significant improvement was found for the control group.

However, difference in service performance was found only for experimental groups for the qualitative evaluation test  $F(2, 33) = 4.848$ ,  $p < .05$ , and this improvement was significant only for the Service Group ( $F(1, 33) = 10.01$ ,  $p < .01$ ) and not for the Strength Service Group ( $F(1, 33) = 2.5$ ,  $p > .05$ ) (Table 6).

## Discussion

The present study evaluated the service performance in young tennis players with quantitative and qualitative evaluations. It was concluded an overall significant quantitative improvement on service performance while, the qualitative findings showed significant improvement in service technique only in group A. These findings support the significant impact of the technique in tennis performance. It is evident that for this age group with at least 2 years tennis practice, improvement only in the technique can increase significantly the service performance. As the player developed and the technique reached at a high level then, strength and flexibility are more important physical abilities to be developed (Elliot, Fleisic, Nicholls, & Escamilia, 2003).

In the present study both groups (A and B) increased average speed of service. Previous investigations have been shown that strength training can increase athletic performance in tennis (ITF). More specific, studies on tennis service showed low correlation between ball speed and isokinetic strength of the upper body (Cohen et al. 1994; Ellenbecker, & Roetert, 1999). The ball speed during service maybe a combination of several factors such as technique, coordination, flexibility and strength. Cohen et al. (1994) found low correlation between shoulder internal rotation and ball speed. The present study showed that although only group B had significant increase in strength of internal rotation, both groups (A and B) increase significantly the range of motion in the internal rotation. Furthermore, group A had greater increase in the range of internal rotation compared to group B. This evidence suggests that strength training program may be an important factor in reassuring shoulder stability. Consecutively, a smaller increase in range of motion in group B may be related to less increase of ball speed compared to group A.

The present study showed that both groups (A and B) increased significantly the strength of external rotation muscles, but only group A showed significant increase in the range of motion of external rotation muscles. Thus, it is suggested that for the external rotators muscles, strength training program restricted the improvement of range of motion, revealing again the important role of strength training in keeping joint stability. Gordon, & Dapena (2006) measured the contributions of the motion of body segments to the racquet head speed during the tennis service and suggested that among the main contributors were the external shoulder rotation.

Both groups (A and B) improved significantly the quantitative performance of the service. The findings from the strength intervention program in the present study are in agreement with the study by Treiber et al. (1998), although, this study had different age group (college tennis players) and different duration of the program (4 weeks). The improvement in the present study ranged from  $44.33 \pm 14.63$  to  $52.08 \pm 17.35$  km/h in average service velocity. Others studies (Mont et al. 1994; Ellenbecker et al. 1988) found also increase in service performance. The average and peak service velocity increased 7.9 % and 6.0 % respectively (Treiber et al. 1998). These increases are less than the finding of Mont et al. (1994) study and Ellenbecker et al. (1988) study. These discrepancies of the results may due in the different age groups and the designs of the studies, such as the duration of the intervention program, method of training and the intensity of the program.

Previous studies (Cohen et al. 1994; Ellenbecker, & Roetert, 1999; Pugh, Kovaleski, Heitman, & Gilley, 2003) indicate a moderate correlation between upper body strength and ball speed in the tennis service. This suggests that an absolute level of strength is necessary but not sufficient for ultimate ball speed.

The present study showed that since service is complex movement and requires optimal timing, coordination, and strength of many segments of human body, it is crucial to primary develop the service movement skill for an efficient service performance.

The findings of the present study suggest that for young athletes with at least two years tennis practice improving technique can significantly increase tennis performance. As the athlete is growing up and his technique reaches at a higher level, then strength and flexibility are more important physical abilities to be developed.

The results of the present study also suggest that although only strength training can increase the internal rotators strength; both strength training and service practice can increase significantly the range of motion in the internal rotation. Furthermore, service practice in young tennis players can better increase the internal rotators range of motion compared to strength training. This evidence suggests that strength training program may be an important factor in reassuring shoulder stability for young athletes. It is suggested also for the external rotators muscles, strength training program restricted the improvement of range of motion, revealing again the important role of strength training in keeping joint stability. Finally, both strength training and service practice can efficiently improve the service ball speed.

## References

- Andrews, J., Harrelson, G., & W. K. (2004). Physical Rehabilitation of the Injured Athlete. *Saunders, Elsevier*, 106-111.
- Bartlett, L. R., Storey, M. D., & Simons, B. D. (1989). Measurement of upper extremity torque production and its relationship to throwing speed in the competitive athlete. *American Journal of Sports Medicine*, 17, 89-91.
- Beneka, A., Malliou, P., Giannakopoulos, K., Kyrialanis, P., & Godolias G. (2002). Different training modes for the rotator cuff muscle group: A comparative study. *Isokinetic Exercise Science*, 73-79.
- Brzycki, M. (1993). Strength testing-predicting a one rep max from reps-to-fatigue. *Journal of Physical Education Recreation Dance*, January, 88-90.
- Chandler, T. J., Kibler, W. B., Stracener, E. C., Ziegler, A. K., & Pace, B. (1992). Shoulder strength, power, and endurance in college tennis players. *American Journal of Sports Medicine*, 20, 455-458.
- Cohen, D. B., Mont, M. A., Campbell, K. R., Vogelstein, B. N., & Loewy, J. W. (1994). Upper extremity physical factors affecting tennis serve velocity. *American Journal of Sports Medicine*, 22, 746-750.
- Eason, R. L., Smith, T. L., & Plaisance, E. (1989). Effects of proactive interference on learning the tennis backhand stroke. *Perceptual and Motor Skills*, 69, 923-939.
- Ellenbecker, T. S., Davies G. J., & Rowinski M. J. (1988). Concentric versus eccentric isokinetic strengthening of the rotator cuff. Objective data versus functional test. *Journal of Sports Medicine*, 16, 64-69.
- Ellenbecker, T. S., & Roetert, E. P. (1999). Testing isokinetic muscular fatigue of shoulder internal and external rotation in elite junior tennis players. *Journal of Orthopedic and Sports Physical Therapy*, 29, 275-281.
- Ellenbecker, T. S., & Roetert, E. P. (2004). Velocity of a tennis serve and measurement of isokinetic muscular performance: brief review and comment. *Perceptual and Motor Skills*, 98, 1368-1370.

- Elliot, B., Fleisic, G., Nicholls, R., & Escamilla, R. (2003). Technique effects on upper limb loading in the tennis serve. *Journal of Sport Science and Medicine in Sport*, 6, 76-87.
- Giannakopoulos, K., Beneka, A., & Malliou, P. (2004). Isolated versus complex exercise in strengthening the rotator cuff muscle group. *Journal of Strength and Conditioning Research*, 1, 144-148.
- Gordon, B.J., & Dapena, J. (2006). Contributions of joint rotations to racquet speed in the tennis serve. *Journal of Sports Science*, 24, 31-49.
- Jug Company. (2000). *Jugs users and installation manual*. Tualatin, Oregon: Jugs Company.
- Kibler, W. B., Chandler, T. J., & Livingston, B. P. (1996). Shoulder range of motion in elite tennis players: Effect of age and years of tournament play. *American Journal of Sports Medicine*, 3, 279-285.
- Magill, R. A. (1985). *Motor learning: Concepts and applications*. 2nd ed. Dubuque, IA: Wm. C. Brown.
- Mayhew, J., Ware, J., & Rinster, J. (1993). Using lift repetitions to predict muscular strength in adolescent males. *N. S. C. A. J.*, 15, 35-38.
- Mcpherson, S., & Thomas, J. R. (1989). Relation of knowledge and performance in boys' tennis: Age and expertise. *Journal of Experimental Child Psychology*, 48, 190-211.
- Mont, M. A., Coen, D. B., Campbell, K. R., Gravare, K., & Mathur, S. K. (1994). Isokinetic concentric versus eccentric training of shoulder rotators with functional evaluation of performance enhancement in elite tennis players. *American Journal of Sports Medicine*, 22, 513-517.
- Ng, L. R. and Kramer, J. S.(1991). Shoulder rotator torques in female tennis and nontennis players. *Journal of Orthopedic and Sports Physical Therapy*, 13, 40-46.
- Perry, J. (1983). Anatomy and biomechanics of the shoulder in throwing, swimming, gymnastics, and tennis. *Clinical Journal of Sports Medicine*, 2, 247-270.
- Pugh, S. F., Kovaleski, J. E., Heitman, R. J., & Gilley, W. F. (2003). Upper and lower body strength in relation to ball speed during a serve by male collegiate tennis players. *Perceptual and Motor Skills*, 97, 867-872.
- Treiber, F. A., Lott, J., Duncan, J., Slavens, G., & Davis, H. (1998). Effects of Theraband and lightweight dumbbell training on shoulder rotation torque and serve performance in college tennis players. *American Journal of Sports Medicine*, 26, 510-515
- Wooden, M. J., Greenfield, B., Johansonm M., Litzelman, L., Mundrane, M., & Donatelli, R. A. (1992). Effects of strength training on throwing velocity and shoulder muscle performance in teenage baseball players. *Journal of Orthopedic and Sports Physical Therapy*, 15, 223-228

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