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Research article

Effects of a 6-Week Junior Tennis Conditioning Program on Service Velocity

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Abstract

This study examined the effects of a 6-week strength-training program on serve velocity in youth tennis players. Thirty competitive healthy and nationally ranked male junior tennis players (13 years of age) were randomly and equally divided into control and training groups. The training group performed 3 sessions (60-70 min) weekly for 6 weeks, comprising core strength, elastic resistance and medicine ball exercises. Both groups (control and training) also performed a supervised stretching routine at the end of each training session, during the 6 week intervention. Service velocity, service accuracy and shoulder internal/external rotation were assessed initially and at the end of the 6-week conditioning program for both, control and training groups. There was a significant improvement in the serve velocity for the training group ($p = 0.0001$) after the intervention, whereas in the control group there were no differences between pre and post-tests ($p = 0.29$). Serve accuracy was not affected in the training group ($p = 0.10$), nor in the control group ($p = 0.15$). Shoulder internal/external rotation ROM significantly improved in both groups, training ($p = 0.001$) and control ($p = 0.0001$). The present results showed that a short-term training program for young tennis players, using minimum equipment and effort, can result in improved tennis performance (i.e., serve velocity) and a reduction in the risk of a possible overuse injury, reflected by an improvement in shoulder external/internal range of motion.

Key words: tennis, strength, flexibility, service, performance.

Introduction

Today, tennis is a world-class competitive sport attracting millions of players and fans worldwide. Since early ages tennis players travel and compete extensively year round, with, for example, tournaments on the junior calendar numbering 397 in 118 countries (USTA, 2002). Success in tennis depends on several physical, technical/tactical and psychological factors, and in order to be competitive, players require a mixture of speed, agility, and power combined with medium to high aerobic and anaerobic capacity (Fernandez-Fernandez et al., 2009). Although performance cannot be defined by one predominant physical attribute, strength and power seem to be influential in tennis performance, with functional links observed between muscular strength in the dominant lower and upper extremities and ranking in competitive tennis players (Girard and Millet, 2009; Kraemer, et al., 2003).

Among tennis strokes the tennis serve has received more attention in the literature than the other strokes, as it does produce large loads on the shoulder and lower back, which can result in overuse injuries (Chow, 2009; Fleisig et al., 2003; Kovacs and Ellenbecker, 2011). It is also a highly complex stroke because of the reliance on multiple body segments to produce power through properly timed rotations and complex coordinated muscular activations (Ryu et al., 1988), as well as the most important from a strategic standpoint (Kovacs, 2007). The coordination of body segments has been termed the kinetic chain, and allows generation, summation, transfer, and regulation of forces from the legs to the hand (Elliott, 2006; Elliott et al., 2003). It is well known that in order to increase serve performance, muscle strength of the entire kinetic chain must be increased without affecting serve accuracy (Roetert et al., 2009).

Although muscle strength is thought to play a main role in tennis performance, a paucity of scientific consideration has been afforded to establishing an evidence base for tennis-specific strength training in light of its popular integration into current practice (Reid and Schneiker, 2008). In this regard, just a few studies have been conducted evaluating the effects of strength training on tennis serve performance, most of them after isokinetic concentric and eccentric training (Cohen et al., 1994; Ellenbecker and Roetert, 1999; Pugh et al., 2003), showing an improvement in the tennis serve. However, the actual needs of tennis require strength training programs that can be readily implemented with minimal equipment and effort.

It has been suggested that both the upper and lower body 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 and Roetert, 2004). Repetitive muscular exertion in the upper extremity, required during performance of tennis specific movement patterns, leads to the development of sport specific muscular adaptations in tennis players (i.e., muscular imbalances in the rotator cuff and scapular musculature; loss of internal rotation range of motion (ROM) in the shoulder) which, in the long term, can lead to overuse injury in the glenohumeral joint (Ellenbecker and Roetert, 2004; Ellenbecker et al., 2002). This is especially important in developmental players, as tennis-specific strength and conditioning pro-

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grams can play a key role in preventing common injuries in tennis players.

To the best of our knowledge this is the first study that has examined the effects of a strength-training program on serve velocity in youth tennis players. Therefore, the aim of this study was to determine the effects of a 6-week conditioning program (comprising throwing, elastic resistance exercises and stretching) on serve velocity.

Methods

Subjects

Thirty competitive healthy and nationally ranked male junior tennis players (mean ± SD: age 14.2 ± 0.5 years, weight 58.1 ± 8.8 kg, height 1.71 ± 0.07 m) participated in this study. Subjects were randomly and equally divided into control (n = 15) and training (n = 15) groups. All the players participated on average in 8-10 h of combined training (i.e., on and off-court) per week. The program focused on development of on-court technical/tactical tennis behavior, as well as tennis-specific aerobic and anaerobic capabilities enhancement, which included on and off-court aerobic exercises, agility exercises, and repeated sprints. None of the players in the study had regular experience in strength training, with just some experience (i.e., familiarization sessions) in a variety of plyometric (e.g., medicine ball, hopping) and injury-prevention training (e.g., elastic tubing and core training). All players had a minimum of 3 years of prior tennis-specific training. Inclusion criteria for all subjects required each participant to be a healthy tennis player, no history of upper extremity surgery, no shoulder pain for the past 12 months, no rehabilitation for the past 12 months, and no participation in a formal strength-training program the 4 weeks before the study. 26 players were right-handed and 4 were left-handed. Written informed consent was obtained from the players and their parents. The institutional research ethics committee, conformed to the recommendations of the Declaration of Helsinki, approved the study.

Experimental set up

This study examined the effects of a 6-week strength-training program on throwing velocity in elite junior tennis players. Because young athletes increase muscle strength through maturation, which can affect serve velocity, we used a control group to compare to the experimental (training) group. To control the effects of age and training status on service velocity, we employed a randomization process in assigning the subjects to the experimental and control groups. During the testing sessions players were advised to have no strength or endurance training at least 48 h prior to the test and to take a carbohydrate rich meal 2 h before testing.

Measurements

Maturity status: Pubertal timing was estimated according to the biological age of maturity of each individual as described by Mirwald et al. (2002). The age of peak linear growth (age at peak height velocity (PHV)) is an indicator of somatic maturity representing the time of maximum growth in stature during adolescence. Biological age of maturity (years) was calculated by subtracting the chronological age at the time of measurement from the chronological peak-velocity age (Sherar et al., 2007). Thus, a maturity age of -1.0 indicates that the player was measured 1 year before this peak velocity; a maturity of 0 indicates that the player was measured at the time of this peak velocity; and a maturity age of +1.0 indicates that the participant was measured 1 year after this peak velocity (Mendez-Villanueva et al., 2010).

Shoulder internal/external rotation: Dominant shoulder range of motion was measured following the methods by Ellenbecker et al. (2009), with the player lying supine on a treatment table, and using a 12-inch, 3601 goniometer, marked in 11 increments, with two adjustable overlapping arms was used. The test began with the shoulder abducted on the testing arm to 90º with the elbow flexed to 90º. The player's fingers pointed upward toward the ceiling in the starting (0°) position. The examiner exerted a posteriorly directed force on the front the shoulder throughout the test, to ensure that the scapula was stabilized. The player slowly moved the arm into external and internal rotation. Care was taken to ensure minimal to no motion occurred at the scapulothoracic joint. This test measures a player's active range of motion and the examiner did not apply overpressure to the arm at end range of motion during measurement. The examiner measured and recorded the angle using a universal goniometer. Total rotation ROM was calculated by summing the internal and external rotation ROM measures taken at 90 degrees of glenohumeral joint abduction in the coronal plane.

Velocity analysis and radar specifications: A radar gun (Stalker Professional Sports Radar, Radar Sales, Plymouth, MN) was used to measure first-serve velocity. The radar gun was set on "Peak mode" to detect maximal ball velocity between the range of 80 to 232 $km \cdot h^{-1}$. Before each experimental session, the radar gun was calibrated in accordance with the manufacturer's specifications. The radar was positioned on the center of the baseline, 4 m behind the server, aligned with the approximate height of ball contact (~ 2.2 m) and pointing down the center of the court. After a brief warm-up for the joints involved in the service motion (i.e., dynamic movements in the shoulder, plus five slow services), players performed eight maximum serves, all to the advantage court. To be recorded, serves had to be in the service box. The highest speed recorded was used for analysis. The inter-trial reliability for serve velocity was 3.2%, similar to previous research (Hornery et al., 2007).

Serve accuracy: The accuracy scores for the serve were determined by counting the number of times the ball landed within the designated target perimeter (Figure 1). Target dimensions were designed considering similar methodologies, available resources, through discussion with coaches and athletes and preliminary trials (Hornery, et al., 2007). As illustrated in Figure 1, the target area for the serve was inside the intersection of the service line and the centre line. Participants served from the deuce court and were instructed to "serve first serves flat and down the T" (centre line). Shots landing within target

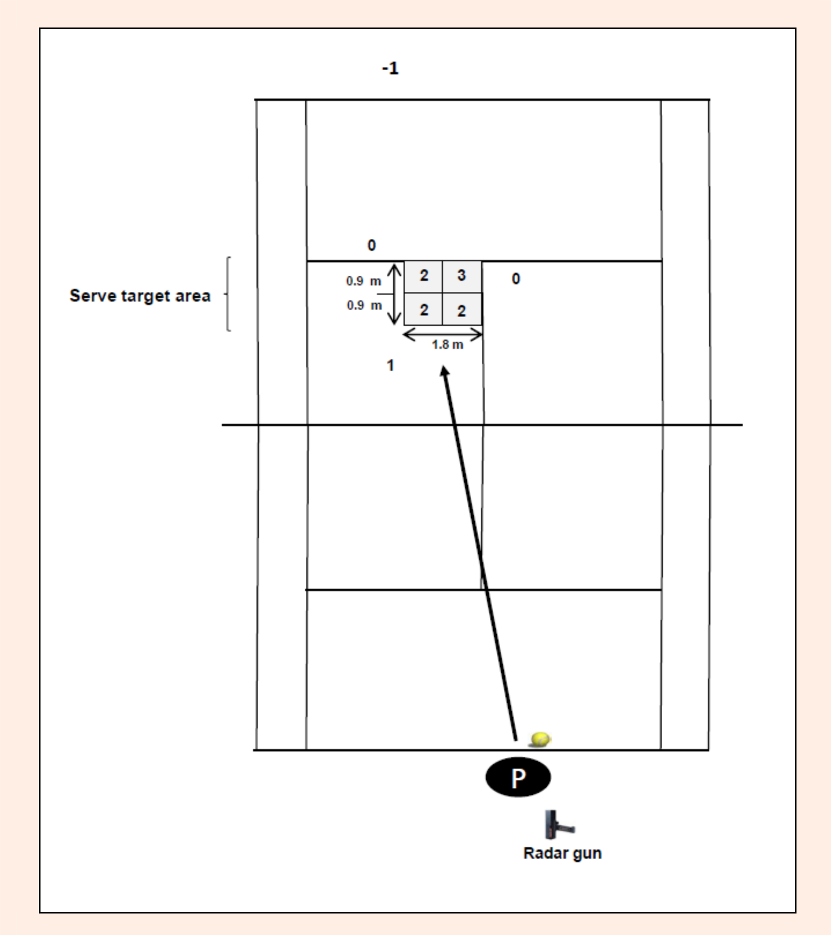

Figure 1. A schematic representation of the serve performance test and target area dimensions. P: Player.

areas were ranked according to a 3, 2, 1, scoring system. Balls landing outside the perimeter of the target areas (i.e., errors) received a 0 score. A total score, expressed as a percentage of the maximum, was recorded for each trial.

Training program

One week before the training period started two experienced strength and conditioning coaches demonstrated and explained how to correctly perform all exercises. Moreover, they trained all 15 subjects (i.e., divided in two groups) in the training group throughout the 6-week intervention. Another experienced researcher supervised the training program in the control group. Both groups participated in a similar tennis training program (see “subjects” subheading) with competitive matches on the weekends, while the experimental group had additional training sessions. The experimental group subjects were asked to come around 1 hour before joint tennis training sessions so they could perform additional training, and then participate in regular training together with controls. In order to be included in the analyses, subjects had to attend more than 90% of the training sessions. The program for the training group was approximately 60-70 minutes in duration, and performed three times a week, for 6 weeks. Each session comprised of a 10 min warm-up, and approximately 50 min of strength training (combining core, elastic tubing and medicine ball exercises). All training sessions were preceded by a 10-min standardized dynamic warm-up (arm circles in multiple directions, side stretch to the right and left, forearm supination and pronation, and wrist flexion and extension). The next 10-15 min consisted of basic core training exercises (i.e., crunches, reverse crunches, oblique crunches, plank, side-plank). Each player performed two sets of 20 repetitions for the first three exercises, and two sets of 20 s for the last two exercises.

The subsequent 25 minutes of the program consisted of using elastic tubing (Theraband, Performance Health Corporation, Akron, Ohio) for nine upper extremity strength exercises. The elastic tube was attached to a wall at the height midway between the subject’s hand and elbow. Subjects stood upright facing toward the wall for external rotation exercises and away from the wall for internal rotation exercises, at a distance from the wall that was sufficient to cause fatigue at the end of each set without compromising form. Theraband resistance was selected and increased, if necessary, by changing the band grade (red or green). Exercises were performed for 2 sets of 20 repetitions, with 45 s rest between exercises, and included the following: (a) triceps (elbow extension); (b) rowing; (c) external rotation with shoulder flexed 90°; (d) external rotation with shoulder abducted 90°; (e) shoulder abduction to 90°; (f) diagonal pattern flexion; (g) reverse throw; (h) standard forward throw; and (i) wrist flexion-extension. Each exercise was performed in a 3-s repetition (1 s for the concentric phase and 2 s for the eccentric

Table 1. Individual characteristics of the players. Data are means (±SD).

	Age (years)	Height (m)	Weight (kg)	PHV (months)	Age at PHV (years)
Intervention group (n = 15)	13.2 (.6)	1.61 (.09)	49.8 (8.9)	-.7 (.8)	13.9 (.5)
Control group (n = 15)	13.2 (.5)	1.63 (.08)	49.8 (7.4)	-.5 (.8)	13.8 (.6)

phase). Each subject was instructed on how to perform each exercise with proper form and technique and use enough resistance for each exercise that allowed them to perform 20–25 repetitions but no more. The subjects adjusted the tension in the elastic tubing (i.e., by using greater elongation during exercise to increase the resistance, or changing to more resistant bands if necessary) to accommodate their improvements in muscular strength throughout the 6-week duration (Escamilla et al., 2010).

The next 20 minutes consisted of a medicine ball-throw (e.g., 2 kg) training program consisted of seven exercises, which were performed for two sets of 8 repetitions (i.e., each side if the exercise was performed with just one arm), with ~1 min rest between exercises, including the following: (a) Chest pass; (b) Overhead throw; (c) Ear throw; (d) Squat to thrust; (e) Overhead slam; (f) diagonal wood-chop; and (g) close-stance throw.

At the end of the regular training both groups, training and control, performed ~15 min of a supervised stretching program with more emphasis in the major muscle groups involved in the serve. Two 15-s static stretches were performed for each of nine stretches. Stretches included a bilateral quadriceps stretch, hamstring stretch, and trunk twists. Unilateral (racket side) stretches were performed for the latissimus dorsi, pectoralis major, triceps brachii, wrist flexors, and shoulder (i.e., sleeper stretch & horizontal adduction cross-body stretch (Kovacs and Ellenbecker, 2011). Stretches were held just ''before the point of discomfort'' with approximately 10 s between repetitions (Knudson et al., 2004).

Statistical analyses

All data are presented as mean (±SD). Paired t tests were used to compare mean differences between pre- and post-test data for the separate experimental and control groups, and independent samples t tests were used to compare mean differences of changes (i.e., serve velocity, accuracy and shoulder rotation) by the experimental versus the control group. The level of significance used was $p < 0.05$. Statistical analyses were performed using the SPSS version 17.0 (SPSS Inc., Chicago, IL) software. In addition, the standardized difference or effect size (ES) of changes in each parameter between the training and control groups were calculated using the pooled pre-training standard deviation. Threshold values for Cohen ES statistic were > 0.2 (small), 0.5 (moderate) and > 0.8 (large) (Cohen, 1988).

Results

Mean (±SD) of the individual characteristics of the players are presented in Table 1. There were no significant differences in age, mass, height and PHV comparisons between control and training groups.

Mean (±SD) serving velocity comparisons between pre-test and post-test measurements for the control and training groups are shown in Table 2. There was a significant improvement in the serve velocity for the training group ($p = 0.0001$) after the intervention, whereas in the control group there were no differences between pre and post-tests ($p = 0.29$). Serve accuracy was not affected in the training group ($p = 0.10$), nor in the control group ($p = 0.15$) after the 6 week study. Shoulder internal/external rotation ROM significantly improved in both groups, training ($p = 0.001$) and control ($p = 0.0001$), after the 6 week intervention. Independent sample *t*-tests showed significant differences between training and control groups in the serve velocity, with the training group showing significantly higher serve velocities ($p = 0.01$) after the training intervention. There were no differences between groups in the serve accuracy ($p = 0.95$) and shoulder internal/external rotation ($p = 0.07$) after the 6-week study. The training group increased 13.6 degrees in total rotation ROM while the control group increased 8.2 degrees All subjects participating in the study did not miss any training sessions, demonstrating excellent compliance with the training program.

Discussion

The present results showed that a short-term training program for young tennis players, using minimum equipment and effort, can result in improved tennis performance (i.e., serve velocity) and a reduction in the risk of a possible overuse injury, reflected by an improvement in shoulder external/internal range of motion.

To the best of our knowledge this is the first study conducted with competitive young tennis players evaluating functional performance (i.e., serve velocity) after a combined strength-training intervention consisting of

Table 2. Mean (± SD) serve velocity, serve accuracy and shoulder rotation comparisons between pre-test and post-test measurements for the control and training groups.

	Group	Pre-test	Post-test	Effect size
Serve velocity (km·h^{-1})	T	150.3 (12.3	157.9 (12.5) *	.41
	C	146.1 (10.7)	146.6 (10.4)	.01
Serve Accuracy (points)	T	12.2 (2.5)	13.5 (3.6)	.29
	C	12.5 (2.5)	13.5 (2.7)	.25
Shoulder rotation (°)	T	166.0 (20.2)	179.6 (14.0) #	.50
	C	161.4 (15.5)	169.6 (14.1) #	.36

* Significant ($p < 0.001$) differences between training and control group.
# Significant ($p < 0.001$) differences between pre- and post-test.

core-strength, elastic tubing and medicine ball exercises. Serve velocity increased 4.9% in the training group, which is lower than the results from previous research (Ellenbecker and Roetert, 1999; Mont et al., 1994; Treiber et al., 1998) showing improvements in serve velocity between 6-10% after short (4-6 weeks) strength training interventions. The differences observed may be due to several factors including age groups (college tennis vs young players) differences in the duration of training, method of training (isotonic compared with isokinetic), and the intensity of training sessions. Because serve velocity improvement in youth may simply occur from normal aging and maturation, it was important to control the PHV and the predicted age at PHV (Mirwald et al., 2002), as well as the use of a control group. Results showed that players involved in the study were around 6 months to achieve their PHV. Previous data showed that peak strength development occurs about 1-1.5 years after PHV (Armstrong and McManus, 2011). Moreover, given the random assignment of the subjects within the 2 groups, and that the strength training program was the only variable that differed between the groups, it can be suggested that the intervention was the main reason for the improvement in serve velocity in the training group, especially given that the control group did not improve in their serve velocities.

Although the importance of the serve in modern tennis has not been questioned, information about the effects of different strength training programs in tennis player's performance is limited. To the best of our knowledge there are no intervention studies regarding developmental age tennis players. The present results are similar to previous research conducted with young or high school baseball players (Escamilla et al., 2010; Wooden et al., 1992) which also examined the effects of strength training on throwing velocity, and finding significant improvements (2-3 $km \cdot h^{-1}$) after short term training interventions (4-8 weeks). Interventions used were similar to those conducted in the present study, with combined elastic tubing and plyometric (throws) exercises. Because the tennis serve is a complex movement, involving a summation of forces sequenced in a largely proximal to distal (legs, trunk, and arm/racquet) fashion (Elliott, 2006; Roetert and Ellenbecker, 2007), we decided to use a combined strength-training program, using core-stability, elastic tubing and plyometric (i.e., medicine ball throws) exercises.

Given the prevalence of shoulder joint injury in the modern professional game, strengthening the rotator cuff is considered a fundamental component of any tennis-specific resistance training program (Reid and Schneiker, 2008). Although elastic tubing exercises are often recommended for athletes' shoulder strengthening and rehabilitation (Myers et al., 2005), only one previous study empirically evaluated the influence of elastic bands combined with lightweight dumbbells on shoulder strength and performance in college tennis players (Treiber et al., 1998). Results showed an increase in pre-post training levels of internal and external shoulder rotation torque together with an increase in serve velocity. Moreover, studies in baseball have also shown performance improvements (i.e., throwing velocity) after training interventions using isolated shoulder internal and external rotation exercises (Carter et al., 2007; Wooden et al., 1992). Therefore, it seems that the use of elastic resistance (e.g. therabands) is highly recommended for developmental tennis players in order to improve their performance levels.

During the tennis serve, rotation of the trunk is an integral part of the development of power and transfer of energy up to the kinetic chain from the lower to upper extremities (Ellenbecker and Roetert, 2004), and the use of training programs utilizing medicine balls and core stabilization exercise in various patterns of trunk and pelvic rotation are strongly recommended for tennis players (Ellenbecker and Roetert, 2004; Roetert et al., 2009; Roetert and Ellenbecker, 2007). Therefore, we can suggest that players involved in the training program also improved their performance through an improvement in the kinetic chain, as some basic exercises focussed on strengthening the core musculature were included in the training program (Kovacs and Ellenbecker, 2011; Roetert and Ellenbecker, 2007). Unfortunately, we are not able to prove this statement as we did not measure trunk rotation strength directly (e.g., isokinetic measurements), and further research is needed to determine the relative contribution of core-stabilization training in tennis performance.

Upper extremity plyometric exercises have gained popularity, and their use by strength and conditioning specialists is increasing. Previous research has supported their use in other sports such as baseball (Carter et al., 2007), with results showing increases in both throwing velocity and shoulder peak torque strength. In tennis, just one recent study showed that a training intervention performing handled-medicine-ball throws, included in the regular tennis practice, improved peak ball velocity during crosscourt forehand drives in a group of adult tennis players (Genevois et al., 2012). Therefore we can suggest that upper-extremity plyometric exercises can be frequently used by athletes in the pursuit of more powerful functional performance.

As previously mentioned, shoulder injuries are very common overuse injuries among tennis players and muscle imbalance between the external & internal rotators has been attributed as one possible cause of these overuse injuries (Ellenbecker and Roetert, 2003; Pluim et al., 2006). In the modern game of tennis, up to 75% of all strokes consist of serves and forehands (Roetert and Ellenbecker, 2007). These strokes are both characterized by the inherent use of powerful concentric internal rotation for power generation along with the trunk and lower extremity musculature in the kinetic chain. Due to this repetitive shoulder internal rotation and imbalance has been objectively measured (Ellenbecker et al., 2009; Ellenbecker and Roetert, 2003). Significant emphasis in both preventative conditioning and rehabilitation strength and conditioning programs is placed on the posterior rotator cuff (external rotators) since the external rotators undergo tremendous eccentric contraction and overload during the deceleration phase of the service motion (Ellenbecker et al., 2009; Ellenbecker and Roetert, 2004; Kovacs and Ellenbecker, 2011).

Results from the present study showed that both groups, training and control, improved their shoulder internal/external rotation ROM levels (7.6% and 4.6%, respectively) after the 6 week intervention, which can be due to the supervised stretching programme that both groups performed after the training sessions. A limitation of the present study was that functional strength ratios of the shoulder rotators were not investigated, which could have provided more specific information about the effectiveness of the present training program. Although there is an incomplete understanding of the effects of stretching on performance and injury risk, data from the literature can be used to suggest general guidelines appropriate for tennis players (Knudson et al., 2004). Based on the present data young tennis players should perform static stretching exercises in the cool-down phase following matches or conditioning in order to maintain or increase ranges of motion particularly for potential areas of limitation, such as shoulder internal rotation (Ellenbecker et al., 2002; Roetert and Ellenbecker, 2007).

Practical application points

The present study showed that a short-term tennis-conditioning program is effective in enhancing serve velocity in junior developmental tennis players. In just 6 weeks of combined strength training players participating in the training groups increased their serve velocities almost 5%, while players in the control group showed a small increase of only 0.2%. Due to the importance of the tennis serve, as the most powerful and potentially dominant shot in tennis, these strength-focussed training interventions, especially in developmental players, can be helpful to increase performance levels. Based on the results of this study, young tennis players who want to improve their performance levels should perform supervised strength training, three times a week, combining core stabilization, elastic resistance exercises, and upper body plyometric exercises (i.e., medicine ball throws), focussing on the primary muscle groups and stabilizers involved in tennis specific movement patterns. One of the primary advantages of this training program is that only inexpensive resistance devices are needed (elastic tubing, dumbbells, medicine balls), so it can be easily implemented during the daily training routine. For example, the use of elastic tubing rank among the most common training tools used by professional players, because of their portability and flexibility in allowing athletes to explore variable ranges of motion, resistances, and limb positions (Reid and Schneiker, 2008).

Conclusion

In conclusion, the present study showed that a short-term training program for young tennis players, combining core-strength, elastic resistance and medicine ball exercises resulted in improved tennis performance (i.e., serve velocity) and a reduction in the risk of a possible overuse injury, reflected by an improvement in shoulder external/internal range of motion. Limitations of the present study (i.e., evaluation of the functional strength of the trunk or shoulder rotators) warrant future research, which should focus on comparing the direct effects of different durations of training programs (e.g., 4 to 12 weeks) on tennis performance and functional strength.

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Key points

- A short-term training program for young tennis players, using minimum equipment and effort, can result in improved tennis performance and a reduction in the risk of a possible overuse injury, reflected by an improvement in shoulder external/internal range of motion
- A combination of core stabilization, elastic resistance exercises, and upper body plyometric exercises (i.e., medicine ball throws), focussing on the primary muscle groups and stabilizers involved in tennis specific movement patterns, could be appropriate for development tennis players
- Stretching exercises are recommended in the cool-down phase following matches or training sessions.

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