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Review of the Literature

EFFECT OF SPECIFIC STRENGTH AND POWER TRAINING ON SERVING VELOCITY IN TENNIS PLAYERS

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BLUF

Appropriately programmed Tennis-specific Strength and Power training has the ability to increase serving velocity (km/h) amongst semi-professional Tennis athletes.

ABSTRACT

Professional Tennis players are amongst some of the fittest and most robust individuals in the modern sporting world. Greater attention is gradually being placed on Strength and Conditioning (S&C) training for the modern-day Tennis athlete, as significant forces and torques are generated through performing their respective strokes, most notably the Serve. The purpose of this paper was to outline the contribution of the lower- and upper-body on the serving motion, and their impact on absolute ball velocity. A thorough search for literature was conducted via Google Scholar. 25 primary articles was narrowed down to 11 based off inclusion criteria that consisted of a) Tennis experience, b) training program focus, and c) serving velocity measurement. Two of the 11 studies failed to show any positive change in serving velocity which may result from methodological considerations. Majority of studies demonstrated improvements in serving velocity, ranging from ~3.0-29.0%. This large margin reflects the studies differing timeframes, spanning between 4-weeks and 9-months. Majority of the contribution for absolute ball speed comes predominately from lower-body and trunk regions (~50% of total kinetic chain force). The shoulders prove to have a significant contribution to the pace of the ball, however injuries are most common in this region due to agonist-antagonist imbalances. Trunk musculature provides great dynamic support during the momentum shifting of the serving motion. The Tennis serve is fundamentally a whole-body explosive kinetic-chain movement that requires significant practice, especially surrounding technique and coordination. Adopting a full-body periodised S&C program is best suited for the modern-day athlete, with the integration of lower- and upper-body plyometric exercises, and trunk strength and stability.

Key Words – Tennis serve, strength, power, lower-body, upper-body.

INTRODUCTION

Highly trained tennis players, such as the likes of Roger Federer and Rafael Nadal, are said to be some of the fittest and most dynamically robust athletes in the modern world of sport. Considering the advancements in Strength and Conditioning (S&C) training principles and technology over the past few decades (i.e. racquet design) (28), the nature of the game has been shown to gradually gravitate towards a power and speed-dominant play style, with athletes consistently serving upwards of 200+ km/h (20). The serving motion proves to be one of the most challenging shots to perform as several temporal and positional factors must be considered simultaneously (i.e. stance, ball toss, cocking of the racquet, and striking the ball at full extension) (1). Kovacs has provided an in-depth outline of the serving motion, culminating in '8-stages' (21).

The high neuromuscular demand that comes with this movement is reflected by an athlete's ability to maintain total body control and dynamic stability during a three-set match. Furthermore, modern-day players have been seen to place an equal amount of emphasis on off-court training modalities (i.e. strength training) as on-court technical/tactical training (30), in order to help withstand neuromuscular fatigue which is highly evident in intermittent sports such as Tennis (14). This higher demand for Strength and Power only gives rise to the question of the approximate contributions the upper- and lower-body segments provide during the Tennis serve. Several studies have investigated such contributions, leading to an overall consensus that each segment plays a vital role in the velocity of ball at impact (2-8, 10, 14, 17, 19-21, 25, 27, 30, 31, 33-35, 37). Therefore, the purpose of this literature review was to investigate the effect of segment-specific strength and power training modalities on serving velocity.

METHODS

Search Methodology

Searching for the appropriate literature was conducted through the Google Scholar database. Search words/phrases included “Tennis Serve Velocity”, “Strength”, “Power”, “Upper- and Lower Body” and “Training program”. 25 initial articles were chosen and critically analysed. After narrowing the search, 11 primary articles were chosen based on the inclusion criteria presented. The time span of the chosen articles range from 1994-2016.

Inclusion Criteria

The primary articles used for this review were chosen based on the following criteria: a) Subjects were required to have at least two years of competitive Tennis experience; b) Training programs followed either a strength and/or power-dominant focus, and; c) Serving Velocity was measured using Radar Gun.

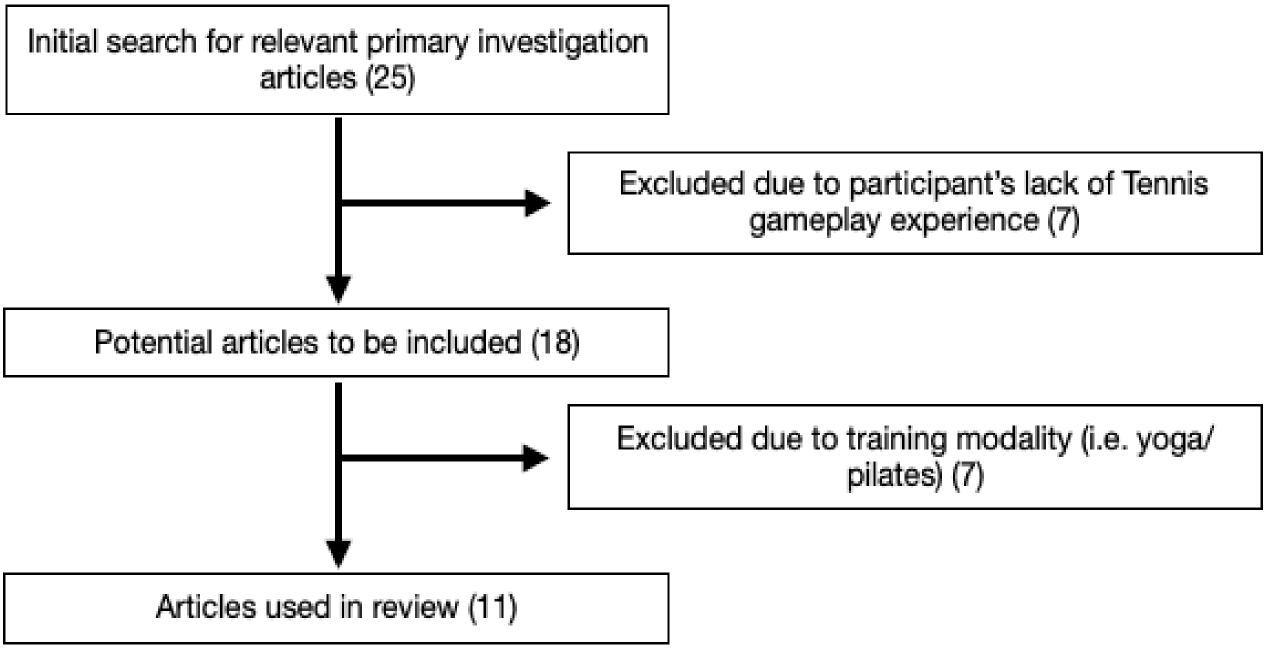


Figure 1 - Schematic diagram of article selection for literature review.

DISCUSSION

The complexity of the tennis serve demonstrates the uniqueness of the Kinetic Chain principle (19) which is evident in most sports that involve throwing (i.e. baseball, cricket) (13, 26) and kicking (i.e. Australian Rules Football, Soccer). Voluntary force production capabilities become more pronounced when the efficiency and fluency of the action becomes more rhythmic and coordinated (9). Being that the tennis serve is a whole body movement (stemming from the lower- to the upper-body), a great deal of technical and temporal factors must be considered in order to adequately perform the skill (34). Figure 2 below shows the transitions within the serving motion. Younger individuals who are new to Tennis will ultimately come to the realisation that the serve is indeed the one of the hardest shots to perform as it taxes the neuromuscular system due to the high inter-muscular coordination demand (15, 24).

Figure 2 - Transitions within the serving motion *(A = Start phase, B = Loading/Cocking Phase, C = Acceleration/Ball Contact Phase, D = Follow-Through/Deceleration Phase).*

Little research has been performed on fitness characteristics of elite tennis players. Ulbricht and Colleagues (38) outlined and compared the performance characteristics of U12, U14, and U16 elite male and female junior tennis players from a regional and national level. As was expected, national level players showed better results in all fitness tests across all ages. For the purpose and foci of this paper, the following results from Ulbricht's study can be used as a guideline for S&C coaches when testing serving velocity amongst elite junior athletes.

	Male	**Female**
CMJ (cm)	~37	~32
Grip Strength (kg)	~43	~35
Overhead Medicine Ball Throw (cm)	~977	~759
Serving Velocity (km/h)	~173	~153

Table 1 - Performance characteristics of u16 elite junior male and female national tennis athletes.

Of the 11 studies reviewed, two showed no positive changes in serving speed. Smart (35) conducted a two 4-week split core-focused training program on intermediate level Tennis athletes (~3.4yrs Tennis experience). For the first 4-week split, exercises revolved around stability and endurance (i.e. planks and sit-ups), while the next 4-week split focused on strength and power (back bridges and medicine ball throws). Other biometric tests were found to strongly correlate with serving velocity (e.g. 5RM bench press [r = 0.76] and vertical jump [r = 0.64]), however core endurance showed negative correlation (r= <0.36), concluding that upper- and lower-body strength and power exercises should be performed alongside core-training. Terraza-Rebollo (36) conducted a PAP-style training program for competitive adolescent Tennis athletes (>4yrs Tennis experience). The premise behind this program was that after performing 80% 1RM Bench Press and/or 80% 1RM Half Squat (3x3), that this would elicit greater serving velocity. Appropriate protocol was followed in terms of time elapsed before testing serve testing (0-, 5-, 10- & 15-min after exercise), however no change was found. Specificity of training was highlighted in the limitations of this study, with a recommendation for future studies to perform power-focused exercises (i.e. trap bar jump squats and medicine ball throws) as these better resemble the movement velocity seen in the serve. Table. 2 below outlines all 11 studies reviewed.

Table 2 - Summary of interventions.

Reference	Subject Characteristics	Training Program	Outcomes Measured	Observations and Conclusions
Behringer (2013) [3]	36 M Adolescent Tennis players ~15.03yrs old ~6.15yrs Tennis experience	Two different 8-week training programs (2d/wk): RTG – Full body machine-based ST: 7 exercises 2x15 w/ CON and ECC focus Rest b/w sets = 1min PTG – Full body Explosive training: 4-8 exercises 3-4x10-15 Rest b/w cycles = 1min	**Serving Tests:** Velocity (km/h) Precision (cm) **10 RM Testing:** Leg Press Chest Press Pull-down machine Abdominal Press	PTG showed a mean increase of ~3.8km/h in serve velocity, whilst the RTG only increased by ~0.5kmh. Both RT and PT groups showed insignificant changes in serving precision.
Fernandez-Fernandez (2013) [12]	30 M Nationally ranked Junior Tennis players ~14.2yrs old ~3yrs Tennis experience	6-week multi-focus training program (3d/wk): Core Training (2x20/20s) Elastic Tubing Strength Training (2x20) Medicine Ball Power Training (2x8)	**Serving Tests:** Velocity (km/h) Accuracy (%) **Biometric Test:** IR & ER Shoulder ROM (˚)	TG showed a 3.6˚ (7.6%) improvement in total Shoulder ROM. 4.9% increase in Serving Velocity, whilst accuracy showed no significant improvement.
Fernandez-Fernandez (2016) [11]	60 M International Academy Tennis Players ~12.5 yrs old ~3yrs Tennis experience	8-week PT focus training program (2d/wk): Bi-weekly sessions (n=16) w/ Upper- and Lower-body Focus: 4-8 exercises 2-4x10-15 Rest = 15-90s	**Serving Tests:** Velocity (km/h) Accuracy (%) **Biometric Tests:** CMJ SLJ (m:cm) 20-m sprint time (w/ 5- and 10-m splits) (s) 505 agility test (s) Overhead MBT (m)	Significant increases in biometric measures (SLJ & CMJ (8.4% & 6.3%, respectively) 6.2% and 9.6% improvement in serve velocity and accuracy respectively.
Gelen (2012) [14]	26 unspecified Elite Tennis Players ~15.1yrs old ~8.4yrs Tennis experience	4 individualised WU protocols performed on non-consecutive days: Traditional (TRAD) 5min Jog + rally & serve TRAD + Static Stretches (SS) TRAD + 7 SS TRAD + Dynamic Exercises (DE) TRAD + 6 DE TRAD + Plyometric Exercises (PLY) TRAD + 6 PLY	**Serving Tests:** Velocity (km/h)	TRAD + DE & TRAD + PLY protocols showed greatest improvement in Tennis serve velocity (1.23% and 3.33%, respectively). Static Stretching prior to performing a multi-jointed highly coordinated action such as the Tennis serve showed no significant change ball speed.
Kraemer (2000) [23]	24F Collegiate-level Tennis Players ~19.2yrs old ~7.8yrs Tennis experience	9-month Full-body RT program w/ differing treatment groups (2-3d/wk): Periodised RTG: 2-4x4-15RM 1-3min rest b/w sets Single-Set RTG: 8-10RM 1-2min rest b/w exercises	**Serving Tests:** Velocity (m/s) **Biometric Tests:** 30s Wingate Test CMJ (cm) 1RM Leg Press 1RM Shoulder Press 1RM BP	Significant improvements in all Biometric measures for Periodised RTG. Max. Serving Velocity for Periodised RTG showed to be well above Single-Set RTG after each time point (4, 6, & 9 months).
Kraemer (2003) [24]	27F Collegiate-level Tennis Players ~19.0yrs old ~8.1yrs Tennis experience	9-month Full-body RT program w/ differing treatment groups (2-3d/wk) Periodised RTG 2-3x4-15RM 1.5-3min rest b/w sets Non-periodised RTG 2-4x8-10RM 1.5-3min rest b/w sets	**Tennis-Specific Tests:** Serve Velocity (m/s) FH & BH Velocity (m/s) **Biometric Tests:** 30s Wingate Test VO2max Test 10- & 20-m Sprint time (s) Lateral Agility Test Grip Strength CMJ (cm)	Significant improvements in all Biometric measures for Periodised RTG at all time points (4, 6 and 9 months). Periodised RTG consistently showed greater results in Tennis-specific shots than Non-periodised RTG (Serve [29% vs. 4%], FH [22% vs. 17%], BH [36% vs. 14%, respectively]).
Malliou (2011) [25]	29M + 31F (n = 60) Junior Tennis players ~14yrs old ~2yrs Tennis experience	7-week Shoulder-Specific Training program (3d/wk): Service-only Group 15mins extra serving per session	**Serving Tests:** Velocity (km/h) **Biometric Tests:** Shoulder rotator strength (IR & ER)	Serving velocity significant improved amongst Junior athletes after engaging in Shoulder-specific ST.

		Shoulder-specific Strength training 6 exercises 2x10-15 0.5-1kg	Shoulder IR & ER ROM	Serving alone showed to improve ROM far greater than ST + serving, however ST provided joint stability.
Mont (1994) [29]	30M Tournament-level Tennis Players ~33yrs old	6-week Shoulder-focused RT program w/ differing treatment groups (3d/wk): ECC IR & ER 8x10 w/ 60s rest b/w sets Pyramidal scheme of varying velocities CON IR & ER 8x10 w/ 60s rest b/w sets Pyramidal scheme of varying velocity	**Serving Tests:** Velocity (mph) **Biometric Tests:** Isokinetic Shoulder Strength (IR & ER) (˚/s)	ECC and CON RT for the shoulder was shown to improve total avg. strength by 11%. Both groups demonstrated a >11% increase in avg. serve velocity (10.5mph & 9.9mph for ECC and CON respectively). Training groups showed less of a drop in speed (~2.2%) compared to control group (6.4%).
Smart (2011) [35]	17M+18F (n=35) Intermediate level Tennis players ~25.2yrs old ~3.4yrs Tennis experience	8-week Core-Focused Training Program (2d/wk): Two 4-week split focus (Wk 1-4 = Stability & Endurance; Wk 5-8 = strength and power).	**Serving Tests:** Velocity (km/h) **Biometric Tests:** Grip strength (kg) 5RM Back Squat 5RM BP VJ height (cm) Core plank time (min:sec) Back ext. time (min:sec) IR & ER Shoulder ROM (˚)	Serving Velocity was not related to core plank times in Intermediate level Tennis players. Additional upper- and lower-body strength/power exercises should be performed alongside core training.
Terraza-Rebollo (2020) [36]	9M + 6F (n=15) Competitive adolescent Tennis Players ~15.6yrs old ~>4yrs Tennis experience	PAP-style training program w/ differing sessional focuses: CON WU + Serve Test Bench Press (BP) WU + 3x3 @ 80%1RM + Serve Test Half Squat (HS) WU + 3x3 @ 80%1RM + Serve Test BP + HS WU + 2x3 @ 80%1RM + Serve Test	**Serving Tests:** Velocity (km/h) Accuracy (%) **Biometric Tests:** 5RM BP 5RM HS	PAP-style training did not show any meaningful gain in serving velocity and accuracy, despite following an appropriate protocol (serve tests performed at 0-, 5-, 10- & 15-min after exercise). Principle of specificity highlights the need to perform sport-specific movements at a velocity similar to that of the movement itself.
Treiber (1998) [37]	12M+10F (n=22) College Varsity Tennis Players ~21.2yrs old	4-week Shoulder-focused RT program using Therabands (TB) and Dumbbells (DB) (3d/wk): TB Exercise: IR & ER w/ 90˚ Abd. 2x20:2x20 (slow:fast) DB Exercise: 'Empty Can' 4x20 (slow)	**Serving Tests:** Velocity (km/h) **Biometric Tests:** Isokinetic Shoulder Rotation Torque (˚/s)	Engaging in Shoulder-specific ST can significantly improve peak serve velocity (6.0%). IR & ER measures showed a drastic improvement (23.8% & 17.0% increase in IR and ER torque, respectively).

M = Male; **F** = Female; **d/wk** = days per week; **RM** = Repetition Maximum; **BP** = Bench Press; **VJ** = Vertical Jump; **ext.** = extension; **IR** = Internal Rotation; **ER** = External Rotation; **ROM** = Range of Motion; **RTG** = Resistance Training Group; **PTG** = Plyometric Training Group; **CON** = Concentric; **ECC** = Eccentric; **TG** = Training Group; **CMJ** = Counter Movement Jump; **SLJ** = Standing Long Jump; **MBT** = Medicine Ball Throw; **WU** = Warm Up; **Abd.** = abduction; **RT** = Resistance Training; **ST** = Strength Training; **FH** = Forehand; **BH** = Backhand.

LOWER BODY CONTRIBUTION

Providing a stable, yet mobile base of support during the serving motion can drastically improve serving performance. With the kinetic-chain principle in this case stemming from the lower-body (ankles, knees and hips) (4), it is essential that athletes devote sufficient amount of time on their lower body force and power production as they do for their upper body. Contrary to popular belief amongst Tennis amateurs, the ability to increase absolute ball velocity actually stems from the lower body as opposed to upper body mechanics (16). High amounts of elastic energy via the stretch-shortening cycle (SSC) is created from the athlete lowering their centre of mass (knee flexion) in preparation to jump up (Figure 2B) and connect with the ball mid-flight with their racquet. This fundamentally creates a larger gap between the height of ball contact, and the height of the fixed net (4). This factor, stated as the vertical lift of the body (4) (Figure 2C), enables a more acute angle of ball projection, and therefore allows athletes to strike the ball harder with a concomitant increase in percentage of successful serves in the appropriate service box (4). Girard and Colleagues (16) found that after restricting knee motion (flexion and extension), a significant reduction in maximum vertical ground reaction force (~0.75 Fz) and absolute ball speed (~25 km/h) was evident. Consequently, the restricted motion in the knees not only directly impacted the ability to generate elastic energy for ensuing rapid knee extension, but also restricted the trunks ability to go into lateral flexion and rotation (Figure 2B). It has been previously estimated that amongst world-class athletes, ~50% of the kinetic energy force production comes from the lower body (25), highlighting the importance of appropriate Strength and Conditioning (S&C) programs. As well, the athletes body height plays a significant role in obtaining a greater standing reach upon impact and absolute serving speeds (4, 17, 34, 39), and has been shown to explain 27-30% of the average variability of the first serve (39).

Rate of force development (RFD) has been shown to improve after participating in power-based training methods such as plyometrics (9, 11). As alluded to previously, increasing an athlete's ability to improve ball velocity is predominantly accomplished through the upwards propulsion of the entire body (4). Making contact with the ball with an outstretched arm during the acceleration phase has been shown to occur at approximately 150% standing height amongst elite Tennis players (16). This can only be achieved when the lower body descends into a flexed position (~110˚-120˚) (34) and begins to generate and store elastic energy through the musculotendinous unit. This potentiated energy is then released and utilised during a jumping motion up and forwards (˚45 projection angle). Lower body plyometric exercises (i.e. box jumps, pogo jumps, multi-directional hurdle jumps) are becoming more popular amongst the Tennis community as they simulate the movements of the serve with respect to movement velocities (33). Fernandez-Fernandez and Colleagues (11) found that after an 8-week full-body plyometric training program that included exercises such as CMJ, multidirectional hurdle jumps and zig-zag jumps, serving velocity improved by 6.2% (138-147 km/h).

Behringer and Colleagues (3) demonstrated that serving velocity failed to show any improvement after an 8-week targeted whole-body resistance training program within adolescent-aged Tennis athletes (~15yrs). Exercise selection within their program showed limited usage of movement velocity specificity which is highly necessary for Tennis athletes (4, 30). Essentially, the closer the exercise resembles the sporting movement in terms of movements velocity and patterning, the greater the performance outcomes (e.g. medicine ball sidearm throws mimicking the forehand and backhand strokes). Similarly, Terraza-Rebollo (36) found no increase in serving velocity within competitive adolescent (~15yrs) Tennis athletes after conducting a post-activation potentiation (PAP) style training program that consisted of Bench Press and Half Squats at 80% 1RM. Ignjatovic and Colleagues concluded that after engaging in sport-specific weighted overhead and throwing movements using a medicine ball, semi-professional handball athletes showed significant increases in upper body throwing power after 12 weeks (22.4%) (18). Similarly, Fernandez-Fernandez and Colleagues concluded that upper-body plyometric exercises involving medicine balls (i.e. overhead throws and slams, closed-stance rotations and diagonal wood-chops) have been shown to increase serving velocity by ~5% (6.2% [11], 4.9% [12]).

Strong positive correlations have been found between peak serving speed and select performance measures such as Isometric Mid-Thigh Pull Peak Force (r = 0.87), Countermovement Jump (CMJ) Height (r = 0.77) and Impulse at 300ms (r = 0.71) (17). Additionally, peak electromyography (EMG) values have been recorded in the vastus lateralis (VL) and vastus medialis (VM) during the acceleration phase of the serving motion (at ball contact) (20). However, Bonato found no association between selected jumping tests (Squat Jump, CMJ, CMJ-Freehanded) and serving speed, concluding that the jump involved is merely coordinative and that maximal jump height is rarely achieved during the serve (4). Despite this statement, it was still concluded that vertical lift of the body is essential to increase distance between net and contact point, and that this can only be performed with the integration of lower-body Strength and power training.

UPPER BODY CONTRIBUTION

Upper body mechanics and muscular involvement have been heavily examined with regards to the Tennis serve, most specifically the internal (IR) and external rotation (ER) of the shoulder (2, 5, 6, 8, 14, 17, 21, 27, 29, 31, 37). This is expected as modern-day gameplay revolves around harnessing a rapid racquet head speed during the serve, forehand and backhand, resulting in greater propulsion velocities (20) However, significant amounts of force and torque comes with these movements and is the main reason why majority of injuries are within the shoulder region (37). Imbalances commonly occur between internal and external shoulder rotation strength, with internal being more developed than external as shown by Cohen (4:3, respectively) (8). This can be attributed to a) the repetitive nature of the game with the serve and forehand being the two most commonly performed strokes (12), and b) the high eccentric forces generated in the serving arm, allowing for greater concentric force production via the SSC (37). A strong positive correlation has been found between shoulder IR and serving speed (r = 0.67), explaining ~55% of the variance when combined with shoulder flexion (2). Similarly, a positive relationship was shown between ER and peak serve speed (r = 0.63) (17). This highlights the importance of strengthening the agonist-antagonist relationship of the shoulder rotator cuff muscles in order to lessen the risk of injury (9). This can be achieved through internal and external rotator cuff work using therabands. Shoulder IR and ER exercises are appropriate additions to the dynamic warm-up, and can be performed with either elbows at 90˚, or the shoulder flexed and abducted to 90˚. As well, emphasis can be placed on the eccentric portion of the movement as this can adequately prime the athlete not only for their strength/power training session, but also before on-court technical training (31).

The musculature at the anterior portion of the upper body (i.e. pectoralis major, anterior deltoids, shoulder internal rotators) are prime movers during the acceleration phase, providing significant contribution to velocity of the racquet before contact (34). Whilst the posterior portion, which consists of the rhomboids, trapezius and shoulder external rotators are responsible for decelerating the movement during the follow-through action (34). Appropriate mobilisation and activation of the muscular required for deceleration often goes overlooked in S&C programs, which can increase the incidence of injury due to significant torque production and absorption through the glenohumeral joint (22). Shoulder-specific exercises that focus on the eccentric phase (i.e. half-kneel 90˚/90˚ reverse catch [20]) help condition the muscle to tolerate loads whilst simulating movement velocity as seen in the follow-through.

Interestingly, with the wrist being the final link in the kinetic-chain, some would assume that the majority of power and speed comes primarily from this region. However, Baiget and Colleagues (2) found that wrist flexion increased the total upper body contribution by only ~3%. The gradual dissipation of force and power throughout the kinetic-chain ((19) [pg.171-172])) and the fact that the wrist musculature displays significantly smaller cross-sectional area in comparison to shoulder internal rotators can explain this. Despite this slight contribution, S&C coaches should not completely abandon wrist flexion and extension priming exercises for their athletes. Gelen and Colleagues (14) demonstrated that after performing upper-body velocity-specific plyometric exercises (i.e. overhead medicine ball throws, 90˚/90˚ reverse catch and throw, and 90˚/90˚ ER side throws) proceeding a dynamic warm-up, serving velocity increased by 3.3% in elite adolescent Tennis athletes (14). The 'dynamic exercise' condition in this study when combined with the same dynamic warm-up only showed a 1.23% increase in serving velocity. Furthermore, after performing a structured non-consecutive three-day therabands and light free-weight (0.5-2kg) shoulder-dominant training program alone for 4-weeks, 22 Varsity level Tennis athletes displayed a 6% increase in their peak serving velocity, which was partly attributed from a significant increase in internal shoulder torque (23.8%) (37). Neurologically, the serve is technically taxing for those individuals commencing Tennis gameplay, due to the time constraints involved (e.g. ball toss) (32). Thereby, technique and the ability to coordinate body segments in an organised fashion must be emphasised before participating in S&C training, as ensuing strength and power development will accentuate movement fluidity and efficiency (9, 32).

TRUNK CONTRIBUTION

The trunk, otherwise known as the core, which consists of the rectus abdominus, transverse abdominus, internal and external obliques and erector spinae muscles, plays a pivotal role in the development of dynamic balance and serving velocity, contributing approximately ~50% of the total generated kinetic energy (4). Ellenbecker and Roetert found a strong positive correlation between trunk rotation and flexion strength, and both FH ($r = 0.833$) and BH ($r = 0.826$) groundstroke velocity (10). As commonly seen in the preparation phase (cocking) of the serve, athletes are shown to be in an arched position (lateral flexion and back extension [Figure 2B]) as the ball is released from their ball toss hand (20, 34). A great deal of eccentric activation from the anterior portion of the trunk is necessary to prevent excessive back extension (7), but also assists to maintain dynamic balance which is complimented by flexing the knees and ankles. For example, a high degree of activation has been seen in the left external obliques in right handed players at the end of the cocking phase (7, 21). Angular momentum of the trunk amongst professional athletes are shown to be greater than their amateur counterparts, demonstrating higher serving speeds (33).

Furthermore, trunk musculature show their highest activation levels as the athlete starts their swing overhead (cocking into acceleration) (20). As seen in the figure below (Figure. 3), the athlete (left handed) goes through a rapid reversal transition of the lower back (B = Hyperextension and left side twist, into C = Flexion and right side twist). Evidently, not only are coordination and timing significant factors when it comes to performing the serve, but also the fact that multiple planes of motion are utilised in rapid succession (34) giving the athletes more of reason to participate in specific S&C training that emulates the serving motion (e.g. overhead medicine ball throw, cable woodchop).

The follow-through phase is critical when it comes to decelerating the racquet and absorbing the shock when landing back on the ground after the explosive jump (20). Despite its significance, training the necessary musculature that are involved in the deceleration phase (i.e. erector spinae, rhomboids) often gets overlooked (22). Being able to distribute the high degree of force build up during the acceleration phase over a longer period of time has its merits when it comes to injury prevention (19, 22). The erectors spinae muscle has been shown to be at its greatest activation during the deceleration phase (~50-60%), aiding in maintaining posture, stabilising the lower back and preventing excessive forward flexion (7). Upon a single-leg landing after ball contact and during deceleration, lower body and trunk mechanics compliment each other, showing a synergistic relationship with active eccentric contractions of the quadriceps and erector spinae (20, 34). S&C coaches must be aware of the loads that come with unilateral landing especially when in an unbalanced position. Individually tailored programming must take place in order to address single-leg strength and balance qualities so that the athlete is adequately prepared with competitive gameplay situations such as receiving the return from the opponent after they have served the ball.

CONCLUSION

The Tennis serve is undoubtedly one of most difficult shots to perform successfully as inter-segmental coordination and timing characteristics are heavily present (20). Elite athletes display excellent use of the kinetic-chain principle, utilising their entire body to generate force onto the ball (20, 34). Despite the fact that the dominant arm is responsible for sticking the ball, majority of the force and power generated comes from the lower body and trunk regions, highlighting the linkage between body segments (4). Adequate technique should firstly be addressed prior to commencing any strength and/or power training, as this latter style of training will assist with joint stability, especially during the deceleration/follow-through phase (32).

Tennis-Specific Strength and Power training has been shown to increase serving velocity amongst semi-professional athletes (2-8, 10, 14, 17, 19-21, 25, 27, 30, 31, 33-35, 37). Some studies showed that simple shoulder IR and ER exercises using therabands and light free-weights can improve serving velocity by up to ~5% (12, 37). However, specificity of training needs to be considered for gains in athletic performance. Simulating FH and BH strokes with medicine balls or cable pulley systems have been widely used as they encourage quick rapid multi-planar movements against a resistance that is typically heavier than the racquet itself (3, 12, 16, 20, 34).

PRACTICAL APPLICATIONS

Due to the serve being a full-body movement that heavily relies in the kinetic chain principle, strength and power qualities must be developed in order to increase serving velocity. Movement specificity has been shown to positively impact athletes' ability to perform their respective tasks. S&C coaches should tailor programs to suit the needs of the athlete, whether it be strength- or power-dominant. Adaptations have been shown to arise after just 4-weeks of shoulder-specific training (37), however integrating a full-body periodised Strength-Development (~85-80% 1RM) and Movement-Specific Power (~30-40% 1RM) program that focuses on inter-muscular coordination between the upper and lower body is ideal for total athletic development (23, 24, 35). In terms of prescription, training 2-3 times per week on non-consecutive days (i.e. Monday, Wednesday and Friday) is appropriate in maintaining athlete wellbeing and allowing sufficient recovery between sessions.

As lower-body plyometric exercises elicit high loads within the hips, knees and ankles (i.e. box jumps, depth jumps, pogo jumps), it is recommended that such activities to be performed on grass or other absorbent surfaces, as this provides cushioning for these major joints, which is especially crucial for younger developing athletes. That being said, the following Tables outline 4-week Maximum Strength (Table. 2) and Power development (Table. 3) programs that revolve around movements specific to the serve.

Table 2 - 4-Week Maximum Strength Training program (3:1 volume load progression).

		Sets & Repetitions			
Session Focus	**Exercises**	**WK 1**	**WK 2**	**WK 3**	**WK 4**
Dynamic Warm-Up (R.A.M.P)	3-way Band-resisted Walks *(see Video #1)*	2 x 10m each way	2 x 10m each way	2 x 10m each way	2 x 10m each way
	Inchworm and Bear-crawl	2 x 10m	2 x 10m	2 x 10m	2 x 10m
	Banded Shoulder IR & ER	1 x 10 each arm	1 x 10 each arm	1 x 10 each arm	1 x 10 each arm
	Knee Grab into Forward Lunge w/ Upper Body Rotation (see Video #2)	1 x 10 (5 each side)	1 x 10 (5 each side)	1 x 10 (5 each side)	1 x 10 (5 each side)
	Side Shuffle w/ Arm Circles (see Video #3)	2 x 20m	2 x 20m	2 x 20m	2 x 20m
	Frankenstein March (see Video #4)	1 x 20m	1 x 20m	1 x 20m	1 x 20m
Max. Strength Building (~85-90% 1RM)	Barbell Back Squat	3 x 6	3 x 4	2 x 3	3 x 3
	Bench Press	3 x 6	3 x 4	2 x 3	3 x 3
	Barbell Hip Thrusts	3 x 6	3 x 4	2 x 3	3 x 3
	Barbell Bent Over Row	3 x 6	3 x 4	2 x 3	3 x 3
Hypertrophy (~70-75% 1RM)	Seated Dumbbell Military Press	3 x 10	3 x 10	3 x 10	3 x 10
	Single-leg Eccentric Iso Glute Bridge	3 x 30s each side	3 x 30s each side	3 x 30s each side	3 x 30s each side
	Side Planks	3 x 30s each side	3 x 30s each side	3 x 30s each side	3 x 30s each side

Table 3 - 4-Week Power Phase Training program.

		Sets & Repetitions			
Session Focus	**Exercises**	**WK 1**	**WK 2**	**WK 3**	**WK 4**
Dynamic Warm-Up (R.A.M.P)	3-way Band-resisted Walks	1 x 10m each way	1 x 10m each way	1 x 10m each way	1 x 10m each way
	Inchworm and Bear-crawl	1 x 10m	1 x 10m	1 x 10m	1 x 10m
	Banded Shoulder IR & ER	1 x 10 each arm	1 x 10 each arm	1 x 10 each arm	1 x 10 each arm
	Knee Grab into Forward Lunge w/ Upper Body Rotation	1 x 10 (5 each side)	1 x 10 (5 each side)	1 x 10 (5 each side)	1 x 10 (5 each side)
	Side Shuffle w/ Arm Circles	1 x 20m	1 x 20m	1 x 20m	1 x 20m
	Frankenstein March	1 x 20m	1 x 20m	1 x 20m	1 x 20m
Power Development (~30-40% 1RM) **2-4kg Med. Ball**	Trap Bar Squat Jump	3 x 6	3 x 6	3 x 6	3 x 6
	Med. Ball Overhead Throws (see Video #5)	3 x 6	3 x 6	3 x 6	3 x 6
	30-45cm Box Jumps & Landings	3 x 4	3 x 4	3 x 4	3 x 4
	Half-Kneeling Med. Ball Rotation Throws (see Video #6)	3 x 6 each side	3 x 6 each side	3 x 6 each side	3 x 6 each side
	Side-on Med. Ball Shot-Put Throw (see Video #7)	3 x 6 each side	3 x 6 each side	3 x 6 each side	3 x 6 each side
Hypertrophy (~70-75% 1RM)	Frontal Shoulder Raises	3 x 10	3 x 10	3 x 10	3 x 10
	Assisted Nordic Curls	3 x 8	3 x 8	3 x 8	3 x 8
	Side Planks	3 x 30s each side	3 x 30s each side	3 x 30s each side	3 x 30s each side

Video 1 - 3-way band-resisted walks.

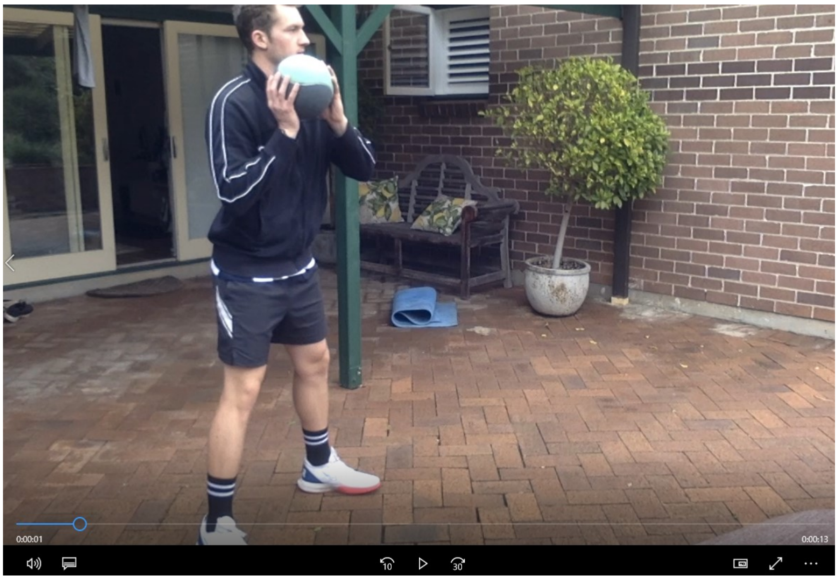
Video 2 - Knee grab into forward lunge with upper body rotation.

Video 3 - Side shuffle with arm circles.

Video 4 - Frankenstein march.

Video 5 - Medicine ball overhead throws.

Video 6 - Half-kneeling medicine ball rotation throws.



Video 7 - Side-on medicine ball shot-put throw.

REFERENCES

1. Antúnez, R., Hernández, F., García, J., Vaíllo, R., & Arroyo, J. Relationship between motor variability, accuracy, and ball speed in the tennis serve. **Journal of Human Kinetics**. 33(1): 45-53. 2012.
2. Baiget, E., Corbi, F., Fuentes, J. P., & Fernández-Fernández, J. The relationship between maximum isometric strength and ball velocity in the tennis serve. **Journal of Human Kinetics**. 53(1): 63-71. 2016.
3. Behringer, M., Neuerburg, S., Matthews, M., & Mester, J. Effects of two different resistance-training programs on mean tennis-serve velocity in adolescents. **Pediatric exercise science**. 25(3): 370-384. 2013.
4. Bonato M., Maggioni M. A., Rossi C., Rampichini S., La Torre A., Merati G. Relationship between anthropometric or functional characteristics and maximal serve velocity in professional tennis players. **The Journal of Sports Medicine and Physical Fitness**. 55 (10): 1157-65. 2015.
5. Roetert, E. P., Ellenbecker, T. S., Chu, D. A., Bugg, B. S. Tennis-specific shoulder and trunk strength training. **Strength and Conditioning Journal**. 19(3), 31-43. 1997.
6. Chandler, T. J., Kibler, W. B., Stracener, E. C., Ziegler, A. K., & Pace, B. Shoulder strength, power, and endurance in college tennis players. **The American Journal of Sports Medicine**. 20(4): 455-458. 1992.
7. Chow, J. W., Shim, J. H., & Lim, Y. T. Lower trunk muscle activity during the tennis serve. **Journal of science and medicine in sport**. 6(4): 512-518. 2003.
8. Cohen, D. B., Mont, M. A., Campbell, K. R., Vogelstein, B. N., & Loewy, J. W. Upper extremity physical factors affecting tennis serve velocity. **The American Journal of Sports Medicine**. 22(6): 746-750. 1994.
9. Cormie, P., McGuigan, M. R., & Newton, R. U. Developing maximal neuromuscular power. **Sports medicine**. 41(1): 17-38. 2011.
10. Ellenbecker, T. S., & Roetert, E. P. An isokinetic profile of trunk rotation strength in elite tennis players. **Medicine and science in sports and exercise**. 36(11): 1959-1963. 2004.
11. Fernandez-Fernandez, J., De Villarreal, E. S., Sanz-Rivas, D., & Moya, M. The effects of 8-week plyometric training on physical performance in young tennis players. **Pediatric Exercise Science**. 28(1): 77-86. 2016.
12. Fernandez-Fernandez, J., & Ellenbecker, T. Effects of a 6-week junior tennis conditioning program on service velocity. **Journal of sports science & medicine**. 12(2): 232-39. 2013.
13. Fleisig, G. S. Biomechanics of overhand throwing: Implications for injury and performance. **In 1 of 1-Conference of Science, Medicine & Coaching in Cricket.** 17-20. 2010.
14. Gelen, E., Dede, M., Bingul, B. M., Bulgan, C., & Aydin, M. Acute effects of static stretching, dynamic exercises, and high volume upper extremity plyometric activity on tennis serve performance. **Journal of sports science & medicine**. 11(4): 600-05. 2012.
15. Girard, O., Lattier, G., Maffiuletti, N. A., Micallef, J. P., & Millet, G. P. Neuromuscular fatigue during a prolonged intermittent exercise: application to tennis. **Journal of Electromyography and Kinesiology**. 18(6): 1038-1046. 2008.
16. Girard, O., Micallef, J. P., & Millet, G. P. Influence of restricted knee motion during the flat first serve in tennis. **The Journal of Strength & Conditioning Research**. 21(3): 950-957. 2007.
17. Hayes, M. J., Spits, D. R., Watts, D. G., & Kelly, V. G. The relationship between tennis serve velocity and select performance measures. **Journal of strength and conditioning research**. 1-29. 2018 (ahead of press).
18. Ignjatovic AM, Markovic ZM, Radovanovic DS. Effects of 12-week medicine ball training on muscle strength and power in young female handball players. **Journal of Strength and Conditioning Research**. 26(8): 2166–173. 2012.
19. Knudson, D., & Elliott, B. Biomechanics of tennis strokes. **In Biomedical engineering principles in sports.** Springer, Boston, MA. pp. 153-181. 2004.
20. Kovacs, M. S., & Ellenbecker, T. S. A performance evaluation of the tennis serve: implications for strength, speed, power, and flexibility training. **Strength & Conditioning Journal**. 33(4): 22-30. 2011.
21. Kovacs, M., & Ellenbecker, T. An 8-stage model for evaluating the tennis serve: implications for performance enhancement and injury prevention. **Sports health**. 3(6: 504-513. 2011.
22. Kovacs, M. S., Roetert, E. P., & Ellenbecker, T. S. Efficient deceleration: The forgotten factor in tennis-specific training. **Strength & Conditioning Journal**. 30(6): 58-69. 2008.
23. Kraemer, W. J., Ratamess, N., Fry, A. C., Triplett-McBride, T., Koziris, L. P., Bauer, J. A., ... & Fleck, S. J. Influence of resistance training volume and periodization on physiological and performance adaptations in collegiate women tennis players. **The American Journal of Sports Medicine**. 28(5): 626-633. 2000.

24. Kraemer, W. J., Häkkinen, K., Triplett-McBride, N. T., Fry, A. C., Koziris, L. P., Ratamess, N. A., ... & Gordon, S. E. Physiological changes with periodized resistance training in women tennis players. **Medicine & Science in Sports & Exercise**. 35(1): 157-168. 2003.
25. Kibler WB. The 4000-watt tennis player: Power development for tennis. **Med Sci Tennis.** 14(1): 5–8, 2009.
26. Lust, K. R., Sandrey, M. A., Bulger, S. M., & Wilder, N. The effects of 6-week training programs on throwing accuracy, proprioception, and core endurance in baseball. **Journal of sport rehabilitation**. 18(3): 407-426. 2009.
27. Malliou, P., Papadimitriou, D., Malliou, V., Beneka, A., Pafis, G., Katsikas, C., ... & Fatouros, I. The effect of strength training on tennis service performance of junior tennis players. **Exercise and Quality of Life**. 3(1): 31-40. 2011.
28. Miller, S. Modern tennis rackets, balls, and surfaces. **British journal of sports medicine**. 40(5): 401-405. 2006.
29. Mont, M. A., Cohen, D. B., Campbell, K. R., Gravare, K., & Mathur, S. K. Isokinetic concentric versus eccentric training of shoulder rotators with functional evaluation of performance enhancement in elite tennis players. **The American journal of sports medicine**. 22(4): 513-517. 1994.
30. Morante, S. Training recommendations based on match characteristics of professional singles tennis. **Medicine and Science in Tennis**. 11(3): 10-12. 2006.
31. Niederbracht, Y., Shim, A. L., Sloniger, M. A., Paternostro-Bayles, M., & Short, T. H. Effects of a shoulder injury prevention strength training program on eccentric external rotator muscle strength and glenohumeral joint imbalance in female overhead activity athletes. **The Journal of Strength & Conditioning Research**. 22(1): 140-145. 2008.
32. Ochi, S., & Campbell, M. J. The progressive physical development of a high-performance tennis player. **Strength & Conditioning Journal**. 31(4): 59-68. 2009.
33. Reid, M., & Schneiker, K. Strength and conditioning in tennis: current research and practice. **Journal of Science and Medicine in Sport**. 11(3): 248-256. 2008.
34. Roetert, E. P., Ellenbecker, T. S., & Reid, M. Biomechanics of the tennis serve: implications for strength training. **Strength & Conditioning Journal**. 31(4): 35-40. 2009.
35. Smart, J., McCurdy, K., Miller, B., & Pankey, R. The effect of core training on tennis serve velocity. **The Journal of Strength & Conditioning Research**. 25: S103-S104. 2011.
36. Terraza-Rebollo, M., & Baiget, E. Effects of Postactivation Potentiation on Tennis Serve Velocity and Accuracy. **International Journal of Sports Physiology and Performance**. 15(3): 340-345. 2020.
37. Treiber, F. A., Lott, J., Duncan, J., Slavens, G., & Davis, H. Effects of Theraband and lightweight dumbbell training on shoulder rotation torque and serve performance in college tennis players. **The American Journal of Sports Medicine**. 26(4): 510-515. 1998.
38. Ulbricht, A., Fernandez-Fernandez, J., Mendez-Villanueva, A., & Ferrauti, A. Impact of fitness characteristics on tennis performance in elite junior tennis players. **The Journal of Strength & Conditioning Research**. 30(4): 989-998. 2016
39. Vaverka, F., & Cernosek, M. Association between body height and serve speed in elite tennis players. **Sports Biomechanics**.12(1): 30-37. 2013.

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