UNIVERSITAT DE BARCELONA

Efectos del entrenamiento de la fuerza en la velocidad y precisión de golpeo en tenistas de competición

Strength training effects in stroke velocity and accuracy in competition tennis players

Manuel Terraza Rebollo

STRENGTH TRAINING EFFECTS IN STROKE VELOCITY AND ACCURACY IN COMPETITION TENNIS PLAYERS

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Tesi per a l'obtenció del grau de Doctor per la Universitat de Barcelona

Dissertation on account for the degree of Doctor by the Universitat de Barcelona

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“Caminante, son tus huellas el camino y nada más;

Caminante, no hay camino, se hace camino al andar.

Al andar se hace el camino, y al volver la vista atrás

se ve la senda que nunca se ha de volver a pisar.

Caminante no hay camino sino estelas en la mar.”

Antonio Machado

“Only those who will risk going too Far

can possibly find out how far they can go”

T.S. Eliot

“The wonderful things in life are the things you do,

not the things you have”

Reinhold Messner

ABSTRACT

Tennis players need a compound of technical, tactical, psychological and physical skills. Regarding physical skills for a high tennis performance, a mixture of speed, agility and power, together with a medium to high aerobic level is essential. As a consequence, strength training has achieved an important role in the tennis training program. Although tennis evolution has led to an increased interest in tennis research, the methodology used by tennis coaches or strength and conditioning coaches is still sometimes based on their intuition and experience rather than on scientific research. Strength training has mainly been used to increase ball velocity and speed displacement and, in addition, for injury prevention. The main aim of this doctoral thesis was to evaluate different strength training methods in ball velocity and accuracy and their long-term (Study I) and acute-term effects (Study II), also investigating the post-activation potentiation (PAP) (Study III) in young players. Long-term effects were investigated by assessing stroke ball velocity during 8-weeks tennis program of resistance training (RT) and medicine ball throws (MB) with elastic tubing. Although ball velocity changes have not been observed after 4 weeks, serve (S) velocity improvement was found at the end of 8-weeks training period of RT, meanwhile, MB and elastic tubing training increased medicine ball velocity but had no effect in stroke ball velocity (Study I). It has also been found a moderate correlation between one-arm and two-arms overhead MB with S velocity (Study I). Regarding acute and delayed effects, they were investigated by evaluating assessing stroke ball velocity and accuracy of MB and RT sessions, assessing the performance before training, after 3 minutes (acute effects) and 24 and 48 hours later (delayed effects). No effects were found in ball velocity and accuracy, suggesting that these methods using similar protocols (i.e., exercises, volume, intensity or repetitions in reserve) do not cause a neuromuscular

fatigue to the involved muscles in the tennis stroke's kinetic chain (Study II). Within the acute effects, PAP in S velocity and accuracy was investigated by using a complex training performing heavy load resistance exercises (80% 1RM). Bench press, half squat and both of them were performed to find PAP. No effects were found in S performance (Study III).

Resumen

Los jugadores de tenis necesitan una combinación de habilidades técnicas, tácticas, psicológicas y físicas. Respecto a las habilidades físicas para un alto rendimiento en tenis, es esencial una combinación de velocidad, agilidad y potencia, junto con un nivel aeróbico de medio a elevado. Como consecuencia, el entrenamiento de fuerza ha alcanzado un papel importante en el programa de entrenamiento de tenis. Aunque la evolución del tenis ha supuesto un mayor interés en su investigación, la metodología utilizada por los entrenadores de tenis y preparadores físicos se basa a veces en su intuición y experiencia más que en la investigación científica. El entrenamiento de fuerza principalmente se ha utilizado para aumentar la velocidad de golpeo y la velocidad en los desplazamiento y, además, para la prevención de lesiones. El objetivo principal de esta tesis doctoral fue evaluar los métodos de lanzamientos de balón medicinal y de entrenamiento con sobrecargas en la velocidad y precisión de golpeo y sus efectos de entrenamiento a largo plazo (Estudio I) y sus efectos agudos (Estudio II), también investigando la potenciación post-activación (Estudio III) en jugadores jóvenes. Los efectos a largo plazo se investigaron mediante la evaluación de la velocidad de golpeo durante un programa de tenis de 8 semanas de entrenamiento con sobrecargas y lanzamientos de balón medicinal junto con ejercicios de banda elástica. Se observó una mejora en la velocidad de servicio después del entrenamiento con sobrecargas después de 8 semanas aunque no se dio a las 4 semanas, mientras que el entrenamiento con lanzamientos de balón medicinal junto con ejercicios de banda elástica aumentaron la velocidad de lanzamiento de balón medicinal, pero no tuvieron ningún efecto en la velocidad de golpeo (Estudio I). También se encontró una correlación moderada entre los lanzamientos de balón medicinal por encima de la cabeza a una y dos manos con la velocidad de servicio (Estudio I). Con respecto a los

efectos agudos y retardados, éstos se investigaron mediante la evaluación de la velocidad y precisión de golpeo de una sesión de fuerza realizando lanzamientos de balón medicinal y de una sesión de entrenamiento con sobrecargas midiendo el rendimiento antes de la sesión, 3 minutos después (efectos agudos) y 24 y 48 horas más tarde (efectos retardados). No se observaron efectos en la velocidad y precisión de golpeo, sugiriendo que estos métodos con protocolos parecidos (ejercicios, volumen, intensidad o repeticiones en reserva) no causan fatiga neuromuscular en los músculos involucrados en la cadena cinética de los golpeos en tenis (Estudio II). Dentro de los efectos agudos, la potenciación post-activación en la velocidad y precisión de servicio se investigó mediante el uso de un entrenamiento complejo realizando ejercicios con sobrecargas pesadas (80% 1RM). Se realizó pres de banca, media sentadilla y ambos para alcanzar la potenciación post-activación. No se encontraron efectos en la velocidad o precisión de servicio (Estudio III).

List of publications

This thesis is mainly based on the following studies, herein referred to by their roman numbers:

Study I **Terraza-Rebollo, M.**, Baiget, E., Corbi, F., & Planas, A. (2017). Effects of strength training on hitting speed in young tennis players. *Rev Int Med Cienc Ac, 17* (66), 349-365.

Study II **Terraza-Rebollo, M.**, & Baiget, E. (submitted). Acute and delayed effects of strength training in ball velocity and accuracy in young tennis players. *Int J Sports Med.*

Study III **Terraza-Rebollo, M.**, & Baiget, E. (in press). Effects of post-activation potentiation on tennis serve velocity and accuracy. *Int J Sports Physiol Perform*.

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1. **Terraza-Rebollo, M.** & Baiget, E. (2016). Effects of post-activation potentiation on tennis serve velocity and accuracy. *XIII Congreso Nacional de Tenis de la Real Federación Española de Tenis*. San Sebastian.

2. **Terraza-Rebollo, M.** & Baiget, E. (2017). Effects of post-activation potentiation on tennis serve velocity and accuracy. *In Proceedings of the 22nd Annual Congress of the European College of Sport Science*. Essen: Open Print, p. 104. ISBN: 978-3-9818414-0-4

Abbreviations

BH	Backhand
BP	Bench press
C	Control group
CA	Conditioning activity
CMJ	Counter movement jump
CT	Complex training
DL	Dead lift
ES	Effect size
FH	Forehand
HR	Heart rate
HR_{max}	Maximum heart rate
HR_{mean}	Mean heart rate
HLRE	Heavy load resistance exercises
HS	Half squat
MB	Medicine ball throws
MBE	Medicine ball throws and elastic tubing
PAP	Post-activation potentiation
RFD	Rate of force development
RM	Maximum repetition
ROW D	Dominant one-arm row
ROW N D	Non dominant one-arm row
RPE	Rate of perceived exertion
RT	Resistance training
S	Serve
SD	Standard deviation
SSC	Stretch-shortening cycle
$\dot{V}O_2$	Oxygen uptake
$\dot{V}O_{2max}$	Maximal oxygen uptake
VT	Ventilatory threshold
VT_1	First ventilatory threshold
VT_2	Second ventilatory threshold

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Introduction

Tennis players require high level skills and training regarding technical, tactical, physical and psychological areas (Kovacs, 2007; Fernandez-Fernandez et al., 2009). In the last years, the requirements of this sport have developed substantially (the distance covered in displacements, the high strength levels and the change in hitting mechanics), turning tennis into a very physically-demanding sport (Kovacs, 2007; Reid & Schneiker, 2008). This suggests that tennis has evolved from being a sport where performance was mostly dependent on technical and tactical skills to a new context where physical capacities have gained relevance (Kovacs, 2007; Fernandez-Fernandez et al., 2009; Fett et al., 2018).

In terms of technical skills, it has been shown that ball velocity and technical effectiveness distinguished between high performing players and lower performing players (Baiget et al., 2014; Kolman et al., 2018). Regarding tactical skills, players with higher performance levels showed strong evidence displaying superior decision-making, better anticipation, more elaborate tactical knowledge and better visual search strategies than players with lower performance levels (Kolman et al., 2018).

Concerning physical skills, a compound of speed, agility and power, together with a medium to high aerobic level is essential for a high tennis performance. Strength training has become essential in tennis training program, not only to develop strength and power, but also to prevent injuries (Cardoso, 2005; Kovacs, 2006; Kovacs & Ellenbecker, 2011; Kilit et al., 2016). As a consequence and due to the importance of ball velocity in the match outcome in the modern game (Signorile et al., 2005; Kovacs, 2007; Genevois et al., 2013), specific strength training should be included in tennis program (Genevois et al., 2013; Fernandez-Fernandez et al., 2013).

Despite the fact that tennis is one of the most popular sports worldwide and that, in the last years, tennis evolution has led to an increased interest in tennis research (Fernandez-Fernandez et al., 2009), the methodology used by tennis coaches or strength and conditioning coaches is still sometimes based on their intuition and experience rather than on scientific research (Fernandez-Fernandez et al., 2006).

Notational analysis and mechanical demands of tennis

Tennis involves intermittent high intensity efforts interspersed with short recovery periods between points (10-20 seconds) and longer recovery periods between games (60-90 seconds), along an extended and unknown match time (Fernandez-Fernandez et al., 2009). Points have an average that last <10 seconds (especially on faster surfaces such as hard and grass courts) and the typical average match duration is 1.5 hours although matches have the possibility to last >5 hours (Kovacs, 2007; Fernandez-Fernandez et al., 2009). During this time, a tennis player runs an average of 3 m per shot (about 80% of all strokes are played within 2.5 m of the player's ready position) and a total of 8 to 12 m in the course of a point with 3-4 changes of direction (Kovacs, 2004; Fernandez-Fernandez et al., 2006) and average point duration around 6 seconds for professional players in hard court (Kilit et al., 2016; Martinez-Gallego et al., 2018) and around 8 seconds for young players and high level adults (Martin et al., 2011; Gallo-Salazar et al., 2018). Point losers cover a greater distance and move faster than point winners (Martinez-Gallego et al., 2018). In a best of three sets match, players complete 300-500 high intensity efforts (Fernandez-Fernandez et al., 2006) covering a distance about 3000 m by adults and young players (Hoppe et al., 2014; Pereira et al., 2016). The work-to-rest ratios of competitive tennis athletes range between 1:3 and 1:5 (Kovacs, 2004; Fernandez-Fernandez et al., 2007; Kilit et al., 2016).

Winner players controlled the game by playing more offensively and forcing losers to play in defensive positions, to move greater distances at a faster speed, and to make more errors in elite tennis players (Martinez-Gallego et al. 2018). No running activity differences were found in young male players (Hoppe et al., 2014). Regarding differences by gender in elite tennis players, it has been observed in males that serve (S) ball velocity was faster producing more aces and that mean movement speeds were higher with a greater proportion of speeds faster than 3 $m \cdot s^{-1}$ (Reid et al., 2016; Whiteside & Reid, 2017).

First S, forehand (FH) and backhand (BH) rally in professional tennis players accounted for approximately 70% of the total strokes with no differences between genders (Figure 1) (Whiteside & Reid, 2017). During services games in male players, S were the predominant stroke, though during return games there were more FH and BH returns and topspin FH and BH than other types of stroke and the distance covered was larger (Johnson & McHugh, 2006; Pereira et al., 2016). Moreover, the greater number of strokes on clay may contribute to an earlier fatigue and possibly to a higher prevalence of injury (Johnson & McHugh, 2006).

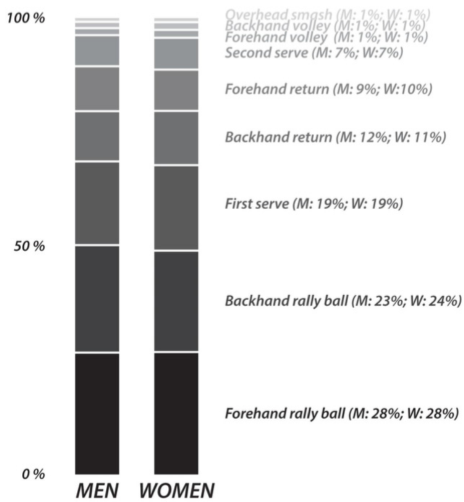

Figure 1. Percentage of total shots during the first week of Australian open tennis competition (Reproduced with permission from Whiteside & Reid, 2017).

Physiological demands of tennis

Elite tennis players require the repeatedly generation of power for explosive stroke production and for moving rapidly along the court during extended matches (Girard, 2006). Therefore, both high anaerobic ATP production during the game and proper aerobic condition to aid in recovery are needed for high performance (Kovacs, 2006). Although aerobic and anaerobic alactic energy systems are the major energy pathways during tennis match, glycolitic metabolism may increase during long and decisive rallies (Fernandez-Fernandez et al. 2006).

High level male tennis players $\dot{V}O_{2max}$ range from 44 mL·kg^{-1}·min^{-1} to 69 mL·kg^{-1}·min^{-1} (Smekal et al., 2001; Kovacs, 2007). During simulated tennis matches $\dot{V}O_2$ values ranging from 23 to 30 mL·kg^{-1}·min^{-1} were observed (Fernandez-Fernandez et al., 2006; Kovacs, 2007; Baiget et al., 2015; Kilit et al., 2016). These values correspond to approximately 50% of $\dot{V}O_{2max}$, although it has been shown differences between player profiles, offensive players achieved lower $\dot{V}O_2$ than defensive players (Smekal et al., 2001).

Based on a three-phase model defined by the ventilatory parameters (VTs zones), it has been shown that during a tennis set simulation players spent up to 77% of the time in their low intensity zone ($\dot{V}O_2$ at or below the first ventilatory threshold (VT_1)), 20% in their moderate intensity zone ($\dot{V}$O2 between VT_1 and second ventilatory threshold (VT_2)), and only 3% in the high intensity zone ($\dot{V}$O2 at or beyond VT_2). Moreover, relatively lower intensities have been observed in higher aerobic players condition (Baiget et al., 2015).

Although mean heart rate (HR_{mean}) in a tennis match in young and 20-30 years trained players ranges between 140-160 beats·min^{-1} (60-80 % HR_{max}) during singles and between 94-164 beats·min^{-1} during doubles tennis competitions, the maximum heart rate (HR_{max}) could achieve 190-200 beats·min^{-1} (over 95% HR_{max}) (Fernandez-Fernandez et al., 2006; Kovacs, 2007; Martin et al., 2011; Hoppe et al., 2014; Baiget et al. 2015; Kilit et al., 2016; Gallo-Salazar et al., 2018). There have been observed physiological differences between S and return game situations, obtaining higher physiological responses in HR and $\dot{V}O_2$ in S situations (Smekal et al., 2001; Fernandez-Fernandez et al 2007; Kilit et al., 2016). Caution should be taken when interpreting HR responses due to the fact that HR does not always correlate with $\dot{V}O_2$ during a match (Fernandez-Fernandez et al., 2006).

Blood lactate concentration measurements are used to provide information regarding energy production from glycolytic metabolism and estimating intensities in competition. It has been shown that mean blood lactate concentration during matches was low, with values around 2 mmol·L^{-1} in junior players and peak values around 4 mmol·L^{-1} (Fernandez-Fernandez et al., 2007; Murias et al., 2007; Fernandez-Fernandez et al., 2008). Although it has been observed mean values around 5.7 mmol·L^{-1} in clay and 3.6 mmol·L^{-1} in hard court with peak concentration around 8 mmol·L^{-1} (Martin et al., 2011), accumulating lactate levels is not a major cause of fatigue in tennis match play (Kovacs, 2006). It should be taken into account that blood lactate concentration only reflects the level of activity during the few minutes before sampling (Martin et al., 2011).

Rate of perceived exertion (RPE) is known as the subjective intensity of effort and fatigue during physical work, measured through the Borg's RPE scale (Borg, 1982). Mean values in tennis match using 15 point RPE scale are around 11 to 14 (fairly light to somewhat hard) (Fernandez-Fernandez et al., 2008; Fernandez-Fernandez et al., 2009; Kilit et al., 2016; Gallo-Salazar et al., 2018). It should be note that the physiological responses such as HR and blood lactate or RPE could change depending on the court surface, achieving higher values on clay court surface (Martin et al., 2011).

Tennis strength requirements

Increasing power output is a key point, probably the most relevant aspect to improve the specific movement performance (Stone et al., 2003; Crewther et al., 2005; Young, 2006). In tennis, the need to increase the power output should be developed in strokes (reflected in racket head speed and ball velocity) and displacements (reflected in acceleration, deceleration and speed displacement) (Reid & Schneiker, 2008). Therefore, the head racket velocity in the contact point is crucial in order to change the momentum of the ball in strokes to improve ball velocity, considering that the same mass (racket) is used and that ball contact time is limited.

Due to the fact that tennis actions have an explosive nature, the ability to develop force rapidly or power, may be more important than maximum strength (Cardoso, 2005; Girard et al., 2014). The expression of rapid force production in sport may be measured as Rate of Force Development (RFD) (Gonzalez-Badillo et al., 2011; Taber et al., 2016). RFD is the ability of the neuromuscular system to increase contractile force per unit of time and may be measured in static and dynamic conditions with force-time curve (Rodriguez-Rosell et al., 2018). The rapid force production and dynamic performance are important factors to evaluate, especially when movement performance last less than 250 milliseconds to generate force (Kawamori & Haff, 2004). Because of the use of stretch-shortening cycle (SSC) movements during strokes and displacements, additional consideration should be given on them in strength training program (Kovacs & Ellenbecker, 2011; Fernandez-Fernandez & Kovacs, 2018). SSC is known as an intricate sequential combination of eccentric, isometric and concentric muscle actions that cause a concentric force output improvement due to the elastic energy and the reflex muscle activity (Lloyd et al., 2011), therefore this kind of actions should be included in tennis specific training program.

Even though isometric maximum strength was strongly correlated with dynamic maximum strength and maximum strength was strongly correlated with peak power output (even at relatively light loads associated with sport-specific performance) (Stone et al., 2003), tennis strength training should emphasize the development of RFD, often using SSC (Cardoso, 2005; Reid & Schneiker, 2008; Fernandez-Fernandez & Kovacs, 2018). However, it should be pointed out that maximum strength training might improve not only the maximum peak strength but also other factors such as power and RFD that may improve sports performance (Stone et al., 2003; Crewther et al., 2005).

High accelerations are necessary in stroke and displacement performances, although deceleration has also an essential role (Kovacs, 2007; Kovacs et al., 2008; Creveaux et al. 2013). On one hand, after a stroke, mainly the upper back muscles responsible for scapular stability (i.e., infraspinatus, teres minor, serratus anterior, trapezius and rhomboids), decelerate the velocity achieved after the ball impact through the eccentric contraction in order to provide stability to prevent injuries and to improve performance (Kovacs et al., 2008). When the player perform a displacement to the ball or recover the position on court, the ability to accelerate is essential to move fast. After the acceleration, the player should decelerate properly to achieve the optimal contact point with the ball and recover the correct position to be ready for the next shot. There have been observed similar acceleration and deceleration values in adolescent tennis players in running activities (Hoppe et al., 2014).

Furthermore, the ability to maintain power and strength during prolonged and intermittent high intensity exercise is also essential (Girard et al., 2006). Fatigue effects could be reduced along a match increasing local muscular endurance and consequently, achieving a smaller power output diminution (Reid & Schneiker, 2008). Above all, the main strength training goal should be injury prevention (Fernandez-Fernandez & Kovacs, 2018). Therefore, the main goals of strength training in tennis are injury prevention, power development, maximum strength and local muscular endurance (Cardoso, 2005; Reid & Schneiker, 2008; Fernandez-Fernandez & Kovacs, 2018).

Predictors of stroke velocity

Ball velocity has been shown as a performance predictor with strong evidence (Kolman, 2018). The correlation between tennis stroke ball velocity and physical and anthropometrical tests has been investigated several times. Although there has not been agreement on the best prediction model, it has been shown moderate to large correlations between strength or power and ball velocity (Kraemer et al., 1995; Pugh et al., 2003; Baiget et al., 2016; Fett et al., 2018; Hayes et al., 2018; Palmer et al., 2018). However, not only strength is important, but also flexibility, coordination, anthropometric factors and technique are necessary to perform a proper stroke (Cohen et al., 1994; Pugh et al., 2003; Fett et al., 2018; Palmer et al., 2018).

In amateur tennis players there were moderate positive correlations between distance medicine ball throws (MB) on the dominant side and hand grip dynamometry with ball velocity in FH ball velocity (Delgado-Garcia et al., 2018). Similarly, performing tennis S in male junior players has shown moderate to large correlations (0.43 to 0.63) between S velocity and MB and between S velocity and grip strength. Similar results were found in female players with slightly lower correlation coefficients (Fett et al., 2018). In addition, in junior and professional players, anthropometric factors as body height (Bonato et al., 2015; Fett et al., 2018; Hayes et al., 2018), body mass, and arm span (Fett et al., 2018) showed a correlation with S velocity. Surprisingly, one maximum repetition (1RM) military press was moderately correlated with S, FH and BH ball velocity in female college players, suggesting the importance of the high activity of deltoids during the strokes (Kraemer et al., 1995) Furthermore, moderate relationship was found between tennis S velocity with knee extension isokinetic strength, shoulder rotation isokinetic strength and grip strength (Pugh et al., 2003). Also, Signorile et al. (2005) found a moderate positive correlation between isokinetic strength and ball velocity at testing speeds from 1.57 to 4.71 $rad \cdot s^{-1}$. Regarding isometric tests, moderate to strong positive relationships between S velocity and isometric shoulder internal rotation strength were found in adolescent tennis players (Baiget et al., 2016; Hayes et al., 2018). The maximum isometric strength levels in shoulder internal rotation and shoulder flexion explained the large part of the variability in S velocity (Baiget et al., 2016).

Besides, there were found correlations between S velocity and several flexibility (i.e., wrist flexion, dominant shoulder flexion and dominant shoulder internal rotation) and strength measurements (i.e., elbow extension torque production and the ratios of internal to external rotational torque production) (Cohen et al., 1994). As a consequence of the multifactorial nature of tennis S and in order to develop powerful strokes, technical skills, coordination, flexibility and strength should be taken into account. It should be considered that a synchronised kinetic chain is necessary to develop a powerful and accurate stroke (Signorile et al., 2005; Reid & Schneiker, 2008; Kovacs & Ellenbecker, 2011). Their effectiveness involved the summation of ground reaction forces transferred through the feet, legs, trunk, upper body, and finally to the racket (Kovacs, 2007; Reid & Schneiker, 2008) using the SSC in the main muscles (Elliot, 2006; Kovacs & Ellenbecker, 2011; Fernandez-Fernandez & Kovacs, 2018).

Tennis strokes kinetic chain

Serve kinetic chain

Kinetic chain of S may be divided in 8 tennis S stages and three phases (preparation, acceleration and follow-through) (Kovacs & Ellenbecker, 2011).

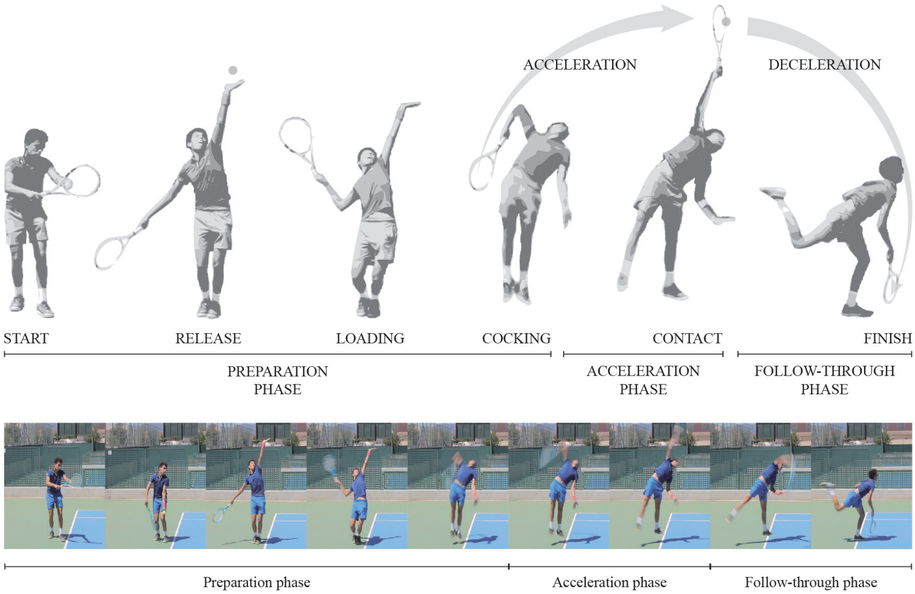

Figure 2. Serve kinetic chain in 8 stages.

Preparation phase

Includes 4 stages: start, release, loading and cocking. The main goals are to release the ball correctly to achieve proper contact point and to pre-stretch the main muscles responsible of acceleration (i.e., legs, trunk and shoulder internal rotators) (Kovacs & Ellenbecker, 2011).

- *Start:* proper and personal position to align the body to use ground reaction forces.

- *Release:* when the ball is released from the non-dominant hand. This stage is important to achieve an accurate ball contact point.

- *Loading:* from the release stage to complete the legs pre-stretch. There are two common techniques of foot position, foot-up and foot-back (Kovacs & Ellenbecker, 2011. The arm starts the external rotation (pre-stretch of the shoulder internal rotators).

- *Cocking:* from the end of the loading stage to the maximal shoulder external rotation of the dominant hand (racket head points to the ground) (Ryu et al., 1988; Kovacs & Ellenbecker, 2011). This stage has a potential risk of shoulder injury and it is when the maximum storage of potential energy happens due to the muscles pre-stretch (Abrams et al., 2011).

Acceleration phase

Includes 2 stages: acceleration and contact. It goes from maximal external rotation to the end of the contact point. It is the shortest phase of S (Ryu et al., 1988).

- *Acceleration:* from the maximal shoulder external rotation until ball impact. In this stage happens a concentric contraction of the main muscles (i.e., legs, trunk and shoulder internal rotators muscles) responsible of ball velocity which has the greatest potential injury risk (Abrams et al., 2011).

- *Contact:* ball contact time with the racket.

Follow-through phase

Includes 2 stages: deceleration and finish. The aim in this phase is to decelerate the accumulated body inertia in the previous stages (Ryu et al., 1988; Kovacs & Ellenbecker, 2011).

- *Deceleration:* just after the contact point and until the end of upper and lower body deceleration of the S. This stage is very aggressive because of the eccentric activation of the rotator cuff and glenohumeral and scapular stability muscles such as infraspinatus, teres minor, serratus anterior, trapezius, rhomboids, biceps brachii and deltoid.
- *Finish:* from the end of the deceleration and just before the beginning of the following movement to prepare the next stroke.

Groundstrokes kinetic chain

Kinetic chain of FH and BH may be divided in three phases: preparation, acceleration and follow-through (Ryu et al., 1988).

Preparation phase

This phase start from the ready position and finish at the end of the backswing. The main goals are to reach a correct position in order to achieve a proper contact point and to pre-stretch the main muscles responsible of acceleration to store elastic energy (i.e., legs, trunk and shoulder internal rotators) (Elliot, 2006).

Acceleration phase

From the end of the backswing to the end of the contact point, also known as forward swing. In this phase happens the concentric contraction of the main muscles (i.e., legs, trunk and shoulder internal rotators muscles) responsible of ball velocity. Shoulder internal rotation has approximately 40% of the velocity contribution in FH (Elliot, 2006). The glenohumeral contact forces are greater in this phase, 1.25 times greater than during the follow-through phase and 5.8 times greater than during the backswing phase (Blache et al., 2016).

Follow-through phase

From the end of the contact point and just before the beginning of the following movement to prepare the next stroke. The aim in this phase is to decelerate the accumulated body inertia in the previous phases (Ryu et al., 1988).

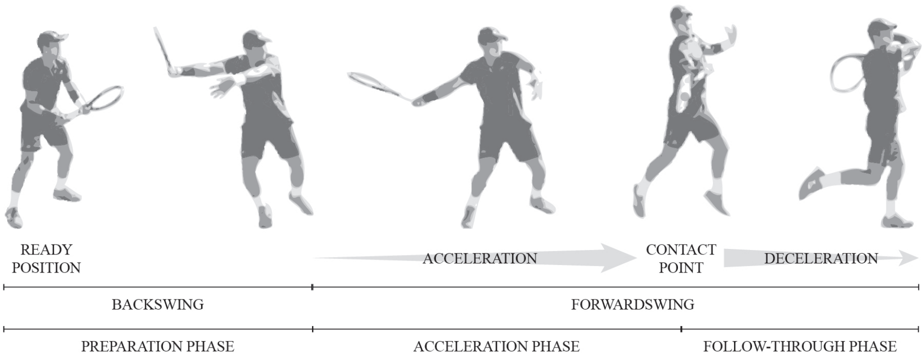

Figure 3. Forehand kinetic chain.

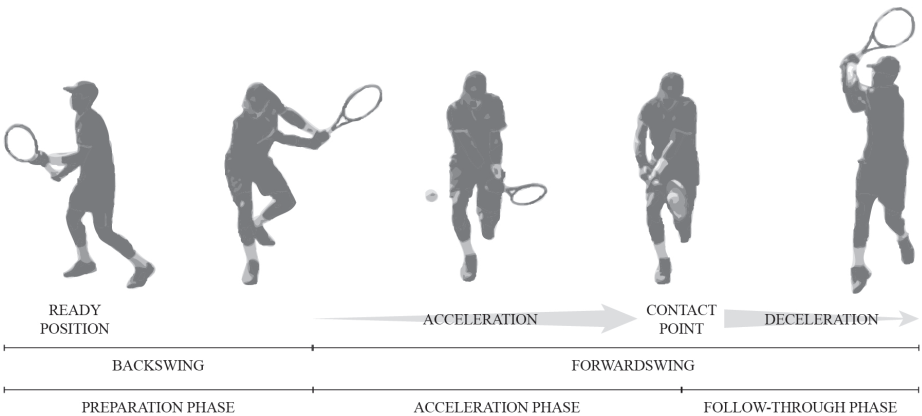

Figure 4. Backhand kinetic chain.

Long-term effects of strength training in tennis

The benefits of strength training programs are widely known on health and sports performance fields including young and elderly people (Faigenbaum et al., 2013; Faigenbaum et al., 2016; Lopez et al., 2018; Fernandez-Fernandez & Kovacs, 2018). As a consequence of long-term strength training, it may result in several adaptations attributed to changes in neural function (e.g., motor unit recruitment, firing frequency, synchronisation and reflex activity) and muscle morphology (i.e., cross sectional area increase) (Stone et al., 2003; Crewther, 2005).

Among all strength training methods, two of the most commons in tennis strength training are MB and resistance training (RT). On one hand, RT has been shown to increase strength, power, and hypertrophy in a large range of ages and types of athletes (Gorostiaga et al., 2004; Grgic et al., 2018; Moran et al., 2018; Pina et al., 2019). On the other hand, plyometric training using MB has been shown to increase strength and power (Faigenbaum & Mediate, 2006; Ignjatovic et al., 2012; Valades et al., 2017; Dobbs et al., 2018) and, due to the more similar kinetic chain and velocity of the exercises, has the advantage to allow a higher degree of specificity (Stodden et al., 2008; Earp & Kraemer, 2010).

Moreover, in overhead throw sports such as baseball, volleyball and handball, ball velocity has been increased through MB and RT methods (Newton & McEvoy, 1994; Van den Tillar, 2004; Escamilla et al., 2012; Myers et al., 2015; Valades et al., 2017). Regarding tennis, it has also been observed ball velocity improvements when trained from 6-8 weeks (Fernandez-Fernandez et al., 2013; Genevois et al., 2013; Fernandez-Fernandez et al., 2016) to 9 months (Kraemer et al., 2000; Kraemer et al., 2003). Despite being two common methods in tennis strength training and being recommended for several studies

(Kraemer et al., 2000; Kraemer et al., 2003; Cardoso, 2005; Reid & Schneiker, 2008; Earp & Kraemer, 2010), only Behringer et al. (2013) investigated both methods (MB and RT using weight-training machine) and their long-term effects during 8 weeks with young players in S ball velocity, observing no changes in S ball velocity when performing RT, but when performing plyometric training (jumps and MB) an increased S ball velocity was found. The long-term effects of both methods, MB and RT using free-weights, have not been investigated in S and groundstrokes ball velocity.

Acute-term effects of strength training in tennis

Despite the long-term effects of strength training in tennis ball velocity have been slightly investigated, their acute and delayed effects in stroke ball velocity and accuracy in competition tennis players had not been investigated until now.

After a strength stimulus, a maximum strength loss has been observed in both isometric and dynamic contractions (Walker et al., 2012; Buckthorpe et al., 2014; Thomas et al., 2018). Furthermore, more pronounced decreases on RFD (especially in the early phase) rather than maximum peak strength have been shown when performing repeated explosive isometric contractions (Buckthorpe et al., 2014) and maximal or explosive strength training (Linnamo et al., 1997). These effects could be altered by several variables that establish the training stimulus such as exercise type and order, sets and repetitions number, rest duration between sets and exercises, loading and velocity movement (Gonzalez-Badillo et al., 2014).

Post-activation potentiation and complex training in tennis

Within the acute effects, Post-Activation Potentiation (PAP) effect is found. The PAP effect is an acute enhancement on performance followed by a conditioning activity (CA), although fatigue effect could also exist simultaneously after a CA decreasing the performance (Tillin & Bishop, 2009). As a consequence the difference between their dissipation determine the net effect on the performance (Rassier & Macinstosh, 2000). This net effect could be determined by several factors, including CA, volume and intensity, recovery period following the CA, type of CA, type of subsequent activity and subject characteristics (Tillin & Bishop, 2009).

Although PAP has been shown in explosive movements, mainly movements with SSC, like jump (Crewther et al., 2011; Kilduff et al., 2011), throw (Judge et al., 2016), upper body ballistic performance activities (Baker et al., 2003; Bevan et al., 2009) and sprint performance (Seitz et al., 2014; Smith et al., 2014), it has not been observed in tennis. PAP effect was small for jump, throw, and upper-body ballistic performance and moderate for sprint performance as shown by the latest metaanalysis of Seitz and Haff (2015). In order to enhance the sports performance through the PAP effect, especially in strength, power and speed activities, several researches have implemented heavy load resistance exercise (HLRE) as a CA such as back squat and bench press (BP) (Baker et al., 2003; Kilduff et al., 2007; Kilduff et al., 2008; Bevan et al., 2009; West el al., 2013; Seitz et al., 2014), followed by an explosive exercise, known as Complex Training (CT) (Docherty el al., 2004; Scott et al., 2017; Tredea, 2017).

CT is a strength method that uses HLRE followed by an explosive exercise, often a plyometric exercise because of the augment of the strength through the PAP (Tredea, 2007). PAP effect in tennis S velocity and accuracy has not been investigated by using HLRE. However, PAP effect has not been found on tennis S velocity and neither has found in accuracy by using CT performing moderate and light loads with MB (200 g and 600 g) in elite young tennis players (12.3 ± 0.8 years) (Ferrauti & Bastiaens, 2007).

OBJECTIVES

General objective

The general objective in this doctoral thesis was to investigate the long-term and acute-term effects of different strength training methods on tennis stroke velocity and accuracy. This general aim can be divided into the following objectives:

1. To determine the long-term effects of strength training on stroke ball velocity.
2. To investigate the acute and delayed effects of strength training on stroke ball velocity and accuracy. The effects can be divided into the acute and delayed effects of different strength training methods or the PAP effect.

Specific objectives

The specific objectives are addressed in the different studies as following:

Study I: Effects of strength training on hitting speed in young tennis players.

The aim of this investigation was to determine the effect of two different strength training methods (MB and RT) on stroke ball velocity during 8 weeks training. The correlation between stroke ball velocity and MB velocity was also investigated.

Study II: Acute and delayed effects of strength training in ball velocity and accuracy in young tennis players.

The objective of this research was to investigate the acute and delayed effects of MB and RT in ball velocity and accuracy of S, FH and BH in young competition tennis players.

Study III: Effects of post-activation potentiation on tennis serve velocity and accuracy.

The objective of this research was to examine the PAP effect on S velocity and accuracy in young competition tennis players by using CT and comparing different CA.

Methods

Subjects

Forty-five competition tennis players, 28 boys and 17 girls, were recruited for the different studies in this investigation. Selection criteria was that all the subjects had over 4 years of experience in competition tennis training, did not practice another competitive sport, had not been injured in the last six months and did not participate in another specific strength training program during the tests. Descriptive characteristics of the subjects are shown in Table 1.

Table 1. Subjects physical characteristics.

	Females (n=17)	Males (n=28)	All (n=45)
Age (years)	15.0 ± 0.9	15.8 ± 1.2	15.5 ± 1.2
Height (cm)	162.1 ± 5.6	174.9 ± 8.0	170.1 ± 9.5
Body mass (kg)	53.6 ± 4.4	64.8 ± 7.8	60.6 ± 8.6

The sample for the Study I was composed by 20 competition tennis players, including 15 boys and 5 girls, (mean ± SD: age 15.5 ± 0.9 years, body mass 61.4 ± 7.6 kg, height 170.3 ± 9.4 cm). The sample for the Study II was composed by 10 competition tennis players, including 4 boys and 6 girls, mean ± SD: age 15.3 ± 1.2 years, body mass 57.6 ± 8.7 kg, height 168.1 ± 10.4 cm). The sample for the Study III was composed by 15 competition tennis players, including 9 boys and 6 girls, (mean ± SD: age 15.6 ± 1.5 years, body mass 61.3 ± 9.9 kg, height 171.0 ± 9.0 cm).

During the previous 2 months in both Study II and Study III, all the subjects practiced between 17.5 to 26 hours per week (24.3 ± 3.3 hours), performing between 10 to 17.5 hours (15.9 ± 3.0 hours) of specific tennis training (i.e., technical-tactical skills) and between 7.5 to 8.5 hours (8.4 ± 0.3 hours) of fitness training. In the Study I case, , all the subjects practiced between 9 to 18 hours per week (13.0 ± 2.6 hours), performing between 8 to 12 hours (8.8 ± 1.6 hours) of specific tennis training (i.e., technical-tactical skills) and between 3 to 6 hours (4.2 ± 1.1 hours) of fitness training.

Experimental design

In Study I, the subjects were assigned in a stratified and randomized design to one of three training groups: medicine ball throws and elastic tubing (MBE), RT and control group (C). The training program lasted for 8 weeks, with 3 sessions per week. All the groups did 2 hours of on-court technical-tactical training and both experimental groups also performed one additional hour of strength training. The RT group performed the additional training mainly with free-weights and the MBE group with medicine ball throws and elastic tubing. The strength training in the additional sessions focused on improving ball velocity and lasted 45 min, after a 15 min warm-up that included running and dynamic stretching, and specific exercises (Ayala et al., 2012). Three assessments of the strokes and throwing velocities were made: pre-test (two days prior to the intervention), inter-test (after 4 weeks of intervention) and post-test (five days after the end of the intervention) (Figure 5).

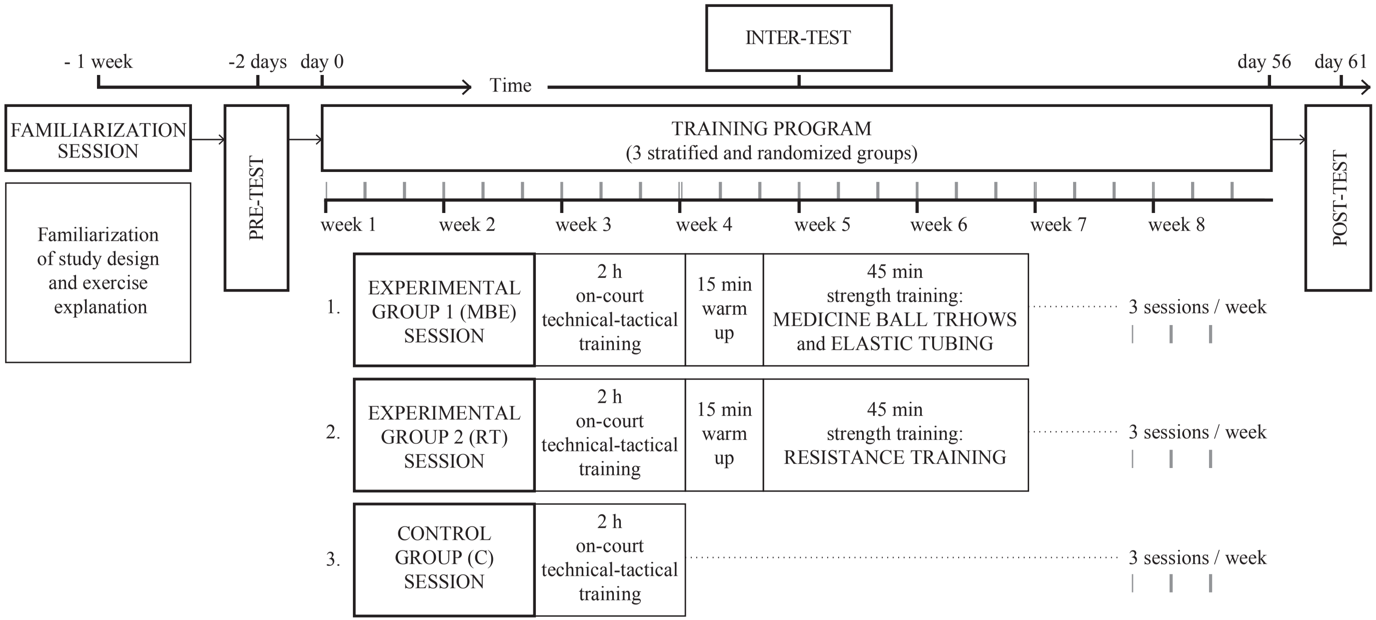

Figure 5. Study I design chronology.
MBE: medicine ball throws and elastic tubing; RT: resistance training; C: control group.

A crossover-randomized design was used in Study II in order to investigate the acute (3 min) and delayed (24 and 48 h post-training) effects of two different strength training protocols (MB and RT) on ball velocity and accuracy in young tennis players in off-season competition. Subjects participated in 1 familiarization session, 1 strength test session (maximum strength test and anthropometric test) and 6 stroke test sessions (3 for each strength training protocol) performed 1 per day in 3 consecutive days (Post, Post24 and Post48). Each strength training protocol was separated by 7 days. On the first day of each strength training protocol, participants completed one of both protocols in randomized order. S, FH and BH velocity and accuracy tests were measured before (basal situation), 3 min (Post), 24 (Post24) and 48 (Post48) hours after strength training protocol (Figure 6).

The Study III used a crossover-randomized design, comprising the control session and three experimental sessions using HLRE: BP, half squat (HS) and BP plus HS (BP + HS). Then, the effects on tennis S velocity and accuracy were analysed to determine the efficacy of using the exercises as a performance enhancer. Subjects participated in 1 familiarization session, 1 test session (maximum strength test and anthropometric test), 1 control session and 3 experimental sessions on different days. In the control session, the subjects only performed the warm-up protocol and then the S test. During the experimental sessions, the subjects completed the warm-up protocol, then the HLRE (BP, HS or BP + HS) and then the S test (Figure 7).

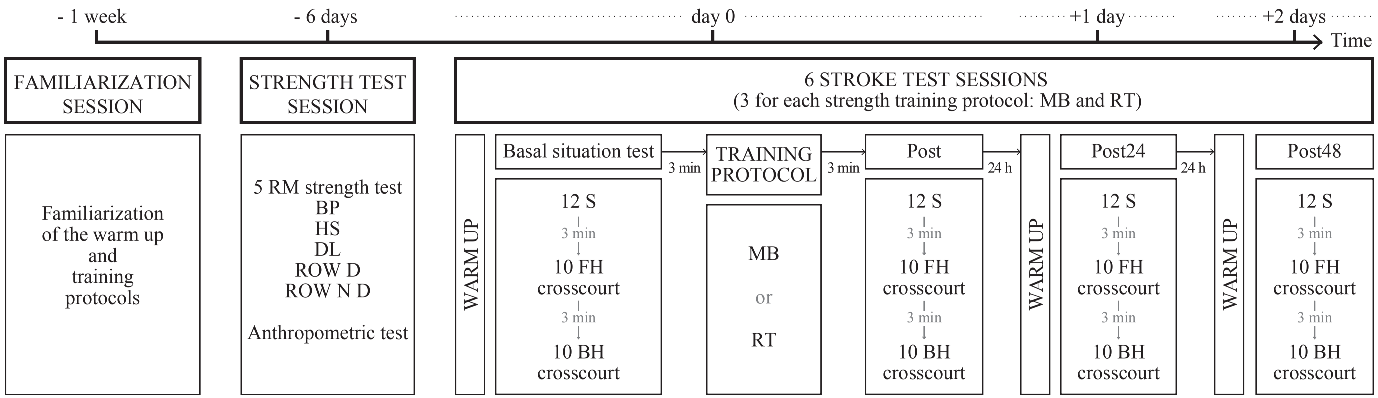

Figure 6. Study II design chronology.

BP = bench press; HS = half squat; DL = dead lift; ROW D = dominant one-arm row; ROW N D = non dominant one-arm row; S = serve; FH = forehand; BH = backhand; MB = medicine ball throws; RT = resistance training.

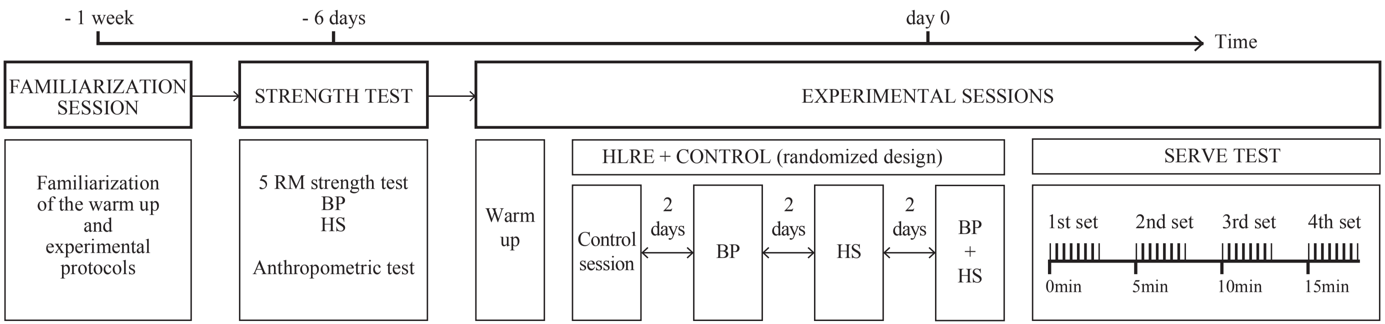

Figure 7. Study III design chronology.

BP = bench press; HS = half squat; HRLE = heavy load resistance exercise.

Procedures

In all studies one week prior to the beginning of the intervention, the participants were asked to attend a familiarization session where they handed in the informed consent, the study protocol was explained, and they were instructed on how to correctly perform each exercise. The following day, the subjects completed the anthropometric test (body mass and height) in all the studies and the 5 maximum repetition (RM) strength test (strength test session) in the Study II (BP, HS, dead lift (DL), dominant one-arm row (ROW D) and non-dominant one-arm row (ROW N D)) and Study III (BP and HS). The Brzycki equation was used to calculate the 1RM (do Nascimento et al., 2007): 1RM = 100 * load rep / (102.78 – 2.78 * rep).

In Study I, after the anthropometric test and 2 days before the training program, the subjects performed the Pre-test that consisted in assessing the strokes and 2 Kg MB velocities. After 4 weeks of training program all the groups performed the Inter-test. Then the training program continued 4 more weeks and after 5 days of the training program end, all the subjects accomplished the Post-test (Figure 5). All the participants attended a minimum of 80% of the programmed training sessions.

In Study II, on the test day, the subjects began with a warm-up protocol that included 10 minutes of general warm-up activities (jogging, skipping, dynamic mobility and dynamic stretching) and 10 minutes of specific warm-up for tennis S (exercises with elastic tubing for upper body, 10 dynamic S, FH and BH imitations, five minutes baseline shots drill and 10 warm-up S). Then, the basal situation test was performed. After 3 minutes, one of both strength training protocols was accomplished (MB or RT). Once finished, and after 3 minutes, the Post-Test was done in order to determine the acute effects of strength training (Post). The next day, they fulfilled the warm-up and 3 minutes later, the post 24 h test was performed (Post24). After two days, the same procedure was followed with the post 48 h test (Post48). Post24 and Post48 were done in order to determine the delayed effects of strength training (Figure 6).

In Study III, on the control and the experimental sessions, the subjects began with the warm-up protocol that included 10 minutes of general warm-up activities (jogging, skipping, dynamic mobility and dynamic stretching) and 5 minutes of specific warm-up for tennis S (exercises with elastic tubing for upper body, 10 dynamic S imitations and 10 warm-up S). After that, in the control session the S test was performed and in the experimental sessions the HLRE was performed followed by the S test (Figure 7).

Measurements

All the tests were performed at the same time of the day due to reliability reasons and to control the circadian variation (Study I: 18:00 to 19:00; Study II and III: 10:00 to 11:00). In order to avoid fatigue, refraining from any high intensity exercise was required, particularly strength training on the day before each test day. During the stroke test, the subjects were allowed to drink water ad libitum in order to reduce dehydration. However, carbohydrate beverages, any kind of food, or other supplementation were not allowed. The participants were constantly encouraged to hit the ball at maximum speed and high accuracy. No further information about the movement was given. No feedbacks about the performance were done during the set, but when the set was finished the subjects were informed about the velocity and accuracy achieved.

In Study I the test consisted of assessing the peak ball velocity of 12 flat S (6 on each court side), 12 BH and 12 FH strokes (6 down the line and 6 crosscourt), 3 two-arm overhead MB with a 2-kg medicine ball and 3 single-arm MB per player. The subjects rested 20 seconds between shots and 3 minutes between tests. Peak ball velocity was used for the analysis.

In Study II peak ball velocity and accuracy of 12 flat S, 10 FH and 10 BH crosscourt were evaluated (Figure 6 and 10), resting 20 seconds between S, 10 seconds between FH and BH and 2 minutes between sets to avoid the neuromuscular fatigue. Mean peak ball velocity and mean score accuracy were used for the analysis.

In Study III the test consisted of assessing the peak ball velocity of 32 flat S (Figure 7 and 11), divided into 4 sets of 8 S (4 each side), resting 20 seconds between S and 2 minutes and 40 seconds between sets in order to avoid neuromuscular fatigue. Only the S that were "in" were registered and the highest speed recorded was used for analysis. Peak ball velocity and mean score accuracy were used for the analysis.

Ball velocity measurement

A Stalker Pro radar gun (Minneapolis, MN, USA) was used for the measurements in Study I meanwhile a Sports-radar R3600 radar gun (Homosassa, FL, USA) was used for the Studies II and III. To reduce any error due to the cosine effect, the radar were placed in the line of the ball's displacement, changing them depending on the serving side.

Figure 8. Ball velocity measurement.

In Study II in order to perform groundstroke test, balls were thrown by a ball machine (Lobster Elite V, Lobster Sports, Inc., North Hollywood, CA, USA) at the average of 73.3 ± 1.2 km·h^{-1} with no rotational effect and at a period of ten seconds per ball (6 shots·min^{-1}).

Figure 9. Ball machine.

International Tennis Federation (ITF) approved balls were used for all the studies, Babolat Gold (Spain) in Study I and Head ATP (Spain) in Study II and III. In order to maintain uniform internal ball pressure, the balls were new in each testing session. The subjects were instructed to use the same racket, strings and string tension to perform the different tests. Study I was performed on an outdoor green set court meanwhile Studies II and III were performed on an outdoor clay court.

Accuracy measurement

In Study II and III to assess stroke accuracy, Pialoux et al. (2015) stroke performance design was followed (Figure 10 and 11).

Serve (S): S1 zone (0.5m*0.5m) 5 points, S2 zone (1m*1m) 3 points, rest of the S box 1 point. Bounce ball out of S box 0 points.

Groundstrokes (FH) and (BH): FH1 or BH1 zone (1m*1m) 5 points, FH2 or BH2 zone (2m*2m) 4 points, FH3 or BH3 zone (3m*3m) 3 points, FH4 or BH4 zone (4m*4m) 2 points, rest of the single court 1 point. Bounce ball out of single court 0 points.

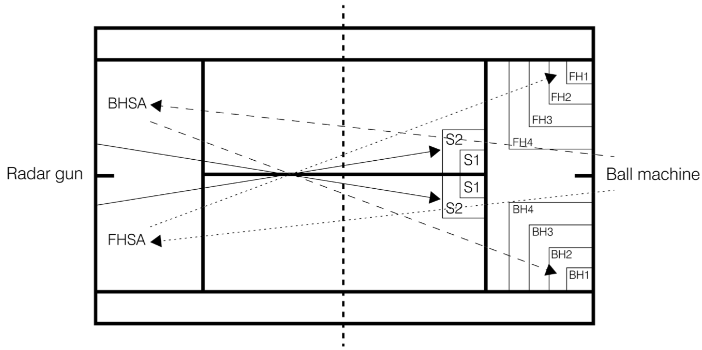

Figure 10. Stroke performance test (Pialoux et al., 2015) of Study II.
S1 and S2: target area for the serve (S); FH1, FH2, FH3 and FH4: target area for the forehand (FH); BH1, BH2, BH3 and BH4: target area for the backhand (BH); FHSA: forehand stroke impact area; BHSA: backhand stroke impact area. Continuous line: S trajectory; dot line: FH trajectory; dash line: BH trajectory.

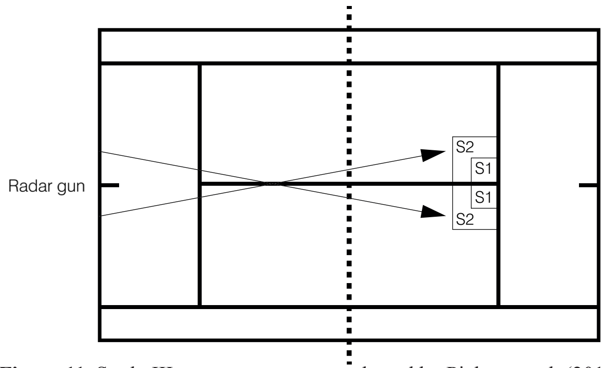

Figure 11. Study III serve accuracy test adapted by Pialoux et al. (2015).
S: serve.

Training protocols

Maximal intended velocity training was performed in order to induce greater strength gains (Gonzalez-Badillo et al., 2014) and improve ball velocity to a greater extent (Escamilla et al., 2012) in all the studies.

Strength training protocols of Study I are shown in Table 2 and Table 3. 3 non-consecutive sets of 9 exercises per session in each protocol were performed. RT protocol was mainly based on free-weights and moderate to high number of repetitions in reserve in the main exercises (4 to 6 repetitions depending on the exercise). The protocol for the MB was designed following the guidelines of Cardoso (2005), Escamilla et al. (2012) and Fernandez-Fernandez et al. (2013). The rest duration was 1 minute between sets and 3 minutes between rounds in both protocols.

Strength training protocols of Study II are shown in Table 4. The total volume was 144 repetitions in 24 sets (21 sets counting only one side of a one-arm overhead forward throw). The protocol for the MB was designed following the guidelines of Cardoso (2005) and Fernandez-Fernandez et al. (2013). According to these guidelines, the subjects performed 3 sets of 6 repetitions with a 2-kg medicine ball at maximal intended velocity of the exercises shown in Table 4. The rest duration was 1 minute between sets and 3 minutes between rounds. In the case of the RT protocol, Cardoso (2005) and Faigenbaum et al. (2009) guidelines were followed. According to the guidelines, the subjects performed 3 non-consecutive sets of 6 repetitions with the 75% 1RM at maximal intended velocity for concentric contraction, and controlled for eccentric contraction, of the exercises shown in Table 4. The repetitions were prescribed in order to avoid failure. The rest duration was 2 minutes between sets and 3 minutes between rounds. The total volume was 90 repetitions in 15 sets (12 sets counting only one side of the one-arm row).

Table 2. Resistance training (RT) exercises used in Study I.

	Day 1					**Day 2**					**Day 3**			
Exercise	Sets (no.)	Reps (RIR) (no.)	Rest set/ round (min)	Int. Vel*	Exercise	Sets (no.)	Reps (RIR) (no.)	Rest set/ round (min)	Int. Vel*	Exercise	Sets (no.)	Reps (RIR) (no.)	Rest set/ round (min)	Int. Vel*
BP	3	8(4)	1/3	Max	Chin-ups	3	6(6)	1/3	Max	Incline dumbbell flies (30º)	3	8(4)	1/3	Max
Crunch	3	50	1/3	Max	Crunch	3	50	1/3	Max	Crunch	3	50	1/3	Max
Incline leg press	3	8(4)	1/3	Max	1/2 squat	3	8(4)	1/3	Max	Incline leg press	3	8(4)	1/3	Max
FH/BH barbell	3	6(6)	1/3	Max	Dumbbell snatch	3	6(6)	1/3	Max	Barbell push-trhow one-arm	3	6(6)	1/3	Max
Trunk extension	3	20	1/3	Max	Trunk extension	3	20	1/3	Max	Trunk extension	3	20	1/3	Max
Dumbbell shoulder ER	3	10(4)	1/3	Max	Dumbbell shoulder ER	3	10(4)	1/3	Max	Dumbbell shoulder ER	3	10(4)	1/3	Max
One-arm dumbbell row	3	8(4)	1/3	Max	Dumbbell pullover	3	8(4)	1/3	Max	One-arm dumbbell row	3	8(4)	1/3	Max
Pulley shoulder IR	3	10(4)	1/3	Max	Pulley shoulder IR	3	10(4)	1/3	Max	Pulley shoulder IR	3	10(4)	1/3	Max
Barbell push-throw one-arm	3	6(6)	1/3	Max	FH/BH barbell	3	6(6)	1/3	Max	Dumbbell snatch	3	6(6)	1/3	Max

Reps = number of repetitions; RIR: number of repetitions in reserve; Int vel = intended velocity; Rest set/round = rest between sets / rest between rounds; *concentric contraction; 1RM = one repetition maximum; BP: bench press; FH: forehand; BH: backhand; ER: external rotation; IR: internal rotation; Max = maximal.

Table 3. Exercises included in medicine ball throws (MB) and elastic tubing protocol in Study I.

MB						Elastic tubing				
Exercise	Sets (no.)	Reps (no.)	Weight (Kg)	Int vel	Rest set/ round (min)	Exercise	Sets (no.)	Reps (no.)	Int vel	Rest set/ round (min)
FH throw	3	6	2	Max	1/3	Two-arm trunk rotation	3	6	Max	
BH throw	3	6	2	Max	1/3	One-arm diagonal trunk flexion	3	6	Max	
Chest throw	3	6	2	Max	1/3					
Two-arm overhead forward throw	3	6	2	Max	1/3					
Two-arm overhead backward throw	3	6	2	Max	1/3					
One-arm overhead forward throw*	3	6	2	Max	1/3					
Two-arm overhead downward throw**	3	6	2	Max	1/3					

*each arm; **each side; Reps = number of repetitions; Int vel = intended velocity; Rest set/round = rest between sets / rest between rounds; 1RM = one repetition maximum; FH = forehand; BH = backhand; Max = maximal

Table 4. Medicine ball throws (MB) and resistance training (RT) protocol in Study II.

MB						RT					
Exercise	Sets (no.)	Reps (no.)	Weight (Kg)	Int vel	Rest set/ round (min)	Exercise	Sets (no.)	Reps (no.)	1 RM (%)	Int vel*	Rest set/ round (min)
FH throw	3	6	2	Max	1/3	BP	3	6	75	Max	2/3
BH throw	3	6	2	Max	1/3	HS	3	6	75	Max	2/3
Chest throw	3	6	2	Max	1/3	One-arm row	3	6**	75	Max	2/3
Two-arm overhead forward throw	3	6	2	Max	1/3	Dead lift	3	6	75	Max	2/3
Two-arm overhead backward throw	3	6	2	Max	1/3						
Two-arm upward throw	3	6	2	Max	1/3						
One-arm overhead forward throw	3	6**	2	Max	1/3						

Reps = number of repetitions; Int vel = intended velocity; Rest set/round = rest between sets / rest between rounds; *concentric contraction; **each arm; 1RM = one repetition maximum; FH = forehand; BH = backhand; BP = bench press; HS = half squat; Max = maximal.

Strength training protocol of Study III is shown in Table 5. The protocol was designed following the meta-analysis of Wilson et al. (2013) developed with the most effective guidelines in order to achieve the PAP effect. As a consequence, the subjects performed dynamic contractions of BP, HS or both (BP + HS) at 80% 1RM, accomplishing 3 sets of 3 repetitions when BP or HS conditions were performed and 2 sets of 3 repetitions of each exercise when BP + HS condition was performed (BP: 35.6 ± 11.6 kg, HS: 68.7 ± 18.2 kg) and the S test was measured at 0, 5, 10 and 15 minutes after HLRE (or in the control session, after warm-up).

Table 5. Study III training protocol.

	Sets (no.)	Reps (no.)	Intensity (% 1RM)	Intended velocity	Rest set (min)
BP	3	3	80	Max	2
HS	3	3	80	Max	2
BP + HS	2	3	80	Max	2

BP = bench press; HS = half squat; Max = maximal.

Statistical analysis

Descriptive data were reported as mean and standard deviations (± SD). The normality of the distributions and homogeneity of variances were assessed with the Shapiro-Wilk test in all the studies. The level of significance was set at $p < 0.05$ in all the studies.

In Study II and Study III due to the fact that accuracy data were not normally distributed, Friedman's test was used to examine the differences at various times during recovery. Moreover, the magnitude of the differences in mean was quantified as effect size (ES) and interpreted according to the criteria used by Cohen (1988) <0.2 = trivial, 0.2–0.4 = small, 0.5– 0.7 = moderate, >0.7 = large.

In Study I ANOVA was applied to determine the differences among groups in body mass, height and age. In order to compare the different types of training, a repeated-measures analysis of variance was conducted, with three groups RT, MBE and C by three moments (within-subject: pre-test, inter-test and post-test). In those cases in which the ANOVA showed significant differences, Bonferroni post hoc tests were applied.

In Sudy II the differences between velocity and accuracy scores measured from the basal situation and at various recovery times (3 minutes [Post], 24 hours [Post24], 48 hours [Post48]) after performing RT and MB were evaluated using a repeated-measures analysis of variance (ANOVA), with Bonferroni-corrected post hoc analysis.

In Study III reliability on the S velocity and accuracy measure was assessed with Cronbach's alpha for intraclass reliability. Differences between the S velocity (baseline) and the scores at various times (5, 10, 15 min) during recovery from BP, HS and BP + HS were evaluated using a one-way analysis of variance (ANOVA) with repeated-measures with Bonferroni-corrected post hoc analysis. Mean differences in absolute and percent values were also used. When a difference was revealed, Wilcoxon's test was used to identify those differences.

All statistical analyses were performed using SPSS, version 20 for Study I and version 23.0 for Study II and III (SPSS Inc., Chicago, IL, USA).

Ethical considerations

All participants volunteered to take part in the studies and were previously informed of their aims, methods and potential risks. The subjects or their legal tutors in case they were under 18 years old signed an informed consent document prior to starting all the studies. The studies were designed according to the Declaration of Helsinki of 1975, revised in 2008, and the Research Ethic Committee (CER) of the University of Vic - Central University of Catalonia approved the protocol (reference 21/2017).

Summary of results

The results from this investigation show that: strength training program during 8 weeks using RT increased S velocity and using MBE increased the power but had no effect in ball velocity; moderate correlation was found between MB (one-arm and two-arms overhead MB) and S velocity; MB and RT have no acute and delayed effects in ball velocity and accuracy; and PAP effect has not been observed using a CT performing HLRE.

Long-term effects of strength training in ball velocity (Study I)

RT group improved stroke ball velocity and throwing velocity with significance differences in S velocity between the Pre-test and the Post-test (4.1%) and between the Inter-test with the Post-test (3.3%) (Table 6).

No significant differences were found in MBE group, however a trend to decrease groundstroke velocity and to increase S velocity was observed. MB power was significantly increased in both throws (1-arm and 2-arms overhead MB) between the Pre-test and the Post-test (1-arm overhead MB: 9.8%; 2-arms overhead MB 9.1%) and between the Pre-test and the Inter-test for 2-arms overhead MB (9.6%) (Table 6).

No significant differences were observed between groups in the different times (Figure 12).

Moderate correlations were found between S velocity and throwing velocity in both throws. Although with less importance, low to moderate correlations were observed between throwing velocity in both throws and FH and BH velocity (Table 7).

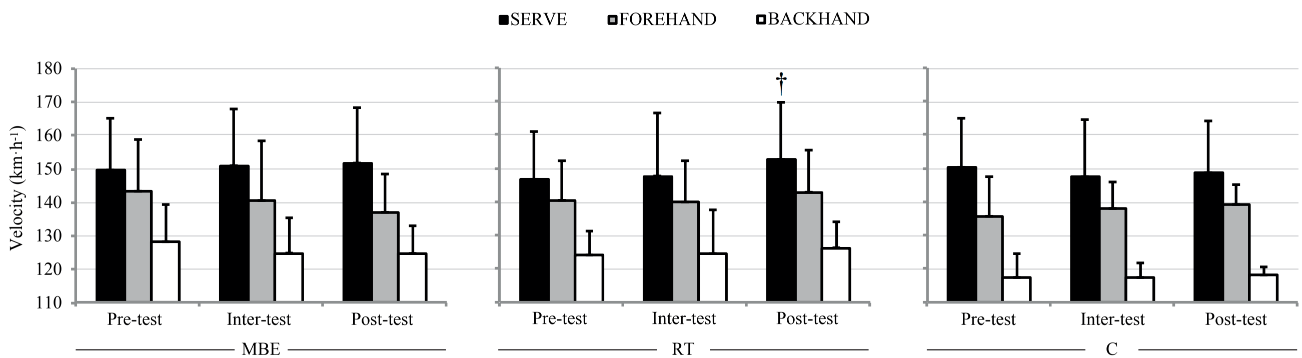

Figure 12. Stroke velocity changes during the 8-week intervention program. MBE = medicine ball throws and elastic tubing exercises group; RT = resistance training group; C = control group. †Significant differences between Pre-test and Post-test ($p < 0.05$).

Table 6. Percentages changes during the 8-week intervention program.

	MBE			RT			C		
	Pre / Post (%)	Pre / Inter (%)	Inter / Post (%)	Pre / Post (%)	Pre / Inter (%)	Inter / Post (%)	Pre / Post (%)	Pre / Inter (%)	Inter / Post (%)
S	1.4	1.0	0.5	4.1*	0.8	3.3*	-1.1	-1.9	0.8
FH	-4.4	-2.0	-2.4	1.7	-0.4	2.1	2.6	1.6	1.0
BH	-2.7	-2.6	-0.1	1.7	0.3	1.4	0.7	0.0	0.7
2-arms MB	9.1*	9.6*	-0.4	4.3	3.0	1.3	1.5	1.0	0.5
1-arm MB	9.8*	3.7	5.8	3.5	4.8	-1.2	3.2	2.1	1.0

MBE: medicine ball throws and elastic tubing exercises; RT: resistance training; C: control group; S: serve; FH: forehand; BH: backhand; MB: medicine ball throws.
*Significant differences ($p < 0.05$).

Table 7. Correlation coefficients (r) between overhead 2 and 1 arm MB velocity and stroke ball velocity.

	S		FH		BH	
	r	*p*	*r*	*p*	*r*	*p*
2-arm MB	0.600	0.005	0.337	0.146	0.405	0.076
1-arm MB	0.617	0.004	0.477	0.033	0.489	0.029

S: serve; FH: forehand; BH: backhand; MB: medicine ball throws.

Acute and delayed effects in ball velocity and accuracy (Study II)

The average peak ball velocity and accuracy and the percentage of changes of S, FH and BH after the training intervention are shown in Figure 13 for the MB method, and in Figure 14 for the RT method. There were no significant differences in ball velocity (Figures 13A and 14A) and accuracy (Figures 13C and 14C) following each time recovery (Post, Post24 and Post48), and for all strokes compared to the baseline in both training methods.

There were non-significant ball velocity increases and trivial effect sizes in S (0.8%; ES = - 0.07), and non-significant decreases and trivial effect sizes in FH and BH (-0.2 and -1.5 %; ES = 0.02 and 0.14) performing MB in Post. In Post24, non-significant increases and trivial to small effect sizes were found in S, FH and BH (0.9, 2.5 and 1.6%; ES = -0.08, -0.27 and -0.19). Regarding accuracy, a non-significant decrease and small effect size were found in Post performing S (14.8%; ES = 0.36), and slightly non-significant trend to increase and trivial to moderate effect sizes in every test performing FH (2.0, 2.6 and 6.6%; ES = -0.06, -0.08 and -0.17) and BH (2.4, 15.8 and 12.1%; ES = -0.1, -0.52 and -0.52).

Performing the RT method, a non-significant ball velocity decrease and trivial to small effect sizes in Post were found in S, FH and BH (-2.7, -1.6 and -2.2%; ES = 0.20, 0.15 and 0.25). These decreases did not happen in Post24 except when performing FH (-2.9%; ES = 0.27). In Post48, non-significant decreases and trivial effect sizes were observed in S, FH and BH (- 0.3, -1.5 and -1.8%; ES = 0.02, 0.12 and 0.16). Regarding accuracy, non-significant decreases and trivial to small effect sizes happened in Post performing S and FH (-17.9 and -4.9%; ES = 0.35 and 0.15). In Post24, non-significant increases and trivial to small effect sizes were found in S, FH and BH (10.7, 5.5 and 17.7%; ES = -0.16, -0.15

and -0.48). However, in Post48, non-significant decreases and small to moderate effect sizes were observed in S and FH (-27.4 and -13.3%; ES = 0.57 and 0.45).

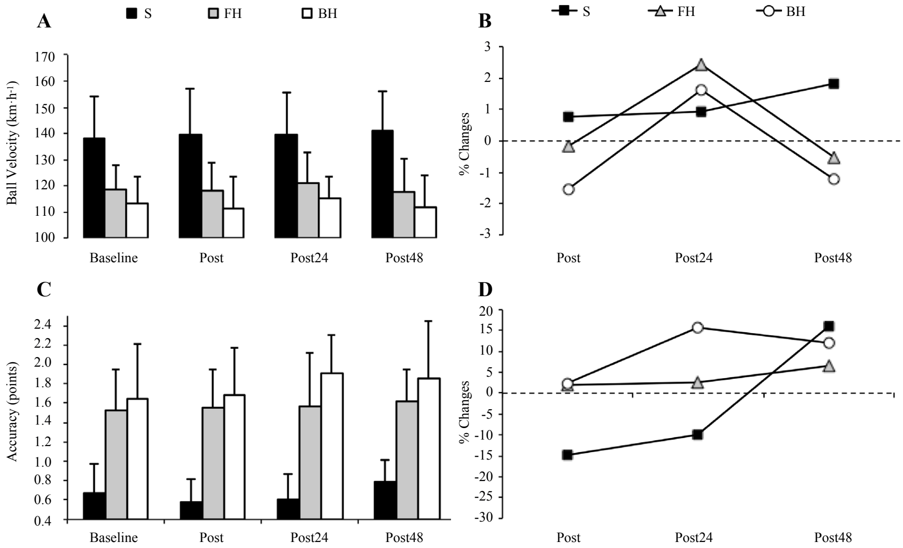

Figure 13. Acute (Post) and delayed (Post24 and Post48) effects of medicine ball throws training (MB) on ball velocity (A) and accuracy (C) and corresponding percentage changes from baseline (B and D). S: serve; FH: forehand; BH: backhand.

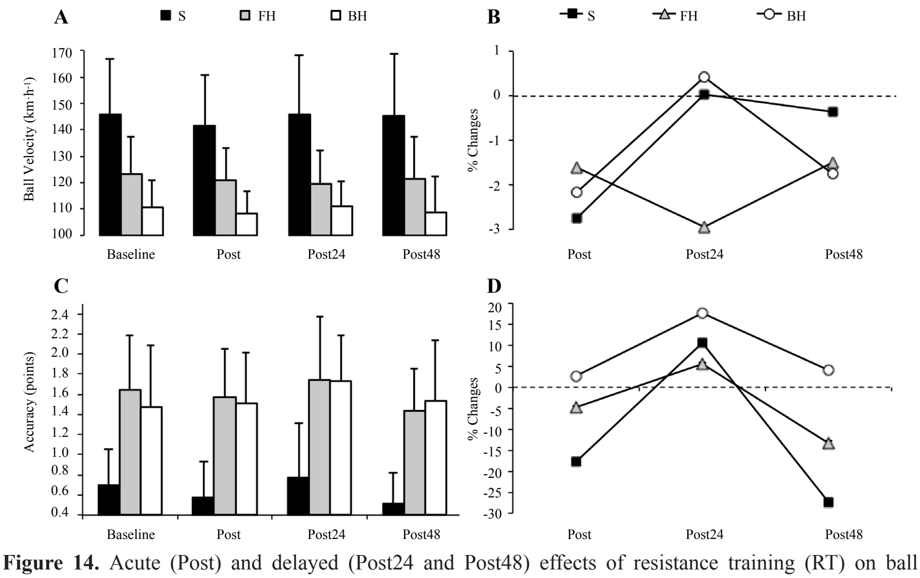

Figure 14. Acute (Post) and delayed (Post24 and Post48) effects of resistance training (RT) on ball velocity (A) and accuracy (C) and corresponding percentage changes from baseline (B and D). S: serve; FH forehand; BH: backhand.

PAP in tennis serve (Study III)

There were no differences in performing any HLRE in peak ball velocity and accuracy following each time recovery (0, 5, 10, 15 min) compared to the baseline (Figure 15A and Figure 15B).

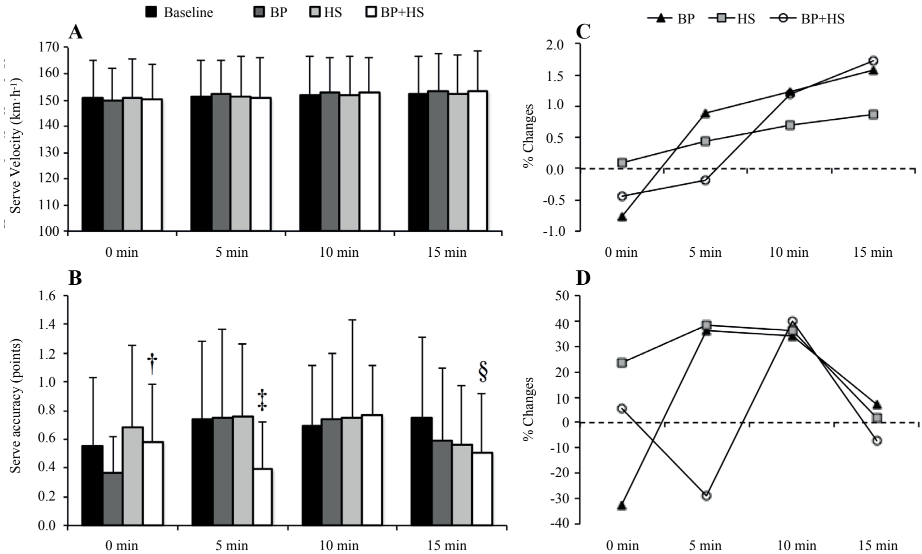

Figure 15. Comparison of peak serve velocity (A), accuracy (B) and corresponding percentage changes from baseline (C and D) after 3 different heavy load resistance exercises (BP: bench press; HS: half squat; BP + HS: bench press plus half squat) across 4 times points (0, 5, 10 and 15 min). Serve velocity and accuracy values are mean ± SD; †Significant differences between minute 10 ($p < 0.05$); ‡Significant differences between minute 10 ($p < 0.05$); §Significant differences between minute 10 ($p < 0.05$).

There were no significant increases and trivial effect sizes of peak velocity since minute 5 in BP (0.9, 1.2 and 1.6%; ES = -0.06, -0.07 and -0.08) and HS (0.44, 0.70 and 0.88%; ES = -0.01, -0.01 and -0.01), and since minute 10 in BP + HS (1.2 and 1.7%; ES = -0.06 and -0.09) until minute 15 compared to the baseline (Figure 15C). The individual responses in peak ball velocity ranges from -8.6 to 8.0%.

Trivial-to-small effect sizes for an increase ($p > 0.05$; ES = -0.01 to -0.25) in minutes 0, 5 and 10 in HS (23.6, 38.2 and 36.4%; ES = -0.25, -0.04, -0.11), minutes 5 and 10 in BP (36.4 and 34.4%; ES = -0.02, -0.01) and minute 10 in BP + HS (40.0%; ES = -0.21), and moderate-to-large effect sizes for a reduction ($p > 0.05$) in BP in minute 0 (-32.3%; ES = 0.47) and BP + HS in minute 5 (-29.1%; ES = 0.78) were found in the S accuracy compared to the baseline (Figure 15D). Significant differences and moderate-to-large effect sizes ($p < 0.05$; ES = 0.51 to 1.12) in S accuracy performing BP + HS were found comparing minute 10 with the other recovery times (0, 5, 15 minutes; -24.7, -49.4, -33.8%; ES = 0.51, 1.12, 0.69) (Figure 15B and Figure 15D).

Discussion

In order to investigate the long-term effects of strength training in Study I, a longitudinal design during 8 weeks performing MB and RT was used. Then, in Study II, acute and delayed effects of MB and RT in stroke ball velocity and accuracy were investigated. Finally, in Study III, CT was performed in order to find PAP effect in tennis S.

The main findings were: 1) strength training using MB during 8 weeks were useful to increase MB power and would justify the utility of strength training programs in youth; 2) 8 weeks RT increased ball velocity in young players; 3) 4 weeks of RT could be not enough to observe ball velocity improvements; 4) Moderate correlation was found between MB (one-arm and two-arms overhead MB) and S velocity; 5) MB and RT using similar protocols (exercises, volume, intensity or repetitions in reserve) do not cause an acute detrimental effect in stroke ball velocity and accuracy; 6) a trend to decrease ball velocity and accuracy was greater after RT than after MB in all strokes, although there were non-significant differences; 7) PAP effect was not observed performing a CT using HLRE in S velocity; 8) no S accuracy changes were found after a CT using HLRE; 9) due to the large variation of individual responses, it could be suggested that subjects respond differently when using CT.

Long-term effects of strength training in ball velocity (Study I)

Strength training programs in youth from 4 weeks onwards has been shown to increase power and strength (Treiber et al., 1998; Ignjatovic et al., 2012; Faigembaum & Mediate, 2006; Faigenbaum et al., 2013; Fernandez-Fernandez et al., 2013; Faigenbaum et al., 2016). Our results show that power (measured as MB velocity) was increased after 4 weeks and after 8 weeks of MB training program, especially in the first 4 weeks.

Regarding stroke ball velocity, although performing MB has shown improvements in ball velocity baseball throwing (Escamilla et al., 2012), FH and S velocity (Genevois et al., 2013; Fernandez-Fernandez et al., 2013; Fernandez-Fernandez et al., 2016), we did not find a ball velocity improvement in MBE group in spite of the MB velocity improvement and the moderate correlation found between MB velocity and S velocity. However, when performing RT, S ball velocity was increased (4.1%) during the 8-week training program, mainly in the second period of 4 weeks (Inter-test to Post-test), suggesting that RT program for just 4 weeks might be not enough to increase ball velocity. Similar improvements were observed by other investigations in baseball throwing using MB and elastic band (2.1%) (Escamilla et al., 2012), in tennis FH using MB (11%) and overweighed racket (5%) (Genevois et al., 2013), in tennis S using Theraband and lightweight dumbbell (6.0%) (Treiber et al., 1998) and using MB and elastic tubing exercises (4.9%) (Fernandez-Fernandez et al., 2013). Nevertheless, in contrast to our results, Behringer et al. (2013) compared plyometric training (performing jumps and MB) and RT and observed that plyometric training increased S ball velocity, but no changes in S velocity were observed performing RT based on weight machines. Various authors (Haff, 2000) recommended free-weight instead of weight machines because greater improvements had been shown (Schott et al., 2019). Furthermore, a higher transference to sports movements is possible because free-weights allow for multi planar movements that imitate better the sports movement rather than machines (Myers et al., 2017). Although in our investigation a RT exercise based on weight machines was used (incline leg press), RT using free-weights were mainly performed.

Regarding correlations, a positive moderate correlation was found between S velocity with overhead 2-arms MB (r = 0.600) and overhead 1-arm MB (r = 0.617), possibly due to the fact that S and overhead MB have more similar kinetic chain than groundstrokes. However, in MBE group, the MB velocity increase in both throws was not reflected in ball velocity.

Due to the more similar kinetic chain used, the correlation between S and MB velocity and the results of other investigations (Genevois et al., 2013; Behringer et al., 2013; Fernandez-Fernandez et al., 2013; Fernandez-Fernandez et al., 2016), it could be hypothesized that MB would obtain higher improvements in ball velocity. However, RT obtained better results in ball velocity. It is possible that the combination of higher loads of RT and the subjects' strength training experience could cause higher improvements in ball velocity.

Acute and delayed effects in ball velocity and accuracy (Study II)

The aim of this study was to investigate the acute (3 min) and delayed (24 and 48 h) effects of maximum strength (75% 1RM RT) and explosive training (2 kg MB) in ball velocity and accuracy in young competition tennis players. The main results reported that explosive training (MB) and maximum strength (RT) does not have any acute and delayed effect in S, FH and BH ball velocity and accuracy. Taking into account that velocity loss could be considered as a neuromuscular fatigue indicator (Sanchez-Medina & Gonzalez-Badillo, 2011; Pareja-Blanco et al., 2016), it could be suggested that MB and RT do not cause neuromuscular fatigue to the involved muscles in the tennis stroke's kinetic chain.

Although this investigation did not find any negative effect in the stroke ball velocity and accuracy in young competition tennis players, it has been observed an acute performance decrease performing an explosive strength training (plyometric training or resistance training at 40% 1RM) (Linnamo et al., 1997; Drinkwater et al., 2009; Thomas et al., 2018) and maximal strength training (isometrics contraction at maximal voluntary contraction or dynamics contractions at 80 to 100% 1RM) (Linnamo et al., 1997; Walker et al., 2012; Buckthorpe et al., 2014; Thomas et al., 2018). Moreover, a decrease was observed in power, repeated-sprint ability, and shot accuracy in semi-professional male basketball players performing heavy RT (6 repetitions to failure) (Freitas et al., 2016). However, similarly to our results, it has not been observed changes in vertical jump, anaerobic power, or shot accuracy performing RT (5-12 repetitions at 60-80% 1RM) in collegiate women basketball players after 6 hours of recovery time (Woolstenhulme et al., 2004).

This disparity of results may be explained by the different training variables performed in the investigations such as volume, intensity, and rest duration. In our investigation the subjects did not perform the repetitions to failure in order to properly perform strength training for young athletes (Faigenbaum et al., 2009), and the rest interval between sets was enough to avoid the excessive neuromuscular fatigue and to maintain the number of repetitions per set (de Salles et al., 2009). Although repetition to failure is commonly used in strength training (Campos et al., 2002), it is not a critical aspect to enhance muscle hypertrophy (Sampson & Groeller, 2015) or strength (Izquierdo et al., 2006; Sampson & Groeller, 2015), and it could cause a phenotype muscle change to slower fibers (Campos et al., 2002; Pareja-Blanco et al., 2016) and an increase of blood ammonia level (Sanchez-Medina & Gonzalez-Badillo, 2011; Moran-Navarro et al., 2017). Besides, repetition to failure could increase the time needed for the recovery of neuromuscular function and metabolic and hormonal homeostasis (Moran-Navarro et al., 2017).

Even though this investigation did not find a performance stroke decrease, neuromuscular fatigue could happen due to the fact that the central nervous system uses different neuromuscular strategies to overcome the fatigue in order to maintain the performance (Bonnnard et al., 1994). Similarly, during a tennis match, it has been shown technical impairments with no effect in S velocity and accuracy (Hornery et al., 2007), remaining stable during five-set professional matches on grass surface (Maquirriain et al., 2016) or during a 2-hour match with young competition tennis players (Mc Rae et al., 2012). Moreover, during a three-day tennis tournament, a decrease in lower extremities of RFD and maximal voluntary contraction was found after the first day, but the S velocity remained stable until before the third match, and no effects were found in CMJ (Ojala & Hakinnen, 2013) suggesting the theory of strategies to compensate for the fatigue effects of Bonnard et al. (1994). Also in soccer, after a match, a decrease in RFD and maximal voluntary contraction were found with no effect in CMJ (Thornlund et al., 2009). Therefore, in spite of not measuring the RFD and the maximal voluntary contraction, it could be hypothesized that a decrease in RFD and maximal voluntary contraction with no effect in ball velocity could have happened in this investigation, involving strategies to compensate the fatigue effects.

A trend to decrease ball velocity and accuracy was greater after RT than after MB in all strokes although there were non-significant differences. This trend could have diverse causes: estimated total time under tension was longer in RT than in MB (even though the time under tension was not measured) and higher loads were performed in RT exercises. The RT trend to decrease ball velocity was higher in the acute effects (Post), but similar levels to the baseline were found, except when performing FH in the delayed effects (Post24). A non-significant accuracy decrease in S was shown when performing both RT and MB, likely due to the complexity of this shot, and the muscles involved in the protocol exercises.

PAP in tennis serve (Study III)

The aim of this study was to investigate PAP effect using CT with HLRE in tennis S velocity and accuracy in junior highly trained tennis players. The main results reported that CT performing HLRE does not show an improvement in S velocity or any detrimental effect in accuracy, though it has been shown that CT improves SSC explosive movements such as sprint, countermovement jump, throws and upper body ballistic movements (Crewther et al., 2011; Wilson et al., 2013; Judge et al., 2016; Seitz & Haff, 2016; Dello Iacono et al., 2017; Scott et al., 2017; Dello Iacono & Seitz, 2018).

Ferrauti and Bastiaens (2007) found similar results not observing beneficial effects by using light (200 g) and heavy (600 g) MB on tennis S velocity in junior players. In addition, they found a decrease in S velocity when using a heavy medicine ball (600 g). The difference with our investigation is that they used moderate loads through MB, their sample was slightly younger (15.6 ± 1.4 vs. 12.3 ± 0.8 years) and the recovery period was shorter (0, 5, 10, 15 min vs. immediately after intervention). It should be pointed out that the protocol used could affect the result because it includes recovery time, HLRE, intensity, volume, strength level, training experience, age, and muscle fibres (Wilson et al., 2013; Seitz & Haff, 2016). Therefore, due to the multiple variables affecting PAP effect is very complex to detect the causes of not achieving an enhancement.

This complexity could be explained, for instance, by the specificity principle and the force vector theory (Dello Iacono et al., 2017; Dello Iacono & Seitz, 2018). Therefore, velocity enhancement could be achieved by using a tennis S more similar kinetic chain exercises, such as tennis-specific exercises (i.e., cable pulley machines or ballistic movements) or shoulder internal rotation exercises (i.e., using cable), because shoulder internal rotation is the movement with more velocity contribution in tennis S (Elliot, 2006; Kovacs & Ellenbecker, 2011; Baiget et al., 2016).

Another reason for not finding PAP effect could be explained by the training experience and age sample due to the fact that several studies have shown that training experience (Kilduff et al., 2007; Wilson et al., 2013) or strength level (Chiu et al., 2003; Wilson et al., 2013) could be a performance enhancer of PAP. Compared to these studies, our sample was younger (15.6 ± 1.5 years) and, therefore, that could cause a lower PAP response or no effect, as with the research of Ferrauti and Bastiaens (2007).

It should be pointed out that due to the large variation of individual responses (-8.6 to 8.0%), it could be suggested that subjects respond differently when using CT. Consequently, it is necessary to individualize the protocol and identify the recovery windows in each subject in order to know the subjects that respond positively and the protocol followed (Till & Cooke, 2009; Mola et al., 2014).

Regarding accuracy, our findings do not show a detrimental effect, probably due to the fact that the protocol used do not have motor coordination impairment in the muscles involved in the S kinetic chain. Similar results were found by Ferrauti and Bastiaens (2007) in tennis S using a CT and by Woolstenhulme et al. (2004) performing traditional RT after 6 hours rest. It should be taken into account that this research only investigated a closed tennis situation and that in a match the psychological pressure and the tactical requirements could condition the S performance. Although significant differences performing BP plus HS were observed comparing minute 10 with the other recovery times (0, 5 and 15 minutes), no significant differences were observed compared to the baseline.

Practical Applications

The current findings suggest that some practical applications could be used by tennis and strength and conditioning coaches:

1. RT is a useful method to increase tennis S velocity in trained young players.

2. RT programs should last at least 8 weeks to achieve significant improvements in trained young players.

3. Although MBE does not increase stroke ball velocity in our investigation, it would be interesting to increase strength and power. Furthermore, due to the results of other researches (Behringer et al., 2013; Fernandez-Fernandez et al., 2013; Fernandez-Fernandez et al., 2016) and the correlation found in the present investigation, we can not discourage MBE to increase stroke velocity.

4. MB and RT protocols could be used before a technical-tactical on-court session, off-season and in-season, due to the fact that they do not have any detrimental acute effect on stroke performance. It should be pointed out that these results are exclusively for these training methods; changing the protocol, for example by using other exercises, repetition to failure, or larger volume, could cause more neuromuscular fatigue and, consequently, a decrease on stroke performance.

5. When training RT, it would be advisable to avoid the repetitions to failure because do not cause any detrimental effect in stroke performance and could increase strength and power (Faigenbaum et al., 2016; Lopez et al., 2018; Fernandez-Fernandez & Kovacs, 2018).

6. It is possible that RT causes more acute neuromuscular fatigue than MB due to a slightly higher trend to decrease stroke performance; therefore, it should be

taken into account when applying this method close to competition.

7. CT performing HLRE (80% 1RM) could be used together with a technical-tactical session due to the fact that it does not have a detrimental effect on accuracy and velocity.

8. CT performing HLRE (80% 1RM) is not a useful method to acutely increase S performance in young players, but it should be taken into account the protocol used and the individual responses. Therefore, coaches should be careful when applying this training method, and it would be advisable to individualize it in order to find the best protocol for each player.

Conclusions

This doctoral thesis is composed of three investigations regarding strength training in tennis, in which it has been investigated: long-term effects of MBE exercises and RT in stroke ball velocity (Study I); the acute and delayed effects of MB and RT in stroke ball velocity and accuracy (Study II); and the PAP effect using a CT performing HLRE in S velocity and accuracy (Study III). From the current investigation it could be outlined the following conclusions:

1. RT during 8 weeks can improve ball velocity and the MB power in young tennis players (Study I).
2. MBE training during 8 weeks improved MB power but had no effect on ball velocity in young tennis players (Study I).
3. Strong correlations were found between MB (one-arm and two-arm overhead MB) and the S velocity (Study I).
4. MB performed at maximal intended velocity execution has no acute and delayed detrimental effects on stroke tennis velocity and accuracy (Study II).
5. RT avoiding repetition to failure and performed at maximal intended execution has no acute and delayed detrimental effects on stroke tennis velocity and accuracy (Study II).
6. It could be suggested that MB and RT do not cause neuromuscular fatigue in the muscles involved in the tennis stroke's kinetic chain (Study II).
7. CT using HLRE does not improve S velocity and does not have detrimental effect in S accuracy in young players (Study III).

8. It has been observed a large variation of individual responses, suggesting that subjects respond differently when using CT (Study III).

FUTURE PERSPECTIVES

In this dissertation three investigations regarding strength training in tennis were conducted. Although each investigation has an individual meaning, all of them have in common the aim to generate and provide scientific knowledge to trainers and strength and conditioning coaches in tennis strength training in order to increase stroke ball velocity. This topic is a point of contention and due to tennis complexity and its constant evolution, more researches should be needed in order to provide solid evidences.

The conclusions of this investigation provide some instructions that should be taken into account in strength programs for developing ball velocity in young tennis players, but it should be pointed out that the results are difficult to extrapolate due to the fact that the sample was small and the range of age was limited. Long-term effects of RT and MBE were observed as a positive power and strength enhancer in young tennis players, both in this investigation and in Behringer et al. (2013) investigation. In contrast to these results, Behringer et al. (2013) found an increase of S velocity using MB. Further research should compare the efficacy of both methods investigating other samples (i.e., elite players). Also, it would be advisable to investigate other strength training methods (i.e., isoinertial resistance machine imitating tennis strokes).

Furthermore, it would be interesting when training with these new methods to investigate the acute and delayed effects in order to observe neuromuscular fatigue and their effect in ball velocity and accuracy. MB and RT (RT at 75% 1RM and 2-kg MB, both executed at maximal intended velocity and avoiding repetitions to failure) do not cause detrimental effects in ball velocity and accuracy, but due to the sample size, it is premature to draw firm conclusions from the data, thus, additional investigation should be made. It would be also interesting to measure muscle activity through EMG in order to know muscle activity variation after a strength training or the possible compensation with other muscles.

Regarding PAP effects in tennis S, it was found that CT using HLRE does not improve S velocity and has no detrimental effect in accuracy, but considering that a large variation of individual responses was observed, further research should be required to develop a proper protocol by investigating different samples, CA, recovery period, volume or intensity in order to obtain PAP effect and consequently a faster ball velocity.

Moreover, long-term CT effect is another interesting line of investigation. It has been shown that long-term CT (from 4 to 16 weeks) has a significant beneficial effect on lower-body performance compared to the traditional training (Bauer et al., 2019). In tennis, it would be interesting to find the best protocol to achieve PAP effect and then follow it for a long-term training period to investigate its effectiveness in tennis ball velocity. Also, it would be interesting to investigate the PAP effect on stroke velocity and accuracy using maximal isometric contraction (i.e. shoulder internal rotation) or similar kinetic chain exercises such as MB, cable pulley machine exercises or isoinertial resistance machine, imitating tennis strokes.

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Studies

STUDY I

Effects of strength training on hitting speed in young tennis players.

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ORIGINAL

EFFECTS OF STRENGTH TRAINING ON HITTING SPEED IN YOUNG TENNIS PLAYERS

EFECTOS DEL ENTRENAMIENTO DE FUERZA EN LA VELOCIDAD DE GOLPEO EN TENISTAS JÓVENES

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ABSTRACT

Nowadays, hitting speed is an important component of tennis performance. The purpose of this study was to determine the effect of two different strength training methods on hitting speed. 20 tennis players were (mean ± SD: age 15.5 ± 0.9 years; weight 61.4 ± 7.6 kg; height 170.3 ± 9.4 cm) randomly divided into 3 groups. During 8 weeks with a frequency of 3 days per week, the first group (SC) performed one additional training with overloads, the second group (L) completed an additional training with medicine ball and elastic band; and the third group (C, control), only completed the technical-tactical training. Each group increased their strength, except the control group. SC group had the best improvement in serve speed. L group increased the strength levels although there was no transfer from the improved strength to the hitting speed.

KEY WORDS: tennis, hitting speed, strength training, resistance training.

RESUMEN

La velocidad de golpeo es uno de los factores fundamentales para el rendimiento en tenis competitivo. El objetivo del estudio fue determinar el efecto de dos métodos de entrenamiento de fuerza sobre la velocidad de golpeo en tenis. 20 jugadores de nivel regional (promedio ± SD: edad 15.5 ± 0.9 años; peso 61.4 ± 7.6 Kg; talla 170.3 ± 9.4 cm) fueron asignados aleatoriamente en tres grupos. Durante 8 semanas a 3 días·sem^{-1}, un grupo realizó un entrenamiento adicional con sobrecargas (SC), un segundo grupo entrenamiento adicional mediante lanzamientos con balón medicinal y banda elástica (L) y un tercer grupo (C, control) únicamente realizó el entrenamiento técnico-táctico. Todos los grupos mejoraron los niveles de fuerza, excepto el grupo control. El grupo SC obtuvo mayores incrementos en la velocidad de servicio. El grupo L mejoró la velocidad de lanzamiento de balón medicinal aunque no hubo transferencia en la velocidad de golpeo.

PALABRAS CLAVE: entrenamiento fuerza, tenis, velocidad de golpeo.

INTRODUCTION

Competitive tennis requires good physical condition, high level of motor skills and big tactical capacity, which makes it a multifactor sport (Fernández et al., 2006, Unierzyski, 2006; Baiget, 2008; Fernández et al., 2012; Fernández et al., 2013). In the last years, the requirements of this sport have changed substantially: the distance covered in displacements, the high strength levels developed and the change in hitting mechanics have made tennis a very physically-demanding sport (Kovacs, 2010). This suggests that tennis has evolved from being a sport where performance was mostly dependent on technical and tactical skills to a new context where physical capacities have gained relevance (Fernández et al., 2012). These changes have influenced on physical and physiological demands of tennis games, giving more importance to power and speed (Sarabia et al., 2010). Simultaneously, there is growing interest in improving these capacities with training. However, sometimes the methods used have been based more on intuition and coaches' experience than on the scientific method (Fernández et al., 2006).

Strength development plays an important role in tennis training and has the purpose to optimize shots and displacements, as well as to prevent injuries (Kovacs, 2006; Ortiz, 2004). Currently, hitting speed is a determining performance factor in modern tennis (Signorile et al., 2005; Baiget, 2011). In order to increase this speed, strength training should focus on maintaining or improving the levels of useful or applied strength (Baiget, 2011), increasing the power developed in the competitive skill (Badillo y Serna, 2002). For this reason, it becomes very important to use training methods which are specific to the necessities of each sport and to have the right tools to monitor its evolution (Van den Tillaar y Ettema, 2004).

Several studies have proved that explosive strength training by means of SSC (stretch-shortening cycle) allows to improve the hitting speed in sports like tennis (Treiber et al., 1998; Fernández et al., 2013; Genevois et al., 2013) or baseball (Escamilla et al., 2012). In this regard, several authors recommend doing rotational medicine ball throws to improve the hitting speed in tennis (Roetert y Ellenbecker, 2008; Roetert et al., 2009; Earp y Kraemer, 2010; Baiget, 2011) or the use of overloads (Kraemer et al., 2000; Kraemer et al., 2003). The aims of the present study are to examine the effectiveness of training with medicine ball and overloads on hitting speed of the serve, forehand and backhand tennis strokes and to analyze the relationship between maximal medicine ball throwing speed and hitting speed in youth tennis players.

MATERIAL AND METHOD

Participants

20 competitive tennis players (15 boys and 5 girls), belonging to under-16 or under-19 categories participated in this study (mean ± SD: age 15.5 ± 0.9 years; body mass 61.4 ± 7.6 kg; height 170.3 ± 9.4 cm). General characteristics of the participants are shown in Table 1. None of them underwent significant

changes in their anthropometric characteristics during the study. Inclusion criteria for this study were: to have longer experience in tennis training than 4 years, not to practice any other competitive sport, not to have participated in any specific strength training program, and not to have been injured in the last six months. All participants volunteered to take part in the study and were previously informed of its aims, methods and potential risks. They did not receive any kind of reward for participating. They, or their legal tutors in case of under-eighteen, signed an informed consent document. This study was designed according to the Declaration of Helsinki of 1975, revised in 2008, and the protocol was approved by the local ethics committee.

Table 1: General characteristics of the groups (mean ± SD). SC: experimental group following overloads training; L: experimental group using medicine ball throws and elastic band; CON: control group. *No significant differences ($p < 0.05$) were found in age, body mass or height among the control and experimental groups.

	n	**Age (years)**	**Body mass (kg)**	**Height (cm)**
SC	7	14.9 ± 0.7	62.5 ± 10.1	170.8 ± 13.3
L	7	16.0 ± 0.8	58.4 ± 3.8	167.5 ± 5.9
CON	6	15.4 ± 0.9	63.6 ± 7.9	173.1 ± 7.8

Instruments

A radar (Stalker Pro, USA) was used for the measurements. It was calibrated before each participant was measured, according to the instructions of the manufacturer. This radar, which had been previously validated by Sedano et al. (2009), uses Ka band microwaves, with 20 miliwatt power and two polarized horns destined to jointly transmit and receive the signals. This kind of band uses a frequency of 34.7 GHz, which protects it against electromagnetic noise. To prevent the error due to the cosine effect, the radar was placed in the line of the ball's displacement and the shots which did not meet this requirement were not considered for the study. Only maximal hitting speeds were considered, following Fernández et al. (2013). The same device has been used in tennis to assess the speed of the serve (Blackwell & Knudson, 2002; Girard et al., 2005), the forehand and backhand strokes (Signoreli et al., 2005; Corbi, 2008). Balls approved by the International Tennis Federation (Babolat Gold) were used for the hitting tests. New balls were used in every testing session, in order to keep internal pressure uniform. A 2-kg Salter medicine ball was used for the throwing tests.

Protocol

The participants were assigned in a stratified and randomized way to one of three training groups: experimental group 1 (SC), experimental group 2 (L) and control group (CON). The inclusion of a control group was necessary to control for the effect of the technical-tactical training completed during the study and for the improvement due to natural development of the participants.

No significant differences were observed among groups once they were created. The three groups completed the same technical-tactical training for 8 weeks. The SC group performed additional training with overloads, the L group underwent additional training with medicine ball throws and elastic bands and the CON group only did the regular tennis training. The training program lasted for 8 weeks, with 3 sessions per week. Both experimental groups did 2 hours of on-court technical-tactical training and one additional hour of strength training, while the CON group only completed the 2 hours of technical-tactical training. The strength training in the additional sessions focused on improving the hitting speed. Each strength training session lasted for 45 min and consisted of a 15-min warm up, which included running and dynamic stretching, and specific exercises (Ayala et al., 2012). During the whole intervention phase, the players did not change their hitting technique, racquets or string tension. All the participants attended a minimum of 80% of the programmed training sessions.

One week prior to the beginning of the intervention, the participants were asked to attend a briefing where they handed the informed consent in, the study protocol was explained to them and they were instructed how to correctly perform every exercise. The SC group performed the exercises with effort rates between 6 (12) and 10 (14), depending on the exercise (González Badillo & Gorostiaga, 1995; González-Badillo & Ribas, 2003; González Badillo, 2008). Execution speed was maximal (maximal intention) in both training methods, since biggest transference seems to occur when execution speed is high and it allowed to compare the power developed by different participants (González Badillo y Gorostiaga, 2011). Three sets per exercise were prescribed in the strength training, according to Rhea et al. (2004). The training protocols used with each group of this study may be found in the table 2 and 3.

Table 2: Exercises used in the overload method (SC) and [effort rate]. 3 sets of each exercise were completed, with 1 minute rest between exercises and 3 minutes between sets.

DAY 1	DAY 2	DAY 3
Horizontal barbell bench press [8(12)]	Supinated and semisupinated grip pull ups [6(12)]	Incline dumbbell flies (30º) [8(12)]
Trunk curl on the floor 50	Trunk curl on the floor 50	Trunk curl on the floor 50
Incline leg press [8(12)]	½ squat [8(12)]	Incline leg press [8(12)]
Forehand/backhand with barbell [6(12)]	Dumbbell snatch [6(12)]	Barbell throw [6(12)]
Trunk extensions on bench 20 kg	Trunk extensions on bench 20 kg	Trunk extensions on bench 20 kg
Dumbbell lying shoulder external rotation [10(14)]	Dumbbell lying shoulder external rotation [10(14)]	Dumbbell lying shoulder external rotation [10(14)]
One-arm dumbbell row to waist [8(12)]	Dumbbell pullover [8(12)]	One-arm dumbbell row to waist [8(12)]
Standing high-pulley internal rotation [10(14)]	Standing high-pulley internal rotation [10(14)]	Standing high-pulley internal rotation [10(14)]
Barbell throw [6(12)]	Forehand/backhand with barbell [6(12)]	Dumbbell snatch [6(12)]

Table 3: Exercises included in the training method using medicine ball throws and elastic band (LT). 3 sets of 6 repetitions were performed per exercise. Medicine ball weight: 2 kg.

MEDICINE BALL	ELASTIC BAND
Forehand and backhand side throws	Two-arm trunk rotation
Chest throws	One-arm diagonal trunk flexion
Two-arm overhead forward throws	
Two-arm overhead backwards throws	
One-arm overhead forward throws	
Side floor throws	

Image 1: A: Side throws starting position (forehand-backhand). B: Side throw end position (forehand-backhand). C: Chest throw starting position. D: Chest throw end position.

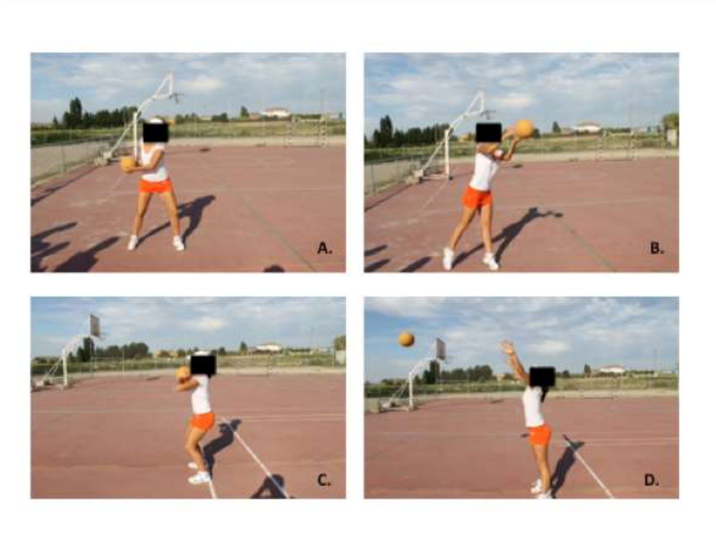

Image 2: A: Starting position for the two-arm overhead forward throw. B: End position for the two-arm overhead forward throw. C: Starting position for the two-arm overhead backwards throw. D: End position for the two-arm overhead backwards throw.

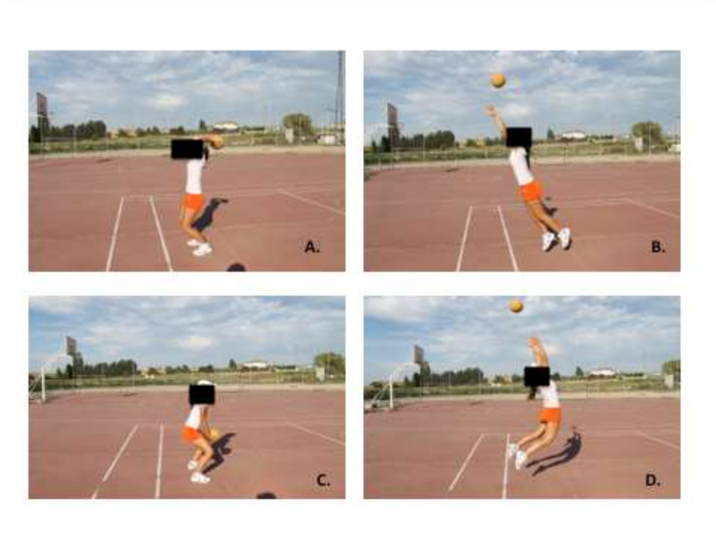

Image 3: A: Starting position for the one-arm overhead forward throws. B: End position for the one-arm overhead forward throws. C: Starting position for the two-arm side floor throws. D: End position for the two-arm side floor throws.

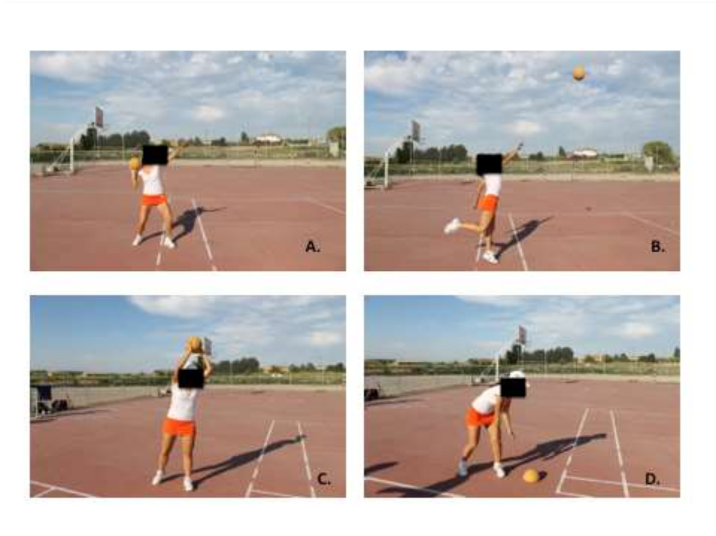

Image 4: A: Starting position for the two-arm trunk rotation with elastic band. B: End position for the two-arm trunk rotation with elastic band. C: Starting position for the one-arm diagonal trunk flexion. D: End position for the one-arm diagonal trunk flexion.

Three assessments of the hitting and throwing speeds were made: pre-test (two days prior to the intervention), inter-test (after 4 weeks of intervention) and post-test (five days after the end of the intervention).

The test consisted in assessing the speed of 12 flat serves (6 on each court side), 12 backhand and 12 forehand strokes (6 parallel and 6 crosscourt), 3 two-arm overhead throws with a 2-kg medicine ball and 3 single-arm throws per player. The participants were constantly encouraged to perform the shots and throws at maximal speed. Only the shots which followed the desired trajectory and landed within the court were taken into account. The participants rested 20 seconds between shots and 3 minutes between tests. During the training sessions, no maximal effort was performed 48 hours prior to the tests. No food rich in carbohydrates was ingested 2 hours prior to the tests.

Statistical analysis

Descriptive statistical methods were used to calculate means and standard deviations. After having applied the Shapiro-Wilk normality test to all the variables, a one-way ANOVA was applied to determine the differences among groups in body mass, height and age. In order to compare the different types of training, a repeated-measures analysis of variance was conducted, with three groups (between-subject: training with overloads –SC-, training with throws and elastic band –L-, control –CON-) by three moments (within-subject: pre-test, inter-test and post-test). In those cases in which the ANOVA showed significant differences, Bonferroni post hoc tests were applied. Statistical significance level was set at $p < .05$. The statistical analysis was conducted with the software package SPSS Statistics 20.

RESULTS

No significant differences were found in age ($F_{2,17}$ = 2.935; p = .08), body mass ($F_{2,17}$ = 0.837 ; p = .45) or height ($F_{2,17}$ = 0.569 ; p = .577) among groups (Table 1). Descriptive statistics regarding hitting speed are shown in Table 4. No significant differences were found among the three groups during the pre-test in the speed of the serve ($F_{2,17}$ = 0.110; p = .897), the forehand stroke ($F_{2,17}$ = 0.639; p = .540), the backhand stroke ($F_{2,17}$ = 2.340; p = .1278), the two-arm medicine ball throw ($F_{2,17}$ = 1.297; p = .299) or the one-arm medicine ball throw ($F_{2,17}$ = 0.412; p = .669).

Significant correlations were observed among most of the studied variables, although the correlations between the one-arm medicine ball throwing speed and both forehand and backhand stroke speeds were not as high as the rest. There were no significant correlations between the two-arm medicine ball throwing speed and both forehand and backhand stroke speeds (Table 5).

Table 4: Hitting speed (mean ± SD) obtained in the three tests (T1, T2 and T3). CON: Control group; SC: Group training with overloads; L: Group training with medicine ball throws and elastic band.

	PRE-TEST (T1)			INTER-TEST (T2)			POST-TEST (T3)		
	CON (n=6)	SC (n=7)	L (n=7)	CON (n=6)	SC (n=7)	L (n=7)	CON (n=6)	SC (n=7)	L (n=7)
SERVE (Km/h)	150.3± 14.6	146.57± 14.39	149.43± 15.38	147.50± 16.87	147.7± 18.63	150.8± 16.89	148.67± 15.48	152.57± 17.16	151.57± 16.62
FOREHAND (Km/h)	135.67± 11.74	140.43± 11.73	143.14± 15.32	137.83± 8.09	139.8± 12.39	140.2± 17.99	139.17± 5.95	142.86± 12.48	136.86± 11.42
BACKHAND (Km/h)	117.33± 7.31	124.14± 7.22	128.00± 11.36	117.33± 4.55	124.5± 13.16	124.7± 10.58	118.17± 2.32	126.29± 7.78	124.57± 8.18
2-ARM THROW (Km/h)	32.62± 2.88	33.00± 4.90	29.71± 4.28	32.83± 3.06	34.00± 5.26	32.57± 3.91	33.17± 3.31	34.43± 3.60	32.43± 3.65
1-ARM THROW (Km/h)	31.67± 3.67	33.00± 5.63	30.71± 4.54	32.33± 3.93	34.57± 4.89	31.86± 3.84	32.67± 2.86	34.14± 5.08	33.71± 4.35

Significant differences were identified in the serve hitting speed ($F_{(2,17)}$ = 3.028; p = .04; ES = 0.151; 1-β = 0.548) between the pre- and post-test (M_{dif} = 2.16 km/h; p = .030; CI95% 0.238 to 4.080 km/h) and between the inter- and post-test (M_{dif} = 2.25 km/h; p = .037; CI95% 0.152 to 4.341 km/h).

Significant differences were also found in the development of SC group (ES = 0.534; 1-β = 0.945) between the pre- and post-test (M_{dif} = 6 km/h; p = .001; CI95% 2.763 to 9.237 km/h) and between the inter- and post-test (M_{dif} = 4.86 km/h; p = .010; CI95% 1.327 to 8.39 km/h).

In forehand hitting speed significant differences (ES = 0.239; 1-β = 0.430) were only observed in L group development, between the pre- and post-test (M_{dif} = 6.29 km/h; p = .035; CI95% 0.501 to 12.07 km/h).

No significant differences were found in backhand hitting speed among groups, among moments or in the interaction of groups and moments.

The two-arm medicine ball throwing speed showed significant differences ($F_{(2,17)}$ = 6.448; p = .01; ES = 0.275; 1-β = 0.877) between the pre- and inter-test (M_{dif} = 1.34 km/h; p =.029; CI95% 0.151 to 2.52 km/h) and between the pre- and post-test (M_{dif} = 1.55 km/h; p = .006; CI95% 0.505 to 2.59 km/h). Mauchly's sphericity test was significant for this variable (null hypothesis rejected) and Greenhouse-Geisser's correction was applied.

Significant differences were also found in the evolution of L group (ES = 0.39; 1-β = 0.741) between the pre- and inter-test (M_{dif} = 2.86 km/h; p = .008; CI95% 0.85 to 4.86 km/h) and between the pre- and post-test (M_{dif} = 2.71 km/h; p = .005; CI95% 0.856 to 4.47 km/h).

There were significant differences in the one-arm medicine ball throwing speed ($F_{(2,17)}$ = 7.912; p = .002; ES = 0.318; 1-β = 0.936) between the pre- and post-test (M_{dif} = 1.71 km/h; p = .001; CI95% 0.79 to 2.64 km/h).

They were also found in SC group (ES = 0.592; 1-β = 0.981) evolution between the pre- and post-test (M_{dif} = 3.00 km/h; p = .001; CI95% 1.442 to 4.56 km/h) and between the inter- and post-test (M_{dif} = 1.86 km/h; p = .004; CI95% 0.666 to 3.05 km/h).

Table 5: Correlation among the speed of the one-arm and two-arm overhead medicine ball throws and the hitting speed of the serve, forehand and backhand strokes in the three testing moments: 1: Pre-test, 2: Inter-test, 3: Post-test. (* p < .05; ** p < .001).

(n=20)	**Forehand 1**	**Backhand 1**	**Ball throw (2-arm) 1**	**Ball throw (1-arm) 1**
Serve 1	.663**	.642**	.600**	.617**
Forehand 1		.667**	.337	.477*
Backhand 1			.405	.489*
Ball throw (2-arm) 1				.912**
	Forehand 2	**Backhand 2**	**Ball throw (2-arm) 2**	**Ball throw (1-arm) 2**
Serve 2	.716**	.571**	.567**	.570**
Forehand 2		.770**	.288	.358
Backhand 2			.348	.385
Ball throw (2-arm) 2				.947**
	Forehand 3	**Backhand 3**	**Ball throw (2-arm) 3**	**Ball throw (1-arm) 3**
Serve 3	.765**	.691**	.680**	.736**
Forehand 3		.696**	.469*	.511*
Backhand 3			.397	.524*
Ball throw (2-arm) 3				.911**

DISCUSSION

The present study shows that an eight-week training program with overloads, medicine balls and elastic bands has positive effects on serve speed, as well as on one- and two-arm medicine ball throwing capacity. These results would justify the introduction of training programs aimed at improving strength of adolescent tennis players.

The results obtained suggest that applying different strength training methods (overloads, medicine ball and elastic bands) leads to improvement of the throwing capacity with low loads (2 kg) in all the studied groups, except for the control group. The magnitude of the changes achieved should be considered according to the sample size (Tejero-González et al., 2012). In our study, the magnitude of the observed changes may be rated as high (Cohen, 1988). This fact justifies the introduction of this type of training methods as a way to improve performance.

Several authors have proved that the implementation of strength training programs may be especially interesting when applied to children and adolescents, and more particularly when neural adaptation processes related to motor unit activation, synchronization and recruitment capacity are involved (Behringer et al., 2011).

The lack of improvement in strength levels observed in the control group in one- and two-arm medicine ball tests suggests that neither the on-court technical-tactical training nor the natural development of the player in this age range had an influence on the strength increase measured in the tests performed. Several authors have verified a considerable improvement in the strength-generating capacity due to the increase of height, age, body mass and biological development (Brent et al., 2013; Beuen & Thomis, 2000; Malina & Bouchard, 1991; Malina, 1994). These changes were dependant on the athlete's gender (Brent et al., 2013). In our study, these differences were not observed, which means that the differences in performance were caused by the intervention protocol and not by a change in strength levels. This could be, at least partly, due to the fact that the tests selected assess the capacity to generate medium and low strength levels in short time intervals, which seems to be less influenced by biological factors (Behm et al., 2008; Christou et al., 2006; Faigenbaum et al., 2002, 2005).

In regard to specific movement patterns, the serve speed experienced the greatest improvement, the biggest increase being detected in the overloads group. These results are in line with those reported by other authors, who observed improvements in tennis and baseball after a training program of similar characteristics (Fernández et al., 2013; Genevois et al., 2013; Escamilla et al., 2012). Fernández et al. (2013) found a significant increase in the serve speed (4.9%) of 30 male junior tennis players who underwent a 6-week training program, including core muscles exercises, elastic bands and medicine ball. In the study conducted by Genevois et al. (2013) 44 male adult tennis players completed a 6-week training program consisting in medicine ball throws. The forehand stroke speed improved significantly (11%). Escamilla et al. (2012) performed a study with 68 youth baseball players (14-17 years old). They found that the group who trained with medicine ball throws and elastic band exercises significantly improved ball throwing speed (2.1%).

Medicine ball throwing exercises were chosen in this study to develop strength since they are mechanically comparable to tennis shots (Roetert et al., 2009; Earp y Kraemer, 2010). The use of medicine balls allows to activate the tennis specific movement chain (Baiget, 2011), generating transference since the ball weight was modified (Van den Tillar y Marques, 2013). However, in our case, the improvement in medicine ball throwing speed did not imply an increase in forehand hitting speed. The improvement in the throwing tests was probably caused by the specificity of the training and by the neural adaptations achieved with it. On the other hand, we must acknowledge a possible learning effect from the exercises used in the training sessions to the tests.

Improvements were observed short-term (after 4 weeks) as well as mid-term (after 8 weeks), which supports the duration of the chosen protocol. Although several authors have reported that biggest strength increases in young athletes occur after 8 to 20 weeks of training (Westcott, 1992, Faigenbaum, 1993), other authors (Fernández-Fernández et al., 2013; Treiber et al., 1998) have found improvements in tennis between 4 and 6 weeks after starting a strength training program. This could be due to the fact that improvements in the first 50 ms of the force-time curve appear after 4 weeks of explosive strength training, caused by higher electromyographic activation of the muscles involved (Tillin & Folland, 2014). In fact, from the first and second weeks of training, improvements in the activation threshold, the muscle activation frequency and the motor evoked potential may be observed (Griffin & Cafarelli, 2003; Patten et al., 2001; Keen et al., 1994). All this suggests that in the first weeks of training the detected improvements may be caused by cortical, spinal and neural adaptations (Griffin & Cafarelli, 2005).

Acceptable correlations (0.70-0.79) (Barrow & McGee, 1971) were found between the forehand stroke and the serve, between the forehand and backhand strokes and between the serve and the single-arm throw ($p<.001$). The rest of the analyzed movements presented controversial correlation values. This could be due to different reasons. Firstly, the existing similarities in the space-time organization of the kinetic chains involved in the movement patterns analyzed. The correct application of the partial impulses generated by each joint in an appropriate time and space guarantees the optimization of hitting and throwing speed (Hochmuth, 1984; Corbi, 2008). Moreover, a certain degree of transference has been proved between motor skills with similar characteristics (Zatsiorsky, 1995). Secondly, the level of the athletes analyzed in this study facilitates the existence of transference among different kinds of tennis shots. Low- and medium-level athletes seem to be much more sensitive to any type of training and to possible transference among different movements (Issurin, 2008, 2013). Despite this, the need of high specificity for strength adaptations prevents from obtaining higher correlation coefficients (Cale-Benzoor et al., 2014; Langford et al., 2007).

CONCLUSION

The implementation of an 8-week training program using overloads, medicine balls and elastic bands led to significant improvement in the serve speed, as well as in the one- and two-arm medicine ball (2 Kg) throwing capacity. These results justify the introduction of strength training programs for youth tennis players, since these seem to improve not only their general but also specific strength levels. Future studies are necessary to know more about which kind of method and temporalization would optimize tennis shot performance.

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STUDY II

Acute and delayed effects of strength training in ball velocity and accuracy in young tennis players

International Journal of Sports Medicine.

Terraza-Rebollo, M., & Baiget, E. (submitted). Acute and delayed effects of strength training in ball velocity and accuracy in young tennis players. *Int J Sports Med*.

Abstract

This study aimed to investigate the acute and delayed effects of medicine ball throws and resistance training in ball velocity and accuracy of serve, forehand and backhand in young competition tennis players. A crossover-randomized design was used with 10 competition tennis players (6 girls and 4 boys between 14 and 18 years old). The subjects performed 6 stroke test sessions, 3 for each strength training protocol. The velocity and accuracy of strokes were measured before (basal situation), 3 minutes, 24 and 48 hours after the training protocol. Medicine ball throws protocol was performed by accomplishing 3 sets of 6 repetitions using a 2 kg ball, throwing it at maximal speed. Resistance training protocol was performed by accomplishing 3 sets of 6 repetitions at 75% 1RM, lifting the load at maximal speed of bench press, dead lift, one hand row and half squat. There were no significant ($p > 0.05$) differences in all strokes, regarding ball velocity and accuracy after each method and each recovery time, compared to the basal situation. These results suggest that medicine ball throws and resistance training methods have no acute and delayed detrimental effects on stroke velocity and accuracy in young competition tennis players.

Keywords**:** tennis stroke, resistance training, medicine ball throws, stroke performance

INTRODUCTION

Competitive tennis players, regarding physical skills, should achieve a compound of speed, agility, and power, together with medium to high aerobic level [1, 2]. As a consequence, strength training is essential for a high tennis performance, not only to develop strength and power, but also to prevent injuries [1-3]. Due to the importance of ball velocity in the outcome match, and the increase of it in the modern game [4-5], specific strength should be trained [4, 6]. Due to tennis actions have an explosive nature, the ability to develop force rapidly, measured as rate of force development (RFD), may be more important than maximum strength [1, 7]. Beside ball velocity, accuracy is important in a successful play [2, 5]. In order to achieve an effective stroke involving a proper ball velocity and accuracy, a synchronised kinetic chain is essential, [2, 3, 5] including ground reaction forces that are transferred through the feet, legs, trunk, upper body, and finally to the racket [3] using the stretch-shortening cycle (SSC) in the main muscles [2]. Therefore, improving RFD and, consequently, power is a key point in strength tennis program [3].

Several studies recommend medicine ball throws (MB) and resistance training (RT) methods to increase ball velocity in tennis [1-4, 6, 8] or overhead throw sports [9, 10]. Despite being two common methods in tennis strength training, which have shown improvements in tennis strokes when trained from 6 to 8 weeks [4, 6, 8], and which can be combined in the same tennis cycle [1], their acute and delayed effects in ball velocity and accuracy in competition tennis players had not been investigated until now. Related to the acute effects, it has not been observed post-activation potentiation effects in tennis serve (S) velocity and accuracy performing complex training by using MB [11] or RT [12]. To our knowledge, no more studies investigated the acute effects of strength training in stroke tennis performance and no studies about acute and delayed effects were found.

Although the acute effects after a strength training have not been widely investigated in tennis, it seems that a maximum strength loss in both isometric and dynamic contractions appears after explosive or maximal strength stimulus (from 40% to 100% 1RM) [13-15], especially in the early phase of RFD [13-14]. These effects could be altered by several variables that establish the training stimulus such as exercise type and order, sets and repetitions number, rest duration, loading and velocity movement [16]. Due to the fact that velocity loss in RT [17, 18] or power loss in countermovement jump (CMJ) [19] are considered a valid tool to quantify neuromuscular fatigue, ball velocity loss could be suggested as a neuromuscular fatigue indicator in tennis strokes. However, information related to the acute and delayed effects of maximum and explosive strength stimulus in tennis performance is scarce, and no previous study analysed the effects in ball velocity and accuracy.

Therefore, the aim of this study was to investigate the acute and delayed effects of RT and MB in stroke ball velocity and accuracy in young competition tennis players. Our working hypothesis was that maximum strength training (RT) and explosive strength training (MB) could produce neuromuscular fatigue, thus decreasing ball velocity, but would have no effect, or only a slight decrease, on accuracy, and that these impairments could be recovered after 24 or 48 hours. Also, RT may cause a greater decrease in performance due to the powerful nature of tennis strokes, the higher loads used and probably due to the higher time under tension.

MATERIAL AND METHODS

Subjects

Ten competition tennis players (6 girls and 4 boys) between 14 and 18 years old and with at least 4 years of experience in competition tennis training participated in this investigation (Table 1). During the previous two months, all subjects practiced between 17.5 and 26 hours per week (24.3 ± 3.6 hours), performing between 10 and 17.5 hours (16.0 ± 3.1 hours) of specific tennis training (technical-tactical skills on-court) and between 7.5 and 8.5 hours (8.3 ± 0.4 hours) of fitness training. All participants volunteered to take part in the study and were previously informed of its aims, methods and potential risks. The study procedures were approved by the Ethics Committee of the institutions involved, and meet the ethical standards of the journal [20].

Table 1. Participant characteristics.

	Whole group (n = 10)	Male (n = 4)	Female (n = 6)
Age (years)	15.3 ± 1.2	16.2 ± 1.1	14.7 ± 0.9
Body mass (kg)	57.6 ± 8.7	65.7 ± 8.1	52.2 ± 3.2
Height (cm)	168.1 ± 10.4	177.3 ± 9.6	162.0 ± 5.3
1 RM BP (kg)	40.6 ± 14.4	52.0 ± 15.6	33.0 ± 7.3
1RM HS (kg)	81.5 ± 25.1	101.3 ± 25.3	68.3 ± 15.2
1 RM DL (kg)	73.4 ± 18.0	88.8 ±17.6	63.7 ± 10.6
1 RM ROW DOM (kg)	31.1 ± 6.6	37.5 ± 2.6	26.8 ± 4.4
1 RM ROW NON DOM (kg)	29.0 ± 6.7	36.0 ± 2.7	24.3 ± 3.3

Values are mean ± SD. 1 RM BP = 1 maximum repetition in bench press; 1 RM HS = 1 maximum repetition in half squat; 1RM DL = 1 maximum repetition in dead lift; 1 RM ROW DOM = 1 maximum repetition in dominant hand row; 1 RM ROW NON DOM = 1 maximum repetition in non-dominant hand row.

Experimental Procedures

A crossover-randomized design was used to investigate the acute (3 min) and delayed (24 and 48 h post-training) effects of two different strength training protocols (MB and RT) on ball velocity and accuracy in young tennis players in off-season competition. Subjects participated in 1 familiarization session, 1 strength test session (maximum strength test and anthropometric test) and 6 stroke test sessions (3 for each strength training protocol) performed 1 per day in 3 consecutive days (Post, Post24 and Post48) (Figure 1). Each strength training protocol was separated by 7 days. On the first day of each strength training protocol, participants completed one of both protocols in randomized order. S, forehand (FH) and backhand (BH) velocity and accuracy tests were measured before (basal situation), 3 min (Post), 24 (Post24) and 48 (Post48) hours after strength training protocol.

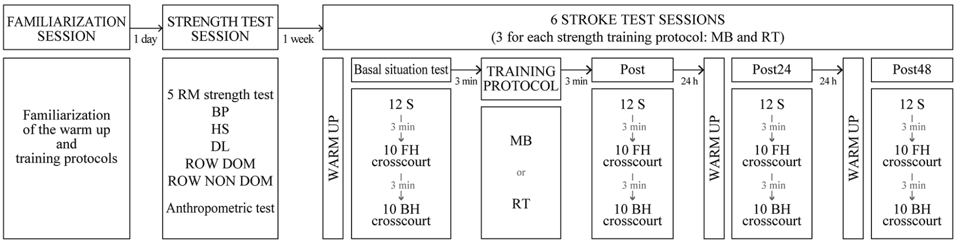

Figure 1. Study design chronology. MB = medicinal ball throws; RT = resistance training; BP = bench press; HS = half squat; DL = dead lift; ROW DOM = dominant hand row; ROW NON DOM = non-dominant hand row; S = serve; FH = forehand; BH = backhand.

One week prior to the intervention, the participants were asked to attend a familiarization session. The following day, the subjects completed the anthropometric test (body mass and height) and the 5RM strength test (strength test session), performing bench press (BP), dead lift (DL), one hand dominant (ROW DOM) and non-dominant row (ROW NON DOM), and half-squat (HS) (Table 1). Brzycki equation was used to calculate the 1RM [21]: 1RM = 100 * load rep / (102.78 – 2.78 * rep).

On the test day, the subjects began with a warm-up protocol. Then, the basal situation test was performed. After 3 minutes, one of both strength training protocols was accomplished (MB or RT). Once finished, and after 3 minutes, the Post-Test was done to determine the acute effects (Post). The next day, they fulfilled the warm-up and 3 minutes later, the post 24 h test was performed (Post24). After two days, the same procedure was followed with the post 48 h test (Post48). Post24 and Post48 were done to determine the delayed effects (Figure 1). During the stroke test sessions, the subjects were allowed to drink water ad libitum. However, any supplementation was not allowed.

Measurements

The stroke test consisted of assessing the peak ball velocity and accuracy of 12 flat S (6 each side), 10 FH and 10 BH crosscourt (Figure 1), resting 20 seconds between S, 10 seconds between FH and BH and 2 minutes between sets to avoid neuromuscular fatigue. The participants were constantly encouraged to hit the ball at maximum speed and high accuracy. Mean peak ball velocity and mean score accuracy were used for the analysis. Only the strokes that were “in” were registered for the velocity analysis. The tests were performed at the same time of the day for reliability reasons and to control the circadian variation. Moreover, the subjects were instructed to use the same racket, strings and string tension to perform the different tests. The subjects were required to refrain from any high intensity exercise on the day before each test day. All tests were performed on an outdoor clay tennis court.

A radar gun (SR3600; Sports-radar, Homosassa, FL) was used to measure the peak ball velocity and was placed in the line of the ball displacement, changing it depending on the serving side or the baseline stroke. In order to perform the FH and BH test, balls were thrown by a ball machine (Lobster Elite V, Lobster Sports, Inc., North Hollywood, CA) at the average of 73.3 ± 1.2 km·h^{-1} with no rotational effect and at a period of ten seconds per ball (6 shots·min^{-1}). International Tennis Federation (ITF) approved balls (Head ATP, Spain) were used and they were new in each testing session.

To evaluate stroke accuracy, Pialoux et al. [22] stroke performance design was followed (Figure 2):

S: S1 zone (0.5m*0.5m) 5 points; S2 zone (1m*1m) 3 points; rest of the serve box 1 point. Bounce ball out of serve box 0 points.

Baseline shots (FH and BH): FH1 or BH1 zone (1m*1m) 5 points; FH2 or BH2 zone (2m*2m) 4 points; FH3 or BH3 zone (3m*3m) 3 points; FH4 or BH4 zone (4m*4m) 2 points; rest of the single court 1 point. Bounce ball out of single court 0 points.

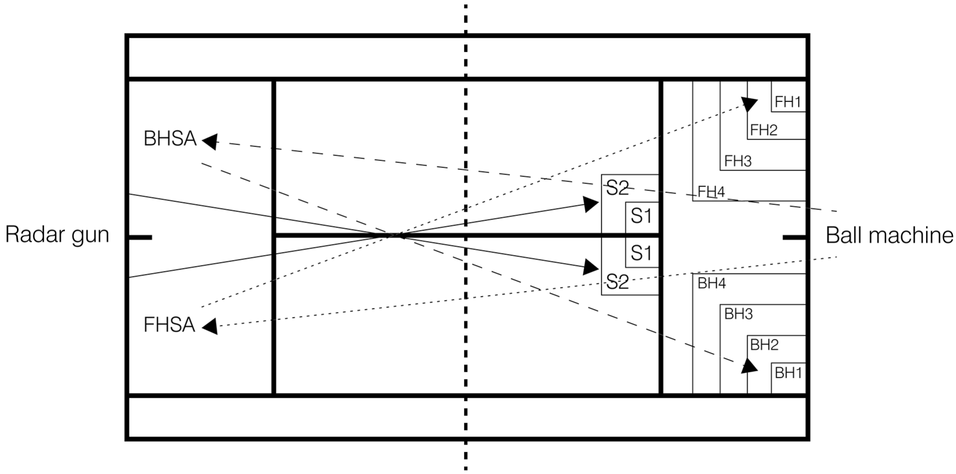

Figure 2. Stroke performance test [22]. S1 and S2: target area for the serve; FH1, FH2, FH3 and FH4: target area for the forehand; BH1, BH2, BH3 and BH4: target area for the backhand; FHSA: forehand stroke impact area; BHSA: backhand stroke impact area. Continuous line: serve trajectory; dot line: forehand trajectory; dash line: backhand trajectory.

Training protocols

Both strength-training protocols are shown in Table 2. Maximal intended velocity training was fulfilled to induce greater strength gains [16]. The exercises in both methods used the main muscles involved in the strokes kinetic chain [1, 2]. The protocol for the MB was designed following the guidelines of Cardoso [1], Fernández-Fernández et al. [6] and Terraza-Rebollo et al. [8]. According to these guidelines, the subjects performed 3 sets of 6 repetitions of the exercises shown in Table 2 with a 2 kg medicine ball. Rest duration was 1 minute between sets and 3 minutes between rounds. MB total volume was 144 repetitions in 24 sets, having a session total tonnage of 288 Kg (21 sets counting only one side of a one-arm overhead forward throw). In the case of the RT protocol, Cardoso [1], Faigenbaum et al. [23] and Terraza-Rebollo et al. [8] guidelines were followed. The subjects performed 3 non-consecutive sets of 6 repetitions with the 75% 1RM at maximal intended velocity for concentric contraction, and controlled for eccentric contraction, of the exercises shown in Table 2. Repetitions were prescribed in order to avoid failure. Rest duration was 2 minutes between sets and 3 minutes between rounds. Total volume was 90 repetitions in 15 sets (12 sets counting only one side of the one hand row), having a session total tonnage average of 3451 ± 924.8 Kg.

Statistical Analyses

Descriptive data were reported as mean ± SD. The normality of the distributions and homogeneity of variances were assessed with the Shapiro-Wilk test. The differences between velocity and accuracy scores measured from the basal situation and at various recovery times (3 minutes [Post], 24 hours [Post24], 48 hours [Post48]) after performing RT and MB were evaluated using a repeated-measures analysis of variance (ANOVA), with Bonferroni-corrected post hoc analysis. Due to the fact that stroke accuracy data were not normally distributed, Friedman's test was used to examine the differences at various times during recovery. The magnitude of the differences in mean was quantified as effect size (ES), and interpreted according to the criteria used by Cohen [24]: <0.2 = trivial, 0.2–0.4 = small, 0.5–0.7 = moderate, >0.7 = large. The level of significance was set at $p < 0.05$. Statistical analyses were performed using SPSS software (version 23.0; SPSS Inc, Chicago, IL).

Table 2. Medicine ball throws (MB) and resistance training (RT) exercises.

MB						RT					
Exercise	Sets (no.)	Reps (no.)	Weight (Kg)	Int vel	Rest set/round (min)	Exercise	Sets (no.)	Reps (no.)	1RM (%)	Int vel*	Rest set/round (min)
Forehand throw	3	6	2	Max	1 / 3	Bench press	3	6	75	Max	2 / 3
Backhand throw	3	6	2	Max	1 / 3	Half squat	3	6	75	Max	2 / 3
Chest throw	3	6	2	Max	1 / 3	One hand row**	3	6	75	Max	2 / 3
Two-arm overhead forward throw	3	6	2	Max	1 / 3	Dead lift	3	6	75	Max	2 / 3
Two-arm overhead backward throw	3	6	2	Max	1 / 3						
Two-arm overhead upward throw	3	6	2	Max	1 / 3						
One-arm overhead forward throw	3	6**	2	Max	1 / 3						

Reps = number of repetitions; Int vel = intended velocity; Rest set/round = rest between sets / rest between rounds; *concentric contraction; **each hand; 1RM = one repetition maximum; Max = maximal.

RESULTS

The average peak ball velocity and accuracy and percentage of changes of S, FH and BH after the training intervention are shown in Figure 3 for MB method, and in Figure 4 for RT method. There were no significant differences in ball velocity (Figures 3A and 4A) and accuracy (Figures 3C and 4C) following each time recovery (Post, Post24 and Post48), and for all strokes compared to the baseline in both training methods.

There were non-significant ball velocity increases and trivial effect sizes in S (0.8%; ES = -0.07), and non-significant decreases and trivial effect sizes in FH and BH (-0.2 and -1.5 %; ES = 0.02 and 0.14) performing MB in Post. In Post24, non-significant increases and trivial to small effect sizes were found in S, FH and BH (0.9, 2.5 and 1.6%; ES = -0.08, -0.27 and -0.19). Regarding accuracy, a non-significant decrease and small effect size were found in Post performing S (14.8%; ES = 0.36), and slightly non-significant trend to increase and trivial to moderate effect sizes in every test performing FH (2.0, 2.6 and 6.6%; ES = -0.06, -0.08 and -0.17) and BH (2.4, 15.8 and 12.1%; ES = -0.1, -0.52 and -0.52).

Performing RT, a non-significant ball velocity decrease and trivial to small effect sizes in Post were found in S, FH and BH (-2.7, -1.6 and -2.2%; ES = 0.20, 0.15 and 0.25). These decreases did not happen in Post24 except when performing FH (-2.9%; ES = 0.27). In Post48, non-significant decreases and trivial effect sizes were observed in S, FH and BH (-0.3, -1.5 and -1.8%; ES = 0.02, 0.12 and 0.16). Regarding accuracy, non-significant decreases and trivial to small effect sizes happened in Post performing S and FH (-17.9 and -4.9%; ES = 0.35 and 0.15). In Post24, non-significant increases and trivial to small effect sizes were found in S, FH and BH (10.7, 5.5 and 17.7%; ES = -0.16, -0.15 and -0.48). However, in Post48, non-significant decreases and small to moderate effect sizes were observed in S and FH (-27.4 and -13.3%; ES = 0.57 and 0.45).

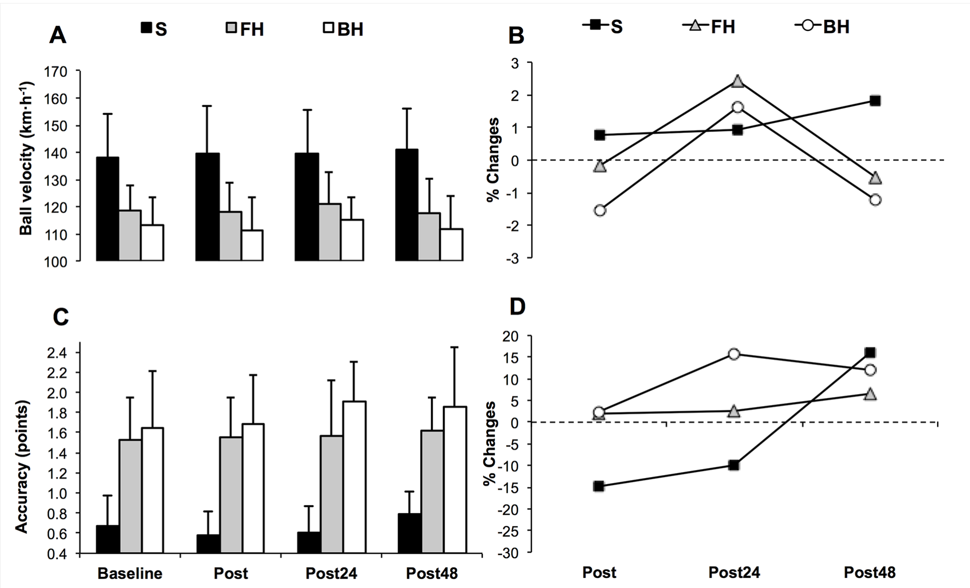

Figure 3. Acute (Post) and delayed (Post24 and Post48) effects of medicine ball throws training (MB) on ball velocity (A) and accuracy (C) and corresponding percentage changes from baseline (B and D). S = serve; FH = forehand; BH = backhand.

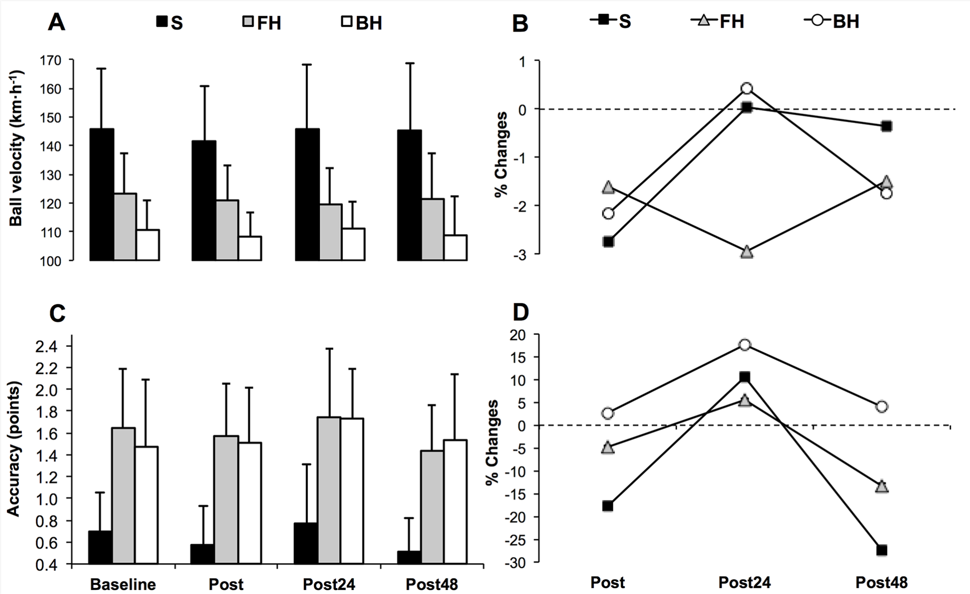

Figure 4. Acute (Post) and delayed (Post24 and Post48) effects of resistance training (RT) on ball velocity (A) and accuracy (C) and corresponding percentage changes from baseline (B and D). S = serve; FH = forehand; BH = backhand.

DISCUSSION

The aim of this study was to investigate the acute (3 min) and delayed (24 and 48 h) effects of maximum strength (75% 1RM RT) and explosive training (2 kg MB) in ball velocity and accuracy in young competition tennis players. The main results reported that explosive training (MB) and maximum strength (RT) does not have any acute and delayed effect in S, FH and BH ball velocity and accuracy. Taking into account that velocity loss could be considered as a neuromuscular fatigue indicator, [17, 18] it could be suggested that MB and RT do not cause neuromuscular fatigue to the involved muscles in tennis stroke's kinetic chain.

Despite some researches found an acute detrimental performance effect after explosive strength-training (plyometric training or RT at 40% 1RM) [13, 14, 25] and maximal strength-training (isometrics contraction at maximal voluntary contraction or dynamics contractions at 80 to 100% 1RM), [13-15, 26] this investigation did not find any negative effect in the stroke performance in young competition tennis players. Similar results were found performing RT (5-12 repetitions at 60-80% 1RM) in women basketball players after 6 hours of recovery time, observing no changes in power and shot accuracy [27]. However, performing heavy RT (6 repetitions to failure) in male basketball players, a performance decrease was observed immediately after training [28].

One explanation for our results could be that training variables used do not cause enough fatigue to affect coordination and velocity strokes in young competition tennis players. In this research the subjects did not perform the repetitions to failure in order to properly perform strength training for young athletes [23], and the rest interval between sets was enough to avoid the excessive neuromuscular fatigue and to maintain the number of repetitions per set [23, 29]. Although repetition to failure is commonly used in strength training [30], it is not a critical aspect to enhance muscle hypertrophy or strength [31], and it could cause a phenotype muscle change to slower fibers [17, 30] and an increase of blood ammonia level [18, 31]. Besides, repetition to failure could increase the time needed for the recovery of neuromuscular function and metabolic and hormonal homeostasis [32].

Another explanation for not achieving impairment in stroke performance could be that the central nervous system uses different neuromuscular strategies to overcome the fatigue to maintain the performance [33]. In this sense, technical impairment without velocity and accuracy loss was observed in S during a tennis match [34]. Moreover, during a three-day tennis tournament, a decrease of RFD and maximal voluntary contraction was found after the first and second day, but S velocity and CMJ remained stable [35]. Similarly in soccer, a decrease in RFD and maximal voluntary contraction were found after a match with no effect in CMJ [36]. Furthermore, after professional tennis matches on clay surface no effects in CMJ and grip strength were observed [37], and ball velocity and accuracy remained stable during five-set professional matches on grass surface [38]. Therefore, it could be hypothesized that a decrease in RFD and maximal voluntary contraction with no effect in ball velocity could have happened in this investigation.

Although there were non-significant differences, a trend to decrease ball velocity was greater after RT than after MB in all strokes. Probably due to the higher load of the exercises, total tonnage and total time under tension. Even though time under tension was not measured, estimated total time under tension in RT was longer than in MB. RT trend to decrease ball velocity was higher in the acute effects (Post), but similar levels to the baseline were found, except when performing FH in the delayed effects (Post24).

Regarding practical applications, it could be suggested that these two strength training methods (RT at 75% 1RM and 2 kg MB) might be useful to improve maximum and explosive strength [1, 8] without high neuromuscular fatigue and could be used before a technical-tactical session on-court or off-season, and in-season. It is advisable to avoid the repetitions to failure and perform the movement at maximal intended velocity. Coaches should take into account that these results are exclusively for these training methods. Although there were no significant differences, it could be suggested that RT causes a higher impairment in stroke performance and, as a consequence, it is important to be more careful when applying RT method, especially close to the competition.

CONCLUSIONS

The present research indicate that MB and RT, avoiding repetition to failure and at maximal intended execution, have no acute and delayed detrimental effects on stroke tennis performance. Furthermore, it could be suggested that these two protocols do not cause neuromuscular fatigue in the muscles involved in tennis stroke’s kinetic chain. Further research should focus on the use of new training devices simulating tennis strokes, such as cable pulley or eccentric overload flywheel resistance training.

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STUDY III

Effects of post-activation potentiation on tennis serve velocity and accuracy

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Abstract

Purpose: This study aimed to examine the post-activation potentiation effect on serve velocity and accuracy in young competition tennis players by using complex training and comparing different upper and lower body heavy load resistance exercises. ***Methods:*** Fifteen competition tennis players (9 boys and 6 girls, age 15.6 ± 1.5 years) performed 1 control session and 3 experimental sessions using heavy load resistance exercises in a crossover-randomized design: (1) bench press (BP), (2) half squat (HS), (3) BP plus HS, and (4) control trial. Heavy load resistance exercises were performed by accomplishing 3 sets of 3 repetitions at 80% 1RM, lifting the load at maximum speed. To assess the serve velocity and accuracy, all participants performed 32 flat serves after the heavy load resistance exercises, divided into 4 sets of 8 serves (0, 5, 10, 15 minutes post-exercise), resting 20 seconds between serves and 2 minutes and 40 seconds between sets. ***Results:*** There were no significant ($p>0.05$) differences in ball velocity and accuracy following each recovery time and exercise, compared to the basal situation. ***Conclusions:*** These results suggest that complex training using heavy load resistance exercises is not a useful method for eliciting the post-activation potentiation effect in tennis serve and does not have any effect in serve accuracy in young competition tennis players.

Keywords: tennis service, tennis performance, serve speed, complex training, resistance training

Introduction

The tennis serve plays an important role in determining the final outcome of a match;[1,2,3] its effectiveness is determined by velocity, spin, reliability and accuracy,[1,2] and particularly, ball velocity has been shown to be a key point in a successful play.[3] Moreover, it should be pointed out that serve velocity is a good performance tennis predictor in young tennis players.[4]

Tennis serve is a complex movement that requires a proper technique, power, strength, speed, flexibility, muscular endurance and muscular balance.[2] A synchronised kinetic chain is necessary in order to develop an effective stroke, where the power starts in the lower limbs and is transferred to the trunk and then to the upper limbs.[1,2,3] As a consequence, stretch-shortening cycle (SSC) happens in the main muscles (i.e., gastrocnemius, soleus, quadriceps, gluteals or shoulder internal rotators),[2,3] therefore, optimal strength, power and acceleration have an important role and should be trained for specifically.[1,2,3] However, the serve is a stroke inside a complex context and although the serve is the only stroke that is totally under control of the player, after that it is necessary to land properly and to be ready for the next shot.[2]

The post-activation potentiation (PAP) effect is an acute enhancement on performance following a conditioning activity. PAP has been shown in explosive movements, mainly movements with SSC, like jumping,[5] throwing,[6] upper body ballistic performance activities,[7] and sprint performance.[8] The recent meta-analysis of Seitz and Haff[9] shows that the PAP effect is small for jumping, throwing, and upper-body ballistic performance, and moderate for sprint performance. In order to enhance the sports performance through the PAP effect, especially in strength, power and speed activities, several studies have implemented heavy load resistance exercises (HLRE) as a conditioning activity, such as the back squat and bench press,[5,6,10,11] followed by an explosive exercise, known as complex training (CT).[12] To our knowledge, the PAP effect in tennis serve velocity and accuracy has not been investigated by using HLRE.

In some cases, when using HLRE protocols to achieve PAP effect, fatigue may also appear decreasing or having no effect in the performance.[16,17] Both fatigue and PAP, despite being opposed, can coexist at the same time and might dissipate differently, determining the net effect on the performance.[14] This net effect could be affected by several factors such as volume and intensity, recovery period, type of exercise and subject characteristics.[9,15] On the other hand, the main determinant key points of shot quality in tennis not only include ball velocity, but also ball placement accuracy.[2] It seems that using moderate and light loads with medicine ball throws in young tennis players does not have a negative effect in accuracy,[13] but the acute effect of HLRE on tennis serve accuracy is still unknown.

Although PAP effect has shown small to moderate effects on different physical abilities,[9] some studies have shown no effect, or only a slight reduction in power performance.[16,17] Furthermore, both decrease and increase in countermovement jump height have been shown in the same study but happening in different recovery times (15 s vs. 8 min).[11] Regarding PAP tennis studies, no PAP effect was found on tennis serve velocity using moderate and light loads with maximum-effort medicine ball throws (200 g and 600 g) in young tennis players (12.3 ± 0.8 years).[13] No changes were found in accuracy either. It might be possible that using HLRE and an older sample with more strength experience may lead to an increase on serve velocity.

Therefore, the aim of the present study is to examine the PAP effect on serve velocity and accuracy in young tennis players, using CT and different upper and lower body HLRE. It was hypothesized that, since the tennis serve is an explosive movement with SSC, and the kinetic chain is similar to that of a throw,[18] CT would enhance the tennis serve velocity but would have no effect, or in the worst case, only a slight decrease on accuracy, and HLRE combining upper body and lower body training would demonstrate a higher PAP level.

Methods

Subjects

Fifteen (9 boys and 6 girls) competition tennis players (age, 15.6 ± 1.5 years) participated in this study (Table 1). During the previous 2 months, all the subjects practiced between 17.5 to 26 hours per week (24.3 ± 3.2 hours), performing between 10 to 17.5 hours (15.9 ± 3.1 hours) of specific tennis training (i.e., technical-tactical skills) and between 7.5 to 8.5 hours (8.4 ± 0.3 hours) of fitness training (i.e., on-court and off-court aerobic and anaerobic exercises and strength training).

All the subjects had over 4 years of experience in competition tennis training, did not practice another competitive sport, had not been injured in the last six months and did not participate in another specific strength training program during the test. All participants volunteered to take part in the study and were previously informed of its aims, methods and potential risks. The subjects or their legal tutors in case they were under 18 years old signed an informed consent document prior to starting the study. This study was designed according to the Declaration of Helsinki of 1975, revised in 2008, and the Research Ethics Committee (CER) of the University of Vic – Central University of Catalonia approved the protocol.

Design

The study used a crossover-randomized design, comprising the control session and 3 experimental sessions using HLRE: bench press (BP), half squat (HS) and bench press plus half squat (BP + HS). Then, their effects on tennis serve velocity and accuracy were analysed. The independent variable that was manipulated (HLRE) was chosen to evaluate its effect on the dependent variable (serve velocity and accuracy) in order to determine its efficacy for using it as a performance enhancer. Subjects participated in 1 familiarization session, 1 test session (maximum strength test and anthropometric test), 1 control session and 3 experimental sessions on different days (Figure 1). The participants performed the different trials in a randomized order.

In the control session, the subjects only performed the warm-up protocol and then the serve test. During the experimental sessions, the subjects completed the warm-up protocol, then the HLRE (BP, HS or BP+HS) and then the serve test (study design chronology explained in figure 1).

Methodology

One week prior to the beginning of the intervention, the participants were asked to attend a familiarization session where they handed in the informed consent, the study protocol was explained and they were instructed how to correctly perform each exercise. Next day, the subjects completed the anthropometric test (body mass and height) and performed the BP and HS 5RM strength test (Table 1). Brzycki equation was used in order to calculate the 1RM[19]: 1RM = 100 * load rep / (102.78 – 2.78 * rep). On the control session and the experimental sessions, the subjects began with the warm-up protocol that included 10 minutes of general warm-up activities (jogging, skipping, dynamic mobility and dynamic stretching) and 5 minutes of specific warm-up for tennis serve (exercises with elastic tubing for upper body, 10 dynamic serve imitations and 10 warm-up serves). After that, in the control session the serve test was performed and in the experimental sessions the HLRE was performed followed by the serve test.

In order to achieve the PAP effect, the protocol was designed following the meta-analysis of Wilson et al.[15], developed with the most effective guidelines according to the authors. As a consequence, the subjects performed dynamic contractions of BP, HS or both (BP + HS), accomplishing 3 sets of 3 repetitions at 80% 1RM (BP: 35.6 ± 11.6 kg; HS: 68.7 ± 18.2 kg), lifting the load at maximum speed, and the serve test was measured at 0, 5, 10 and 15 minutes after HLRE (or in the control session, after warm-up). Although most of the investigations to achieve PAP used back squat to potentiate lower limbs,[6,10,11] in this research HS was chosen because the subjects were used to this exercise. Moreover, back squat is more complex and has specific technical requirements that are difficult to achieve in one familiarization session.

The test consisted of assessing the peak ball velocity of 32 flat serves, divided into 4 sets of 8 serves (4 each side). Only the serves that were “in” were registered and the highest speed recorded was used for analysis. The participants were constantly encouraged to hit the ball at maximum speed and high accuracy. No further information about the movement was given. No feedbacks about the performance were done during the set, but when the set was finished the subjects were informed about the velocity and accuracy achieved. The participants rested 20 seconds between serves and 2 minutes and 40 seconds between sets, with the purpose of avoiding fatigue. All tests were performed on an outdoor clay tennis court. Serve accuracy was evaluated based on the Pialoux et al.[20] stroke performance design (Figure 2).

A radar gun (R 3600, Sports-radar, Homosassa, FL, USA) was used to measure the peak ball velocity during the ball flight. To reduce any error due to the cosine effect, the radar was placed in the line of the ball’s displacement, changing it depending on the serving side. International Tennis Federation (ITF) approved balls (Head ATP, Spain) were used for the serve tests. In order to maintain uniform internal ball pressure, the balls were new in each testing session. The tests were performed at the same time of the day (10:00 to 11:00 a.m.) due to reliability reasons and to control the circadian variation.[21] Furthermore, the subjects were instructed to use the same racket, strings and string tension to perform the different tests. In order to avoid fatigue, refraining from any high intensity exercise was required, particularly strength training on the day before each test day.

Statistical Analysis

Descriptive data were reported as mean ± standard deviation (SD). The normality of the distributions and homogeneity of variances were assessed with the Shapiro-Wilk test. Reliability on the serve velocity and accuracy measure was assessed with Cronbach's alpha for intraclass reliability. Differences between the serve velocity (baseline) and the scores at various times (5, 10, 15 min) during recovery from BP, HS and BP + HS were evaluated using a one-way analysis of variance (ANOVA) with repeated-measures with Bonferroni-corrected post hoc analysis. Mean differences in absolute and percent values were also used. The magnitude of the differences in mean was quantified as effect size (ES) and interpreted according to the criteria used by Cohen[22] <0.2 = trivial, 0.2–0.4 = small, 0.5– 0.7 = moderate, >0.7 = large. Because serve precision data were not normally distributed, Friedman's test was used to examine the differences in various times during recovery. When a difference was revealed, Wilcoxon's test was used to identify those differences. The level of significance was set at $p < 0.05$. All statistical analyses were performed using SPSS 23.0 software (SPSS Inc., Chicago, IL, USA).

Results

There were no differences in performing any HLRE in peak ball velocity and accuracy following each time recovery (0, 5, 10, 15 min) compared to the baseline (Figure 3 A and Figure 3 B).

There were no significant increases and trivial effect sizes of peak velocity since minute 5 in BP (0.9, 1.2 and 1.6%; ES = -0.06, -0.07 and -0.08) and HS (0.44, 0.70 and 0.88%; ES = -0.01, -0.01 and -0.01), and since minute 10 in BP+HS (1.2 and 1.7%; ES = -0.06 and -0.09) until minute 15 compared to the baseline (Figure 3 C). The individual responses in peak ball velocity ranges from -8.6 to 8.0%.

Trivial-to-small effect sizes for an increase ($p > 0.05$; ES = -0.01 to -0.25) in minutes 0, 5 and 10 in HS (23.6, 38.2 and 36.4%; ES = -0.25, -0.04, -0.11), minutes 5 and 10 in BP (36.4 and 34.4%; ES = -0.02, -0.01) and minute 10 in BP+HS (40.0%; ES = -0.21), and moderate-to-large effect sizes for a reduction ($p > 0.05$) in BP in minute 0 (-32.3%; ES = 0.47) and BP + HS in minute 5 (-29.1%; ES = 0.78) were found in the serve accuracy compared to the baseline (Figure 3 D). Significant differences and moderate-to-large effect sizes ($p < 0.05$; ES = 0.51 to 1.12) in serve accuracy performing BP + HS were found comparing minute 10 with the other recovery times (0, 5, 15 minutes; -24.7, -49.4, -33.8%; ES = 0.51, 1.12, 0.69) (Figure 3 B and Figure 3 D).

Cronbach's alpha for intraclass reliability for the serve velocity and accuracy were 0.942 and 0.532, suggesting that the measures showed good consistency in the measurement of serve velocity and a limited reliability for accuracy.

Discussion

The aim of the present study was to analyse the PAP effect using CT with HLRE in tennis serve velocity and accuracy in junior highly trained tennis players. The main finding was that CT using HLRE does not show a beneficial effect in serve velocity or any detrimental effect in accuracy. Although it has been shown that CT improves SSC explosive movements such as sprint, countermovement jump, throws and upper body ballistic movements,[6,7,8,9,12,15,23] our findings did not show any improvement in tennis serve velocity or any decrease in accuracy. However, we found a slight non-significant increasing trend in serve velocity from minute 5 to 15 after BP and, to a lesser degree, HS. The same non-significant tendency was found from minute 10 to 15 after BP plus HS. Our findings are in agreement with the results of Ferrauti and Bastiaens[13] who have not observed beneficial PAP effects on tennis serve velocity in junior players. Not only did they find no beneficial effects, but they also found a decrease in serve velocity when using a heavy medicine ball (600 g). In contrast to our research, they used moderate loads through medicine ball throws, their sample was slightly younger (15.6 ± 1.4 vs. 12.3 ± 0.8 years) and the recovery period was shorter (0, 5, 10, 15 vs. immediately after intervention). It should be noted that the protocol including recovery time, HLRE, intensity, volume, strength, training experience, age, and muscle fibres,[9,15] could affect the result.

Identifying the causes of non-beneficial PAP effects on tennis serve is difficult. One reason could be the importance of the specificity principle and the force vector theory.[8,23] In consequence of that, an improvement in velocity performance might be observed by using a tennis serve more similar kinetic chain exercises, such as tennis-specific exercises (i.e., cable pulley machines or ballistic movements) or shoulder internal rotation exercises (i.e., high cable rotational serve pull), because shoulder internal rotation is the movement with more velocity contribution in tennis serve.[1,2] Another reason for not finding PAP effect in our research could be the sample training experience and age. It has been proved in several studies that training experience[10,15] or strength level[15,24] could be a performance enhancer of PAP. Subjects with higher strength levels or greater strength training experience would have a greater PAP response. Compared to these studies, our sample was younger (15.6 ± 1.5 years) and, therefore, that could cause a lower PAP response or no effect, as with the research of Ferrauti and Bastiaens.[13] Furthermore, PAP response is lower in elderly people (79.2 ± 5.1 years) than in young adults (31.8 ± 9.3 years)[25] and PAP effect was not found in investigations with children[13] and teenagers (as the present one). Every sample in which beneficial PAP effect was observed belongs to young adulthood age.[6,10,14,25] Therefore, it could be hypothesized that the best age to achieve the PAP effect could be young adulthood. Moreover, due to the large variation of individual responses (-8.6 to 8.0%), it could be suggested that subjects respond differently when using CT. Consequently, it is necessary to individualize the protocol and identify the recovery windows in each subject in order to know the subjects that respond positively and the protocol followed.[17,26]

The results have not shown a detrimental effect in accuracy, probably due to the fact that the protocol used do not have motor coordination impairment in the muscles involved in the serve kinetic chain. It should be taken into account that this research only investigated a specific tennis situation and that in a match the psychological pressure and the tactical requirements could condition the serve performance. Although significant differences performing BP plus HS were observed comparing minute 10 with the other recovery times (0, 5 and 15 minutes), no significant differences were observed compared to the baseline.

No detrimental accuracy results were found either in tennis using CT[13] or in basketball performing traditional strength training after 6 hours rest.[27] Regarding the accuracy test reliability, this test was probably limited because the subjects were asked to hit the ball at maximum speed, causing more variability in the accuracy and consequently decreasing it. Similar results were observed in tennis[28] and dart throwing[29] researches, though there is some controversy because it has also been observed a positive correlation between velocity and accuracy.[30]

Practical Applications

Several fitness tennis coaches use CT to achieve the PAP effect in order to enhance serve velocity.[13] Although this research cannot discourage CT use in tennis, the results of the present study indicate that it is not a useful method to acutely increase serve performance in young tennis players. As a consequence, coaches should be careful when applying this training method, and it would be advisable to find the best protocol for each player. However, due to the fact that this protocol of CT did not have a detrimental effect on accuracy and velocity, it could be suggested the use of CT combining HLRE and shots during an on-court tennis session looking for a mid term or long term performance enhancement. Further research should be required to determine how to achieve the maximum PAP effect in tennis serve by investigating different samples, exercises, recovery period, volume or intensity. It would be interesting to investigate the PAP effect on stroke velocity and accuracy using similar kinetic chain exercises such as medicine ball throws or cable pulley machine exercises imitating the tennis serve.

Conclusions

The present research indicates that CT using heavy load in bench press and half squat does not improve serve velocity and does not have detrimental effect in accuracy in young tennis players. Due to the large variation of individual responses, it is necessary to individualize protocols and to identify the subjects that respond positively to CT.

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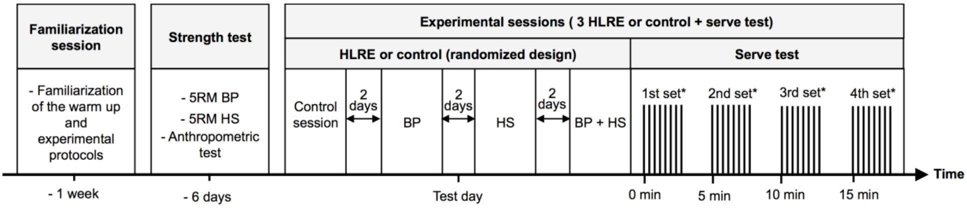

Figure 1. Study design chronology. HLRE: heavy load resistance exercises; RM: maximum repetition; BP: bench press; HS: half squat; BP + HS: bench press plus half squat. *20 seconds rest between serves.

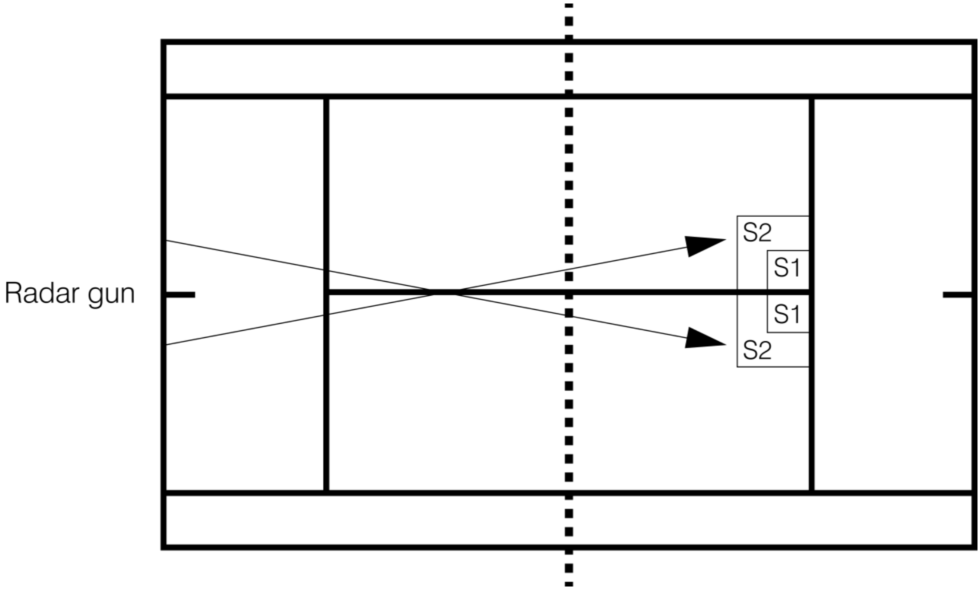

Figure 2. Serve accuracy test adapted by Pialoux et al. (20). S1 zone (0,5m x 0,5m) 5 points, S2 zone (1m x 1m) 3 points, rest of the serve box 1 point.

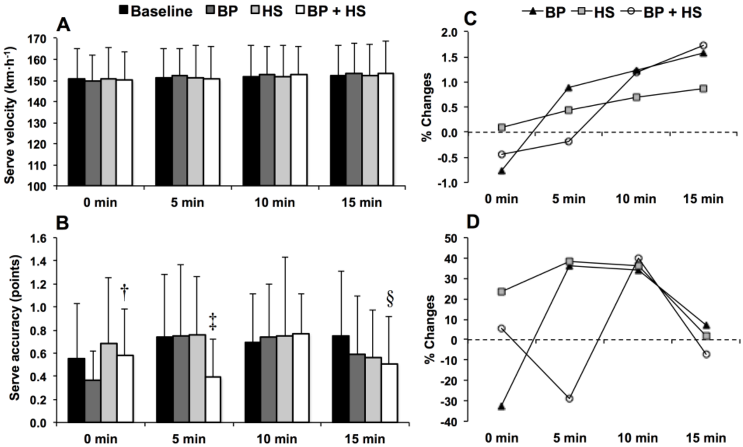

Figure 3. Comparison of peak serve velocity (A), accuracy (B) and corresponding percentage changes from minute 0 baseline (C and D) after 3 different heavy load resistance exercises (BP: bench press; HS: half squat; BP + HS: bench press plus half squat) across 4 time points (0, 5, 10 and 15 min). Serve velocity and accuracy values are mean ± SD; †Significant differences between minute 10 ($p < 0.05$); ‡Significant differences between minute 10 ($p < 0.05$); §Significant differences between minute 10 ($p < 0.05$).

Table 1. Participant characteristics. Values are mean ± SD. 1 RM BP = 1 maximum repetition in bench press; 1 RM HS = 1 maximum repetition in half squat.

	Whole group (n = 15)	Male (n = 9)	Female (n = 6)
Age (years)	15.6 ± 1.5	16.2 ± 1.5	14.7 ± 0.9
Body mass (kg)	61.3 ± 9.9	67.4 ± 7.9	52.2 ± 3.2
Height (cm)	171.0 ± 9.0	177.1 ± 5.9	162.0 ± 5.3
1 RM BP (kg)	42.4 ± 15.5	52.2 ± 12.9	33.0 ± 7.3
1RM HS (kg)	84.1 ± 25.3	97.6 ± 19.6	68.3 ± 15.2
1 RM BP / Body Mass	0.7 ± 0.2	0.8 ± 0,2	0.6 ± 0.2
1 RM HS / Body Mass	1.4 ± 0.2	1.4 ± 0.2	1.3 ± 0.2