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Acute Effects Of The Mid-thigh Power Clean On The Advanced Tennis Serve

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ACUTE EFFECTS OF THE MID-THIGH POWER CLEAN ON THE ADVANCED TENNIS SERVE

by

Luis A. Vial

B.S. University of Mobile, 2010

Research Paper
Submitted in Partial Fulfillment of the Requirements for the
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Department of Kinesiology
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RESEARCH PAPER APPROVAL

ACUTE EFFECTS OF THE MID-THIGH POWER CLEAN ON THE ADVANCED TENNIS SERVE

By

Luis A. Vial

A Research Paper Submitted in Partial

Fulfillment of the Requirements

for the Degree of

Master of Science

in the field of Kinesiology

Approved by:

Dr. Michael W. Olson, Chair

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Graduate School
Southern Illinois University Carbondale
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TITLE: ACUTE EFFECTS OF THE MID-THIGH POWER CLEAN ON THE ADVANCED TENNIS SERVE

MAJOR PROFESSOR: Dr. Michael W. Olson

Post-activation potentiation (PAP) is a phenomenon in which athletic performance is acutely enhanced after a muscle contraction (evoked or voluntary). Most studies have examined isometric maximal voluntary contraction and heavy resistance exercise as PAP inducing protocols, but minimal research exists analyzing Olympic lifting exercises. The purpose of this study was to investigate the acute PAP response of mid-thigh power clean on the tennis serve among NCAA Division I male tennis players. Tennis players (n=6) who were current roster members performed 5 tennis serves before and 4 min after one set of 5 repetitions of the mid-thigh power clean exercise at 60% 1RM. Performance was evaluated by measuring (pre and post) peak velocity [$F(1, 57)=1.456$, $p=.232$], peak power [$F(1, 57)= 0.799$, $p=.375$], total power output [$F(1, 57) = 0.748$, $p=.391$], impulse [$F(1, 58) = 3.163$, $p=.081$], and rate of force development [$F(1, 58) = 0.531$, $p=.469$]. There were no significant differences in any of the outcomes indicating there was no evidence of a PAP. Further research is needed to study the possible applicability of Olympic lifting to induce PAP effects on tennis players. It appears that the effective application of PAP inducing exercises appears to be highly individualized. Thus, the use of PAP complexes in tennis athletes should consider both the absolute and relative strength of each athlete in conjunction with the length of the rest period when attempting to optimize the PAP response using an Olympic lifting exercise.

Keywords: post activation potentiation, tennis serve, power output

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Introduction

Post Activation Potentiation

Post activation potentiation (PAP) is an acute manifestation of increased muscle power and work output seen in explosive movements, produced by a prior muscle contraction stimulus (Sale, 2002). The two main accepted mechanisms that generate PAP are the light chain myosin phosphorylation which is associated with the interaction of actin-myosin through hypersensitivity to calcium (Hodgson, Docherty, & Robbins, 2005, Smith, & Fry, 2007), and an increased recruitment of higher order motor units (Chiu, Fry, Weiss, Schilling, Brown, & Smith, 2003). This later mechanism has been suggested to be closely related to the corticospinal and cortical excitability produced by voluntary muscle contractions (Uematsu, Sekiguchi, Kobayashi, Tsuchiya, Hortobagyi, & Suzuki, 2012).

The extent by which an exercise can produce PAP mechanisms and thus acutely improve muscle performance is subject to the relationship between potentiation and fatigue, which in fact are simultaneously present in the muscular system. Consequently, the net balance of fatigue and potentiation will determine if the performance of a muscle is enhanced or undermined (Rassier & MacIntosh, 2000). Among other performance measurements enhancements (i.e. power output, peak force, impulse) PAP has mainly shown positive results in the rate of force development (Rassier, 2000; Baudry & Duchateau, 2004; Gilbert, & Lees, 2005; Tillin & Bishop, 2009). These effects postulate PAP generation as beneficial for exercises that are based on explosive, voluntary, and dynamic muscle contractions (Docherty & Hodgson, 2007), and they have been investigated and demonstrated in various athletes from disciplines such as sprinting

(Smith, Hannon, McGladrey, Shultz, Eisenman, & Lyons, 2014), fencing (Tsolakis, Bogdanis, Nikolaou, & Zacharogiannis, 2011), rugby (Tobin & Delhanunt, 2014), gymnastics (Donti, Tsolakis & Bogdanis, 2014), soccer (Mola, Bruce-Low, & Burnet, 2014), martial arts (Liossis, Forsyth, Liossis, & Tsolakis, 2013), basketball (Tsimahidis, et al. 2014), football (Conley, Molacek, Meier, McIntyre & Evetovich, 2013), rowing (Feros, Young, Rice, & Talpey, 2012), volleyball (McCann & Flanagan, 2010), softball (Sygulla & Fountaine, 2014) and tennis (Gelen, Dede, Meric, Bulgan & Aydin, 2012).

It has been of great difficulty however, to establish a proper conditioning protocol to enhance the PAP effects on athletic performance due to the significant influence of diverse factors such as the training level of the athlete, the predominant muscle fiber type, the preload activity characteristics (the type, intensity and duration), as well as the rest period between the pre-stimulus and the performance measure (Docherty & Hodgson, 2007). PAP studies have yielded varying and sometimes contradictory results due to the numerous possible combinations of these factors when designing a research protocol (Wilson, et al., 2013).

The effectiveness of PAP has been shown to be influenced by the training level of an individual. Athletes undergoing high performance training show significantly increased responses to PAP compared to individuals involved in recreational activities (Chiu, et al., 2003). This improved adaptation exposed by trained athletes can be attributed to a more synchronized and higher recruitment of motor units. A study conducted by Gourgoulis, Aggeloussis, Kasimatis, Mavromatis, & Garas (2003) found that stronger, more trained athletes, demonstrated greater improvements in vertical jumping ability (4.01%) compared to their less trained counterparts (0.42%), after performing submaximal intensity (75% 1RM) half-squats. It was concluded that a submaximal load of a heavy resistance exercise can produce PAP effects, at a greater rate in trained athletes than in untrained athletes (Gourgoulis, et al., 2003). Moreover, Chiu et al. (2003) found that a trained group of subjects showed a 1-3% increase in vertical and drop jump performance after performing 5 sets of 1 repetition at a high intensity (90% of a 1 RM) while the recreationally trained group showed a 1-4% decrease on the same measurements. The study showed that trained athletes exhibited significantly higher force and power measurements ($p < 0.05$) and recommended PAP as a method to enhance explosive strength in trained athletes but not to those that train for recreational purposes (Chiu, et al., 2003). Rate of force development, velocity and power values were found to be similar in a study comparing positive and negative responders to PAP (elevated vs diminished regulatory myosin light-chain phosphorylation) among recreational athletes suggesting that the training level and strength are crucial aspects to for PAP responses to be exploited (Smith, & Fry, 2007).

On the other hand, a study performed with high performance level female athletes showed no evidence of PAP (maximal jump height and peak power) response after a back squat exercise at 90% 1RM. The participants were athletes of various sports such as volleyball, softball, and basketball. The authors concluded that absolute and relative strength are factors that have to be considered when designing a PAP protocol and that these protocols should be designed with great individualization for each athlete (Sygulla & Fountaine, 2014).

It has been shown, that another important factor that affects the relationship between potentiation and fatigue is the muscle's predominant fiber type (Fukutani, Hirata, Miyamoto, Kanehisa, Yanai, & Kawakami, 2014). PAP effectiveness has been more evident in activities where speed, power and force are maximally challenged and the result from those activities relies highly on the quantity of type II muscle fibers. (Hamada, Sale, MacDougall & Tarnopolsky, 2003). Hamada, Sale, MacDougall, and Tarnopolsky (2000) conducted a study where participants performed 10s of maximal voluntary contraction (MVC) preceded and followed by evoked maximal twitch contractions of the vastus lateralis to analyze twitch time to peak torque, evidence of PAP. Participants with the highest PAP values (104%) had a higher percentage of type II fiber (72%) compared with the lowest PAP values (43%) who exhibit only 39 % of type II muscle fiber (Hamada et al., 2000). Also, Hamada et al. (2003), had two groups of participants (predominance of type I vs. type II vastus lateralis fibers) undergoing a fatigue protocol consisting of 16 MVCs of 5s of the knee extensors. During the fatigue protocol, MVC force decreased, over time, at a greater rate in the type II group (49.3%) than in the type I group (22.8%), while twitch force potentiation (associated with the M-waves recordings) was greater for the type II group (126.4%) than for the type I group (38.2%) early in the fatigue protocol. Therefore, the distribution of fiber type is a major influence for the relationship of potentiation and fatigue (Hamada et al., 2003).

Another important factor to enhance PAP, is the rest period between the explosive exercise (either at competition or training), and the prior activity. Evidence shows that PAP effects are evident immediately following a pre-load activity (Hamada et al., 2003; Baudry, & Duchateau, 2004) and can last up to 30 min (Rixon, Lamont & Bemben, 2007). Research has also shown PAP evidence after brief (5 min) (Tobin & Delahunt, 2014), moderate (8-12 min) (Kilduff, et al., 2007), and large (≥18 min) (Chiu, et al., 2003) rest periods. The time needed to observe enhanced muscular performance (PAP) will strictly depend on the aforementioned factors such as the level of training of the athlete, and this also requires additional research. It has been found however, that relative 1 RM negatively correlated with rest duration, generating superior PAP responses (r=-0.771) (Jo, Judelson, Brown, Coburn, & Dabbs, 2010).

However, a study found detrimental effects on jump performance (height and peak ground reaction forces) when the exercise immediately followed a conditioning protocol (at 10 seconds and 1, 2, 3, and 4 min) but noticed (not statistically significant) a trend to performance enhancement through time. They concluded that possibly performance enhancement can be noticed after 4 min recovery period (Jensen & Ebben, 2003). Furthermore, a meta-analysis study investigated the effects of rest intervals on jumping performance as it was measured by jump height and total power output. The recovery period ranges included were 0-3, 4-7, 8-12, and 16 min. It was found, that the 0-3 minute range actually hindered performance, while the range 8-12 min induced increased it (Gouvea, Fernandes, Cesar, Silva, & Gomes, 2013). Nevertheless, a study with professional soccer players which aimed to determine the optimal recovery time to elicit PAP responses –jump height and peak power- on a countermovement jump following a conditioning protocol (a set of 3RM squat) found no significant differences between the intervention group (conditioning protocol) and a control group. Moreover, no time effect for jump height or peak power was found when the participants were analyzed after 15 seconds, and at 4, 8, 12, 16 and 20 min of the PAP inducing protocol. The authors also suggest that PAP responses are subject to a high degree of individualization (Mola, Bruce-Low, & Burnet, 2014).

There are diverse conclusions about the proper intensity of the contraction prior to the explosive movement. Some studies have shown that even a very low intensity (25% MVC) can elicit PAP (Baudry, & Duchateau, 2007), whereas other studies have exposed that just high intensity contractions (+75% to MVC) generate PAP (Vandervoort,, Quinlan, & McComas, 1983). According to a meta-analysis study on PAP, a moderate intensity (60-85% 1RM) was found to be more appropriate at producing PAP effects than high intensities (+85% 1RM) regardless of the experience of the athlete (Wilson, et al., 2013). This statement is supported by Fukutani, et al. (2014) who concluded that moderate intensity was ideal to effectively induce PAP (80% for plantar flexion and 60% for thumb adduction). Nonetheless, a study by Gossen and Sale (2000) failed to show any PAP effects (measured by enhanced evoked twitch torque and attained peak velocity) on maximal dynamic knee extensions at different intensities: 15%, 30%, 45%, and 60% of maximal isometric knee extension peak torque. PAP was induced by a 10 seconds MVC and knee extension activity was analyzed after 15 seconds of this PAP protocol. The authors concluded that the short rest period could have influenced negatively on the PAP response (Gossen & Sale, 2000).

A study conducted by Pearson and Hussain (2014) aimed to find the optimal duration of a MVC conditioning protocol to induce PAP responses and the relationship between PAP and jump performance. Performance measures (peak twitch torque, jump height, total power, rate of force development, takeoff velocity) were assessed before and 4 min following three PAP protocols differing in the duration of the MVC: 3, 5 and 7 seconds. Increase in peak twitch torque was found but not statistically significant. They did not find any significant differences in any of the variables with any of the three MVC protocols. Furthermore, they did not find any relationship between the variations of twitch torque and jump height for any MVC duration. This study suggested that PAP was not associated with jump performance following a MVC of different durations (Pearson, & Hussain, 2014).

The characteristics of the PAP-inducing contraction are of great importance in regards to the delicate balance of potentiation and fatigue and there is differing evidence in this topic. Tsolakis and Bogdanis (2012) compared the effects of two different types of contractions on PAP in elite athletes. The participants performed either an isometric or a plyometric protocol for bench and leg press. Peak leg power was measured before, immediately after, and following 4, 8, and 12 min of this intervention. The isometric group decreased peak leg power by the 8^{th} and 12^{th} min (by 7.5% and 8.7% respectively) compared to baseline scores, whereas the plyometric group peak leg power was maintained over the course of the study (Tsolakis & Bogdanis, 2012). Moreover, Tobin and Delahunt (2014) examined the acute effects of plyometric exercise on jump height and peak force. Professional rugby players were tested with a countermovement jump (CMJ) to examine jump height and peak force at 1, 3 and 5 min after the conditioning protocol and the results were compared to studies utilizing heavy resistance exercise as the conditioning protocol. They found that plyometric protocol induced an important enhancement in CMJ height and peak force after a recovery period interval range of 1 to 5 min when compared to baseline values and those improvements were similar to those found in other studies after a heavy resistance exercise but requiring less recovery time to show PAP responses (Tobin & Delahunt, 2014).

Contrary to these results, Rixon, Lamont and Bemben (2007) showed that a maximal isometric squat protocol produced higher PAP as displayed by jump height and power output (countermovement jumps) than a dynamical approach. On the other hand, Baudry and Duchateau (2004), tested the effects of isometric, eccentric, or concentric MVC and found no relationship to the amount of PAP responses being generated. Furthermore, there is evidence to suggest that conventional neuromuscular electrical stimulation (Baudry & Duchateau, 2007), submaximal tetanic contraction (Hamada, et al., 2003), and whole body vibration (Cochrane, Stannard, Firth, & Rittweger, 2010; Guggenheimer, Dickin, Reyes, & Dolny, 2009) have the ability to generate PAP on subsequent explosive exercises. Nonetheless, research utilizing explosive activity protocols (i.e. Olympic lifting) as preload activities (Seitz, Trajano, & Haff, 2014) are limited and further research is required.

Olympic lifting as a plyometric activity inducing PAP. As it was stated earlier, even though the main benefit of plyometric exercise is to generate high amounts of power, this methodology has not been extensively examined as a possible conditioning protocol to induce PAP effects (Tobin & Delahunt, 2014). In fact, the ability to produce a great amount of power is desired by most athletes, especially those who participate in sports where force generation in a brief period of time is vital for success, such as tennis (Baiget, 2011; Ortiz, 2004; Newton, 2006).

Due to the nature of plyometric activity, in which a quick generation of force and the capability to accelerate a resistance are the main goal, the typical Olympic lifting exercises (the snatch, the clean, and the jerk) are essentially a mode of plyometric actions (Newton, 2006). However, plyometric exercise is characterized by its explosive ballistic aspect (moving/ throwing an external resistance into space), while Olympic lifting requires the safe manipulation of an object (barbell) with heavier resistance that cannot be thrown (Newton, 2006).

Olympic lifting exercises, -explosive exercises- have been vastly recommended for athletes because of their high specificity characteristics related to sports activities (Baechle & Earle, 2008; Stone, 1993; Newton, 2006). It has been claimed that these kinds of exercises have important applications and training effects to many sports where strength and power are required because of their similarities to movement patterns, joint range of motion, angular velocities, and power output. Therefore, the utilization of sport-specific explosive exercise have been suggested to improve performance by promoting the use of explosive power while performing a sport-specific action (Baker, 1996; Hori et al., 2008; Newton, & Jenkins, 2013; Stone, et al., 2003).

The mid-thigh power clean is considered to be a simple yet efficient Olympic lifting exercise mainly used to enhance power output. This exercise is proposed to be the most beneficial variation of the power clean since it elicits higher peak power output, higher peak force and greater immediate rate of force development when compared to other variations (Comfort, Allen, & Graham-Smith, 2011). In this exercise, the whole body executes explosively a sport-specific movement and it is advantageous especially for sports where vertical and horizontal movements are needed (Newton & Kraemer, 1994; Newton, 2006). The mid-thigh power clean involves moving the barbell from the mid-thigh (starting position) to the front of the shoulders without pauses. This action requires a quick and forceful pull of the bar with proper technique and balance (Baechle & Earle, 2008; Newton, 2006). From a PAP standpoint, the utilization of a (mid-thigh) power clean as a pre-load activity might enhance acute adaptation, thus acute PAP effect, during a following sport movement such as sprint or vertical jumping, due its kinematic and kinetic similarities with such manifestations (Newton, 2006; Seitz, Trajano, & Haff, 2014)

Currently, three studies have been performed where the researchers investigated the effects of PAP through the use of the power clean (and its variations) as the pre-load activity in rugby (Seitz, Trajano, & Haff, 2014), volleyball (McCann, & Flanagan, 2010), and track & field athletes (Guggenheimer, Dickin, Reyes, & Dolny, 2009). Seitz et al. (2014) reported greater performance measurements (sprint time, velocity, and acceleration) using the power clean as a conditioning activity when compared with the back squat. Both protocols were performed at a 90% 1RM intensity and both induced significant PAP effects.

On the other hand, there was no significant improvement when the effects of one set of three repetitions of power cleans (90% 1RM) were investigated for sprint performance as measured by reaction times and split times (Guggenheimer et al. 2009). Furthermore, a study performed with volleyball players examined ground reaction forces while performing vertical jumps after 4 or 5 min of a conditioning protocol, either a back squat or a mid-thigh power clean (one set of five repetitions at 5RM intensity -85-90% 1RM-). No significant differences on the variables of interest were found between the two exercises thus concluding that the prescription of exercise should be highly personal according to each population (McCann & Flanagan, 2010). It is important to note however, these two studies utilized near-maximal intensities (90% 1RM) and this fact may have hindered the results.

Explosive Exercise for Tennis Players

Only two studies have been found which investigated the acute effects of a conditioning activity on tennis players either utilizing a maximum isometric contraction on lower limbs (Kovačić, Klino, Babajić, & Bradić, 2010), or a plyometric exercise on upper limbs (Gelen et al., 2012). The first study examined explosive power of lower limbs through measuring jump height. They employed an isometric protocol as the conditioning activity to induce PAP on elite tennis players. It was found that, after 60 and 90 seconds of the conditioning isometric activity, the experimental group showed significantly higher jump heights than the control group (Kovačić et al., 2010). In the second study, the participants (elite junior tennis players) performed four conditioning protocols in different days: traditional warm-up (TRAD), TRAD and static stretching, TRAD and dynamic stretching (TRDE), and TRAD and upper-body plyometric activity (TRPLYO) prior to performing a tennis serve speed test. The results were compared by repeated measurement ANOVA and showed that TRDE (1.23%) and TRPLYO (3.3%) protocols elicited a significant increase in serve speed. The authors concluded that dynamic exercises can activate PAP in the tennis serve (Gelen et al., 2012).

Even though in a tennis match, a tennis player is not required to move heavy objects, Olympic lifting conditioning is widely applied by coaches and trainers to improve sport-specific skills –such as power and balance- that are needed for an optimal racquet speed production (Newton, 2006; Reid & Schneiker, 2008). Olympic lifting exercises (i.e. mid-thigh power clean) are often applied to tennis players because they also boosts the capacity of the muscle to eccentrically decelerate the body or body segment after a stroke while simultaneously generating power, vital for stroke control and injury prevention (Kovacs, Roetert & Ellenbecker, 2008).

The tennis serve. Because its importance in the game, the serve stroke has been object of a large amount of studies and it is generally considered as one of the most significant, and difficult skills a tennis player must possess in order to be successful (Bahamonde, 2000; Girard, Micallef, & Millet, 2005; Kovacs et al., 2008; Reid, Elliott, & Alderson, 2008). In order to produce high speed serves, a tennis player must be able to generate high amounts of power from the lower limbs (leg drive) and transfer it to the racquet utilizing all possible body segments in a highly coordinated and rhythmic movements sequence; a mechanism referred as the kinetic chain (Putnam, 1993; Bahamonde, 2000; Kibler, 2009; De Subijana & Navarro, 2010). It has been suggested that an elite tennis player can generate approximately up to 4000 watts of power on the tennis serve (Schonborn, 1998).

The leg drive generates approximately 51% of the kinetic energy and 54% of the total force of the kinetic chain making it the most important mechanism to generate proximal force (Putnam, 1993; Girard et al., 2005; 2007). It has been demonstrated that elite players can generate ground reaction forces in the vertical direction up to two times their body weight (Girard et al., 2005). The main purpose of an efficient leg drive is to enhance the utilization of trunk rotations and upper limb actions to position the dominant arm in maximal external rotation and to exert lower loads in the shoulder joint (Reid, Elliott, & Alderson, 2008).

Furthermore, Fleisig, Nicholls, Elliot, and Escamilia, (2003) showed that inferior front knee flexion (<10º at the moment of maximal external rotation of the shoulder), which was a predictor of poor leg drive, place higher loads to the shoulder and elbow joints by increasing joint torque. According to Reid et al. (2008) the main benefit of an efficient leg drive is to enhance the utilization of trunk rotations and upper limb movements to position the dominant arm in maximal external rotation and placing less loads in the shoulder joint thus preventing injuries. They showed a significant reduction of peak internal rotation torque in the shoulder joint related with higher ground reaction forces from the leg drive (Reid et al. 2008). Moreover, effective leg drives (measured by kinetic and kinematic variables), increased the range of motion of racket loops down, behind and away from the back allowing players to generate higher racket speeds (Girard et al., 2005).

In agreement with this, a study showed that 10-20% of the racquet speed was produced by GRF of the lower limbs together with trunk rotation (Elliot et al., 1995). Furthermore, Bahamonde (2000) showed that greater ground reaction forces in the tennis serve produced an off-center angular propulsion in relation to the center of mass, which produces a trunk lateral deviation resulting in higher contact point with the ball thus increasing margin of error.

The serve stroke entails two different foot stances techniques: the foot-back, in which the back foot stays in the initial serve position without moving until push-off, and the foot-up, in which the back foot advances to join the front foot for push-off. Even though similar maximal ball speeds have been observed in players with either technique (Elliott, & Wood, 1983), the foot-up technique has been found to be more beneficial for vertical forces (thus higher impact heights), while enhanced ground reaction forces on the anterior-posterior direction has been seen in the foot-back stance (facilitating the forward movement of the player) (Bahamonde, & Knudson, 2001; Girard et al., 2005; Reid et al., 2008).

The development of more efficient and beneficial training methods is a central topic of discussion among sports researchers and trainers. However up to this date, an investigation examining the acute effects of an explosive exercise on lower limb performance while executing a tennis serve is lacking. Therefore, the purpose of the study was to examine the acute effects of an Olympic lifting exercise (mid-thigh power clean) on the leg drive performance of a tennis serve as measured by peak velocity of the system, peak power, total body power, impulse and rate of force development in NCAA Division I male tennis players. It was hypothesized that the execution of a mid-thigh power clean 4-min before the tennis serve would induce significant performance enhancements in the leg drive of the tennis serve.

Methods

Participants

Six male National Collegiate Athletic Association (NCAA) division I tennis players participated in the study (Table 1). All participants had at least ten years of competitive playing experience (11.6 ± 1.7 years) and a minimum of three years of strength training experience (4.0 ± 1.8 years). Technique and proper execution of the exercise was supervised by a strength and conditioning coach and by the researcher. At the time of the study all participants had been injury free for the previous six weeks and were involved in regular tennis team practices of 2.5 hours at least 4 times/wk. The selection of participants was based on the advanced tennis level and on the experience performing Olympic lifting exercises. Four players were excluded from the study due to injury (2) and poor Olympic lifting technique execution (2). The risks of the study were discussed and explanations about the testing procedures were provided. Each participant attended the experimental session in different days at the biomechanics laboratory in the SIUC Department of Kinesiology. The investigation was performed under the approval of the Southern Illinois University Human Subjects Committee.

Table 1

Subject demographics

N=6	Mean ± SD
Age (yrs.)	20.7 ± 1.7
Mass (Kg)	82.6 ± 10
Height (m)	1.83 ± 0.06
BMI (kg/m²)	24.24 ± 1.59
Tennis experience (y)	11.6 ± 1.7
Olympic lifting experience (y)	4.0 ± 1.8
1RM power clean (kg)	81.59 ± 12.72
60% power clean (kg)	49 ± 7.6
Relative strength (1RM/ mass)	0.98

During the first initial testing session with the researcher, the participants' anthropometric measurements were taken and recorded and the 1-repetition maximum (1RM) of the power clean was determined by the strength and conditioning specialist through a 5RM test (Baechle & Earle, 2008). During the experimental session, each participant was required to perform five tennis serves on a force platform before and 4 min after a set of five mid-thigh power cleans performed with a load of 60% 1 RM power clean, utilizing their own shoes and racquet and a special pair of shorts to attach the retro-reflective markers.

Instrumentation

An optical multi-camera system (Qualysis AB, Gothenburg, Sweden) was used to collect kinematics data from each participant. Retro-reflective markers of 14 mm diameter were positioned on the skin, shorts, and shoes over specific boney landmarks on the lower extremities bilaterally: posterior superior iliac spine, greater trochanter, lateral epicondyle of the distal femur, lateral malleoli, heel of the subjects' shoes, and on the shoes over the location of the 5^{th} metatarsophalangeal joint. Data were collected at a rate of 240 Hz.

Kinetics data were collected using a six degree of freedom force platform (OR-6, Advance Mechanical Technologies Incorporated, Watertown, MA, USA). Specifically, the vertical ground reaction forces were recorded to evaluate the service and leg drive patterns during the procedures. Force data were collected at 1200 Hz. Kinematics and kinetics data were synchronized with a common 12 bit A/D board and saved for future processing.

Procedures

The participants were instructed to abstain from extra practice or engaging in strength training for 48 hrs. prior to the experimental session. This session took approximately three hours in a single day (Figure 1).

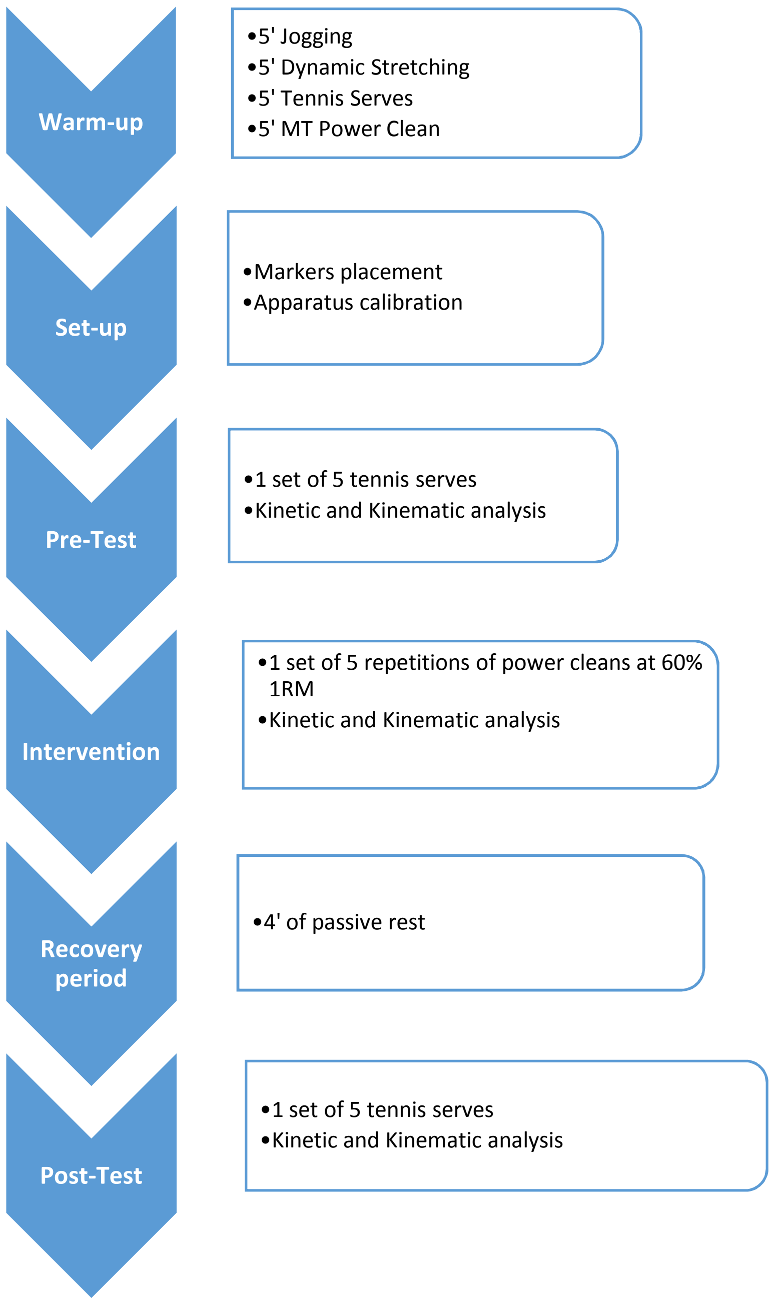

Figure 1. Order and detail of procedures

During this session reflective markers were placed on specific lower body anatomical landmarks following International Society of Biomechanics recommendations (Wu et al., 2002). Before the placement of the markers, the participant completed a 20 min standardized warm up protocol including 5 min jogging on the treadmill, 5 min of dynamic stretching, 5 min performing tennis serves movements with their racquets (without hitting a ball), and 5 min performing the mid-thigh power clean -three repetitions with 20.4 kg (bar alone), 2 repetitions at 30% 1RM power clean, and two repetitions at 60% 1RM. During the 4 min rest after the warm-up protocol, the markers were re-checked to ensure proper location.

Then, the participant was instructed to stand on the force platform and perform tennis serves with 10 seconds rest between the serves. The participants were instructed to perform their flat serves, while five correct executions were recorded for further analysis. To resemble the tennis serve as much as possible, the participants hit a tennis ball hanging from the ceiling with a height adjustable cord. Impact height was set at one and a half times the player's height (Elliott, Reid, & Crespo, 2009; Mendes et al., 2013; Reid, Whiteside, & Elliott, 2011).

Following the first set of five serves, the participants took a 2 min rest period (moment where the researcher set-up the Olympic lifting bar over the force platform for the participant to perform the mid-thigh power clean). Next, the participants performed the mid-thigh power cleans while standing on the force platform. These lifts were performed using a recommended load of 60% (of 1RM power clean) to minimize technical errors associated with higher loads. Moreover, this intensity has been suggested to induce peak power output (Comfort et al., 2011a; 2011b; Comfort, Fletcher, & McMahon 2012). Similarly, five correct executions were recorded for further analysis.

Subsequent to the mid-thigh power cleans, the participants took a 4 min recovery period before they performed another set of tennis serves with the same protocol as the first set of serves. The period of 4 min was utilized as suggested for plyometric activities by Tobin & Delahunt (2014). Also, even though prior research suggests that a range rest period of 8-12 min is advisable to induce PAP responses (Gouvea, Fernandes, Cesar, Silva, & Gomes, 2013), very few studies have applied Olympic lifting exercises as the conditioning protocol.

Data Analysis

Kinematics data were smoothed with a fourth-order Butterworth filter at 10 Hz. After the data were smoothed, joint angle calculations were performed using custom software. Kinematics analysis for right hip vertical velocity was synchronized with kinetics data and started at leg push-off (beginning of concentric phase) while the end of kinematic data analysis were determined at peak vertical velocity of the right hip.

Kinetics data were reduced with a fourth-order Butterworth filter at 50 Hz. The force data were used for analysis of peak power, total body power output, rate of force development and to calculate the vertical force impulse curve. Kinetic data analysis started at push off (beginning of concentric phase) and ended at the instant in which vertical force (F_z) was zero, namely at player's takeoff. These data were resampled so that the number of kinetics data points were the same as the kinematics per trial. This allowed for calculations of power to be performed.

Statistical Analysis

The mean and SD of the selected anthropometric and physical performance tests were calculated for all subjects (Table 1). A within-subjects repeated measures research design was applied to examine the acute effects of the mid-thigh power clean on PAP responses in the tennis serve. Peak velocity, peak power, total power output, impulse and rate of force development were the dependent variables of interest. Five separate one way analysis of variance (ANOVA) with repeated measures and Bonferroni post hoc analysis were conducted to determine if there were significant differences in the dependent variables between pre- and post-power clean tennis serves. Statistical analyses were performed using SPSS software (version 19; SPSS, Inc., Chicago, IL, USA). Alpha level was set to $p<.05$.

Results

There was no significant effect of the explosive exercise for any of the variables. Peak velocity [F (1, 57=1.456, p=.232], peak power [F 1, 57= 0.799, p=.375], total power output [F 1, 57 = 0.748, p=.391], impulse [F 1, 58 = 3.163, p=.081], rate of force development [F 1, 58 = 0.531, p=.469] did not change from pre to post measures (Table 2).

Table 2.

Mean ± SD values of Peak Velocity, Peak Power, Total Power Output, Impulse, and Rate of force development for pre and post intervention conditions.

N=6	Pre	Post
Peak Velocity (mm/s)	2169.03 ± 329.80	2278.02 ± 362.47
Peak Power (W (N*mm)/s))	2839.01 ± 781.42	3026.83 ± 830.54
Total Power Output (W (N*mm)/s))	48931.83 ± 13443.49	51802.52 ± 12027.84
Impulse (N*s)	617.60 ± 62.18	647.65 ± 68.52
RFD (N/s)	2810.11 ± 1701.38	2534.25 ± 1185.15

Discussion

The PAP phenomenon has been greatly investigated but concise and determinant information about the optimal training protocols is still lacking. In an aim to elucidate an effective and advantageous training method for the tennis serve, the purpose of this study was to determine the acute effects of mid-thigh power cleans on the tennis serve in NCAA Division I male tennis players. The results of this study found that a PAP inducing exercise (mid-thigh power clean) consisting of one set of five repetitions at 60% of 1RM (power clean) followed by a 4 min rest period did not improve subsequent peak velocity, peak power, total power, impulse, or rate of force development on the leg drive of the tennis serve in these athletes.

Studies analyzing PAP have yielded different, sometimes conflicting results and the majority of them concluded that PAP response is highly individualized depending on the proper balance of the combination of factors involved such as training level of the athlete, strength level, the intensity of the activity, the duration of the rest period following the PAP inducing exercise, the type of the predominant muscle fiber and the nature of the conditioning protocol (Wilson, et al., 2013; Docherty & Hodgson, 2007; Chiu, et al., 2003; Fukutani, et al., 2014).

Whereas this study involved trained male athletes, their relative strength may explain why they did not show significant PAP responses. Our subjects showed a relative strength of 0.98 (1RM power clean/ BM) while other studies with PAP responses evidence in highly trained athletes with similar ages show relative strength values of 1.08 (Confort, Fletcher, & McMahon, 2012), 1.17 (Seitz, Trajano, & Haff, 2014), and 1.21 (McBride, Haines,& Kirby, 2011). As it was stated before, it has been shown that stronger athletes exhibit greater PAP values, allegedly because their capability to resist fatigue for longer periods of time (Hamada, Sale & MacDougall, 2000; Hodgson, Docherty, & Robbins, 2005; Jo, et al., 2010). Therefore, the low relative strength value of our subjects along with a relatively short rest period following the Olympic lifting exercise may have prevented PAP responses to manifest and also it may be the cause of the rate of force development decrease. This is in accordance with the study of Sygulla & Fountaine (2014) who concluded that the low relative strength of their participants was the main reason for which they did not find evidence of PAP.

The recovery time following the conditioning activity has been investigated but an optimal time to induce PAP responses has been difficult to find mainly due to, as mentioned earlier, the large variability among athletes. There is a time span however, when the particular athlete's muscles have recovered from fatigue but still has the potentiating effects of the exercise (Hamada et al., 2003; Rassier, & MacIntosh, 2000), thus enhancing performance. On the other hand, if fatigue overcomes potentiation due to an improper recovery time period, then the conditioning exercise which was intended to improve performance, can in fact hinder it (Rassier, 2000). Consequently, this factor becomes vital when designing training programs. Even though the number of possible combinations is immense, research suggests that moderate rest period lengths ranging from 7-10 min appear to optimally augment power output after a conditioning activity. However, it has been shown that plyometric activity produced similar power outputs compared to heavy resistance exercise, but required less time to recover (1-5 min) (Tobin & Delahunt, 2014). Moreover, moderate exercise intensity (60-85% 1RM) have been suggested to enhance PAP response (Wilson et al., 2013).

It is arguable, that the intervention protocol used in this study was not the ideal to elicit significant PAP responses. A weight-lifting exercise (one set of five repetitions of mid-thigh power cleans) performed at 60% of 1RM followed by 4-minute rest period was implemented. The results of this study showed that there were no significant detrimental effects to performance in the tennis serve, although no significant improvements were found either. It is possible, that the rest period length provided in this study was not enough for acute fatigue to subside therefore preventing potentiation effect to take place. Possibly, this short rest interval was the cause of both, the inability to reach statistical significance for the increasing variables, and for the decrease of rate of force development.

It is very difficult to compare the results of this study with other PAP investigations because there are only two other PAP studies performed with tennis players (Kovačić et al., 2010; Gelen et al., 2012). None of these studies however, utilized an Olympic lifting activity as the PAP inducing exercise nor did they analyze the effects of a conditioning protocol directly on the leg drive of the tennis serve.

Due to the time span of PAP effects, which is suggested to last up to 30 min (Wilson et al., 2013; Sale, 2002), PAP protocols have attracted the attention of performance athletes such as sprinters, throwers, high jumpers, pole vault athletes, long jumpers, etc. (Newton, 2006; Newton & Kraemer, 1994). These sports require bouts of highly explosive exercise over brief periods of time. Therefore, it has been argued if PAP protocols are beneficial for individual or team sports that can last for many hours but that also, require high explosive manifestations (Docherty & Hodgson, 2007). However, it is still important to test the applicability of PAP for these kind of sports (i.e.

tennis) for practice sessions to execute movements at enhanced performance parameters. Specifically in the tennis serve, an enhanced leg drive performance, has been shown to decrease shoulder load (joint torque) thus decreasing the chances for injury (Reid et al., 2008).

Limitations of the Present Study

The main limitation of the study was our limited sample size (n=6). It was of great difficulty to recruit participants from the area where the research took place. There were only 9 high performance athletes who could perform both the tennis serve and the mid-thigh power clean properly but, just 6 completed the study.

From the descriptive results, it can be noted that there were non-significant increases in the values analyzed on the posttest regarding the pretests. Possibly a bigger sample size would show statistical significant differences of the dependent variables and even allow for analysis of the results according to the tennis serve stances (foot-up or foot-back) of the players.

The results of this study should be interpreted carefully when trying to relate them to other sports populations since our subjects were part of a very distinctive population of tennis experts with at least three years of Olympic lifting experience. Therefore, the results are less generalizable to other sports populations.

And lastly, another important limitation of the study was the fact that players executed the tennis serve in a laboratory setting and not in a real world situation. Especially regarding the serve toss, players may have had to unconsciously change their coordination patterns because they were not totally controlling the toss, even though the ball was placed at 1.5x their height, height found to be optimal for contact point (Elliott et al., 2009; Mendes et al., 2013; Reid et al., 2011). This of course, may have slightly modified their leg drive mechanics thus altering the results.

Conclusion

This study examined the acute kinematic effects on leg drive during the high performance tennis serve of a power clean variation exercise. It was hypothesized that a mid-thigh power clean would induce PAP effects in the leg drive of the tennis serve of elite athletes. Even though there were increases in peak velocity (5%), peak power (6.6%), total body power (5.9%) and impulse (4.9%), those differences did not reach statistical significance (Table 2), showing that there were no PAP effects in this study. Interestingly, only rate of force development decreased (9%) but this too was not a significant difference. The present results however, show that this protocol with an explosive exercise prior to the tennis serve did not produce detrimental effects to performance.

This study represents the first attempt to investigate the acute effects of an Olympic lifting exercise on the leg drive of a tennis serve performed by elite athletes. Further research is needed to elucidate an appropriate combination of PAP factors (training level, the predominant muscle fiber type, the preload activity characteristics - the type, intensity and duration, as well as the rest period time between the pre-stimulus and the performance measure) to enhance serve performance in competition or practice sessions.

Recommendation for Future Studies

Without the limitations of the present study, future studies should analyze if there are kinetic or kinematic differences of the two serve stances (foot-back, foot-up) after applying a PAP explosive conditioning protocol. This would provide valuable information to improve individualization of training programs for tennis players. Possibly, one stance would result more benefited than the other. In addition, in would also be interesting to explore if the muscle activation patterns of the tennis serve (using electromyography) are altered by a PAP explosive exercise protocol. This would provide valuable information for injury prevention and speed production aspects. And lastly, future research should also investigate outcome measurements of ball speed and shoulder joint torque of the tennis serve when applying a PAP conditioning protocol to find out if there are benefits of this protocols for injury prevention and performance improvements readily transferable to a tennis match or practice situation.

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