THE EFFECTS OF CORE TRAINING ON SERVE VELOCITY IN TENNIS

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Jason Thomas Smart, B.A, B.F.A.

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TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

THE EFFECTS OF CORE TRAINING ON SERVE VELOCITY IN TENNIS

Introduction

While considerable research on core stability and core endurance has been carried out in the physiotherapy/rehab field, the benefits of core training are new in the world of sport science and research, especially with regards to tennis.[1,2] Supplementing core workouts in different sports performed in unstable body positions: tennis serve, a running forehand, baseball pitcher wind-up, etc., may increase ball velocity and overall performance.[3,4,5,6,7,8,9,10,11,12,13,14]

The serve is one of the fundamental strokes in tennis and is becoming more important to the outcome of the match.[15] The serve is also the only shot in tennis where the player is dependent on themselves.[16] On grass surfaces tennis players win about 20% of all points in a match with the serve.[17,18] In view of modern development trends of tennis matches, the importance of the serve and return is increasing. On clay court as much as 33% of points are won immediately after both strokes, while on hard courts the relevant share is 42%.[17,19]

Purpose of the Study

The present study was designed to compare results of an eight week core training program on serve velocity in regularly active tennis players.

Research Hypothesis

It was hypothesized that an eight week core resistance training program would significantly increase serve velocity.

Operational Definitions

1. Core musculature - muscles of the trunk and pelvis including the hip joint complex that are responsible for maintaining the stability of the spine and pelvis and are critical for the transfer of energy from the torso to the smaller extremities during many sport activities. These muscles also connect the trunk to the legs, shoulders, and arms.

2. Core Strength - the ability of core musculature to exert or withstand force.

3. Core Endurance - the ability of core musculature to contract, exert, or withstand force over time.

4. Grand Slams - tournaments that are the most important tennis events of the year in terms of world ranking points, tradition, prize-money awarded, and public attention.

5. Strength - the ability of a muscle to exert or withstand force.

6. Isotonic resistance training - one of the most common forms of strength training, usually involves free weights such as dumbbells and barbells and is performed in a manner that keeps tension on the muscle the same throughout the range of motion, but the length of the muscle changes.

7. The kinetic chain/sequence is the development and transfer momentum of larger body parts (muscle groups) such as the legs, core and torso to the smaller body parts such as the shoulder, upper arm, forearm, hand and through the racket. This is also described as the distal to proximal sequence. Distal being the most distant point from the ball (the feet) and proximal being the closest point to the ball (the hand/racket strings). The total force is due to the combination of individual forces about the body.

Delimitations

This study has delimitations that could affect the data collection and interpretation process.

1. This study is delimited to men and women that have tennis tournament experience.

2. Physically active tennis players who do not have current or previous musculoskeletal injury that affects serving performance.

3. This study is delimited to subjects who are aged 18 to 30 years of age.

Limitations

This experiment has inherent limitations that may affect the collection and interpretation of the data. Generalizations made from the results in this study are comprised by the following:

1. The results of this study cannot be applied to those who do not play tennis.
2. The results of this study cannot be applied to males or females who have musculoskeletal injury affecting serving performance.
3. The results of this study are limited to active tennis players.

Assumptions

The following assumptions for this study include:

1. The subjects who agree to participate in this study will be randomly selected.
2. It is assumed that all subjects will perform the pre- and posttests with maximum effort.
3. Subjects will complete the consent form and medical questionnaire accurately.
4. Subjects will not enroll or participate in any other weight training regime that they are currently not performing.

Significance of the Study

This study will attempt to determine the relationship between core resistance training and overall 1st serve velocity in tennis. There is little research on how core training affects tennis play, but hitting a serve five mph faster could mean the difference in an ace or a returned ball, a service winner and a return winner.[20] With the serve being the most hit stroke in a service game, the benefits of core training could provide the edge needed in winning in match play. The results of this study will assist trainers and coaches in the tennis profession on how to train a tennis player for maximal serve velocity without changing serving technique. This study will also determine the biometric factors that best predict serve velocity.

CHAPTER II

REVIEW OF RELATED LITERATURE

Significance of the Tennis Serve

Over the last 30 years tennis has seen an increase in tie-breakers in men's tennis in the four grand slam tournaments, and it is hypothesized that this is due to an increase in serve velocity[21], possibly through racket technology. However, this hypothesis requires further research to be supported. The only evidence available at this time is tie-breaker data.

Tie-breakers have been increasing on all surfaces for men, while women's games are inconclusive.[21] This may be due to reaction time. While serving speeds for both genders have increased, serve velocity for men has dramatically increased and could be pressing the boundaries of human reaction time. A dominant server could win all of their service games forcing a set into a tie-breaker. On faster surfaces such as grass and hard-court, this increase in serve velocity could cause a player with a stronger serve to progress farther into a tournament.

There is some evidence that a serve of 130 mph ($53.3ms^{-1}$) is approaching the limit of human reaction time.[21] Andy Roddick's serve hase been measured at 155 mph, or 249.4 kph, ace on September 27, 2004 in a Davis Cup match breaking his previous record of 152 mph and 149 mph. Venus Williams holds the women's record with a reported 137 mph. Needless to say these thresholds have been met by both women and men. If core training can in fact increase serve velocity, it would have a major impact on the game of tennis, possibly surpassing the threshold of reaction time for men, and also help women get closer to the threshold.

Wimbledon is the last Grand Slam tournament that is still played on grass. At Wimbledon in 2009, Andy Roddick played 10 tie breakers and won 7 of the 10. Losing 2 of those tie breakers to the number one player in the world Roger Federer. Federer played 24 total sets throughout Wimbledon with 8 of those sets going to tiebreakers. Federer won 6 of the 8 tiebreakers. Federer won the 2009 Wimbledon with Roddick being the runner-up. Therefore, it is important to investigate the means to increase serve velocity.

Biomechanics

When coaches and instructors talk about using the body to serve a tennis ball, they are talking about the kinetic chain. To transfer angular momentum through the kinetic chain and ultimately through the tennis racket, forces have to be initially produced through the legs and into the core.[22] Sequential movements such as the tennis serve follow these mechanical principals. Forces are applied from the ground up producing the final segment along a curved path. Because the tennis racket moves on a curved path towards the ball with forces from the wrist and shoulder, the further the path is from the center of motion, the greater the possibility of the speed of the serve. Therefore, we measured leg strength and muscular endurance of the core.

The tennis serve is a combination of sagittal and transverse planes of movement with the first rotation about the oblique, diagonal axis.[23] The core helps with this process by rotation of the hip and shoulder around the transverse body plane. The plank test used in this study measured muscular endurance in the saggital plane. The second rotation in serving is rotation in the body's sagittal plane.[7 24]

Studies on the kinetics of the tennis serve are not common and are limited.[25] Bahamonde concluded that angular momentum was primarily from trunk flexion as the body moved along the sagittal plane.[26] This flexion is produced through core musculature. The core training program was implemented to enhance trunk flexion as well as rotation.

Biomechanically the volleyball spike is similar to the tennis serve. One study correlated spike velocity significantly with strength performance of the dominant shoulder and elbow.[27]

Bahamonde observed that the forces in serving do not primarily come from angular momentum, especially about the horizontal axis. Angular forces are attributed by forceful flexion at the trunk and racket forearm and hand during elbow extension.[26]

Signorile et al. examined the correlation between internal and external rotation with leg extensions. He concluded that the entire body not just legs and shoulders need to be used as precursors for predicting throwing and serving velocities.[28]

Serving Techniques

There are two main serving techniques: traditional and abbreviated.

Biomechanically the traditional tennis serve is similar to baseball pitching[29], handball throws[7], and overhead throwing actions.[8 11 13 14 30 31] The core bends backwards, or extends, during the windup phase of the serve and then flexes forward in the unwinding or follow through phase.[1 15 16 24 26] These movements are vital in the body's kinetic chain.[1 30] The energy transferred from the ground at the feet, through the core, to the upper extremities and into the racket from the dominant arm, result in greater torque output.[1 30] Key muscles responsible for this type of movement are the internal and external obliques [1 32], which were targeted in the training program. Lower back muscles are also important for body rotation and were targeted in the training program.

Biomechanical research about the abbreviated tennis serve technique is limited.[24] Upon visual inspection of the traditional and abbreviated serve, it is apparent that arm and racquet trajectories differ during the wind-up phase of the serve. Little is known about the subtle differences between the two serves that occur after the wind-up phase. Elliott has the only study that compares the mechanical characteristics of the traditional and abbreviated serves.[15] It is unknown whether neuromuscular activations differ between the two service types.[24] However, core musculature should have the same effect on the kinetic chain in both types of serving techniques as the body still rotates and flexes through the same planes of motion.

De Subijana looked at the energy transfer through the kinetic chain of biomechanically different tennis serves and found that energy must first pass through core musculature before it continues to the proximal arm through the distal arm.[16 23] Accordingly, core training should influence serve velocity as the energy must pass through the core, regardless of which type of serve the player uses. In this study, a specific serve type was not selected. Subjects served with a technique that was most comfortable to them, and no instructions were given on form. They were instructed to serve the same way for both the pre and posttests.

Sport Related Biomechanics and Training

Ferrauti and Bastiaens found that when children threw 600 gram balls and 200 gram balls before serving, there were no significant increases to serve velocity.[31] However, serve velocity did significantly decrease during heavy intervention. The exact short- or long-term effects of light and heavy loads during functional serving techniques require further investigation.[31] As a result, subjects in this study did not perform ballistic warm ups involving medicine ball rotations.

There have been studies that looked at high school and college baseball players that incorporated upper-body isotonic resistance training that suggests an increase in throwing velocity.[33]

Conflicting data is prevalent with baseball training programs: including how long to perform the training and when results are expected.[33] Bagonzi did not report significant increases in throwing velocity until the 16th week of upper-body isotonic training designed to strengthen the throwing muscles.[34] Swangard found a significant increase after only eight weeks of upper-body resistance training that targeted similar musculature.[35] One isotonic training program was performed in the off-season and proved to have significant increases in throwing velocity.[36] However, during in-season the program had no significant effects on high school baseball players in the same age group, but the players did maintain throwing velocity.[37]

Exercise programs that have significant improvement in throwing velocity in collegiate baseball players have focused on isotonic upper-body training, specialized training, and specific training using weighted baseballs, wall pulley, or overloaded baseballs.[33 38] DeRenne et al.'s review on these types of training regime's came to the conclusion that effective resistance training programs need to be eight weeks long.[33] For this reason, the training program in this study took place for eight weeks.Currently there is not a clear answer as to which type of training increases over arm throwing velocity the most.[39]

Training the Core

Core training is often recommended by coaches to tennis players, but the benefits are still unclear.[3 7 40 41 42] Theoretically, core strength and stability training will lead to greater maximal power and thus more efficient use of the muscles of the shoulders, arms, and legs and improved body balance.[1 3 27 33 34 35 36 37 40 43 44] Core training may also lower the risk of injury to the core musculature. [2 3 9 22 32 44 45 46 47 48 49]

Muscle co-activation is the coordination of movement from agonist and antagonist muscles to enable stability. Thus, following this principle to improve stability, it is important to train the entire core musculature, not just one part of it. Chow et al. observed appreciable amounts of abdominal and lower back and bilateral co-activation during the arched back and forward swing of different styles of serving.[45] The biomechanics in tennis seem to cause imbalanced muscle activity patterns in lumbar erector spinae.[48] In a seven week study, seventy tennis players who regularly participated in competitive play were tested for imbalances in muscle activation about the lumbar erector spinae.[48] These imbalances were measured using surface electromyography (EMG). Forty-one tennis players had neuromuscular imbalances about lumbar vertebra two and four, in contrast to twenty-nine players who showed no sign of neuromuscular imbalance.

Because individuals display maximal trunk activity in different postures[47], meaning one individual might use more core musculature serving than another, there may not be a single isometric exercise that is best for all tennis players. A well rounded core training program may help correct these imbalances and develop electric efficiency patterns.[45]

Research does support that core training reduces the risk of injury and overall improved core performance.[2 3 7 22 33 42 44 45 46 48 49 50 51 52] Core muscle activation is needed to support body mass as well as additional loads on the body and during dynamic activities[32 47 53] such as serving in tennis.

Myer et al.'s research looked at how the lack of core musculature endurance and conditioning increased the chances of injury associated with valgus type forces acting on the knee joint, and could lead to anterior cruciate ligament (ACL) injury.[54]

Hornery et al. hypothesized that tissue damage could accumulate during a prolonged match, and even more over the course of a tournament, increasing the susceptibility to performance impairment in the tennis serve.[55] This study supports the argument for incorporating core training to benefit tennis players.

Analyzing other factors for core improvement, Kovacs found that maximal tennis hitting has resulted in 69% deterioration in hitting accuracy in ground strokes, and a 30%

decline in accuracy of the service to the right hand court.[44] These inaccuracies could be decreased by core training.

Filipčič et al. had subjects perform medicine ball puts, oblique sit-ups, turns on a low beam, and other exercises in sixty seconds intervals to enhance tennis-specific motor abilities and the competition efficiency of thirteen to fourteen year old female tennis players.[17] These exercises focused on training core musculature power, and balance, but the research did not test core musculature strength or endurance. This previous study determined the effects for competition efficiency of the player, or how highly ranked the player was.[17] Filipčič et al.'s research showed a significant correlation between medicine ball puts, oblique sit-ups, turns on a low beam and competition efficiency.[17] These data indicate that core training could be directly related to performance enhancement in relation to tennis specific motor abilities, such as serving and competition efficiency, but there is limited data to support these findings.

Imbalances in the core can cause inaccuracies in play, undue stress to the body, and promote injury.[2 22 44 53] Forehands and serves have players rotate in the same direction, opposite of the backhand. Tennis players serve with their dominant arm every time, hypothetically creating muscle imbalances that may cause injury and affect performance. Contrarily, Roetert et al. found symmetrical rotational strength in elite tennis players, emphasizing the need for bilateral core training.[56] Even though playing the game does not indicate that an imbalance is created, the addition of sport specific core training on one side could cause an imbalance in the core musculature. Because of this possibility, the core training program implemented in this study focused on training the entire core.

Weight Training

There have been mixed results through research regarding increases in serve velocity through weight training.[5 33 49] There have been studies that offer no evidence to suggest that core strength or core training programs help in sport performance.[3 33] There have also been studies that suggest core training programs create stability and support, increasing force output and improving time to failure.[13 57]

There are issues with weight training and its effect on serve velocity. One issue is the emergence of new serving techniques that are not biomechanically the same as traditional serving methods. The current record holder for the fastest serve is Andy Roddick, who does not use traditional serving technique. These differences in technique make it more difficult to design a weight training program designed to specifically increase serving power and velocity. However, specialized training on the core musculature should have the same effect on all serving techniques. A second issue is stability. Force output is reduced by instability by liable surfaces.[40] Research suggests that 6 weeks of training, 2 times a week on a Swiss ball significantly improves core stability.[3] By increasing core stability through core exercise, force reduction in the serving motion may diminish. Force output is reduced by instability. [3] However, research has demonstrated that recreationally trained men and women, like those in this study, exhibit significantly greater lower abdominal muscle activity while performing dumbbell chest presses unilaterally on a Swiss ball.[58] Further research is needed to determine the effects of working out on unstable surfaces.

Flexibility

Research has been conducted on the role flexibility plays on serve velocity in tennis with mixed results. Previous studies have shown that flexibility on junior players were not significantly related to any measures of either ball placement or ball velocity.[28 59] In contrast, significant results were found when similar measures were taken with college female players.[52] Kraemer reported that flexibility was significantly related to peak ball velocity in serving and found that no single variance of strength measures with ball velocities suggests that tennis skills play a large role in producing peak ball velocities in her study.[52]

One previous study found a high correlation between elbow extension and dominant wrist flexibility as being highly related to serve velocity.[43] Knudson et al.'s research looked at a five minute stretching warm-up before serving, but it did not affect the tennis serve regardless of skill level or age.[25] In the current study dominant shoulder flexibility was analyzed to determine its effect on serve velocity in intermediate level tennis players.

Internal rotation of the dominant serving arm in tennis players usually has a higher range of flexibility than in the non-dominant arm.[17 43 60] Shoulder external range of motion (ROM) is positively correlated with throwing velocity in the baseball pitch.[61] When shoulder flexibility was tested, it did not significantly predict maximum shoulder external rotation while the serve was being performed. This suggests that both flexible and inflexible players may be able to achieve the same excessive ROM during the tennis serve.[62] Similar results may also be found for internal rotation.

There has been little research determining the effects of core flexibility and its effects on serve velocity, but Filipčič et al.'s research suggests back flexibility as a tennis efficiency precursor.[17] Results suggest that a sport-specific flexibility program may be necessary for tennis players in order to promote maximum performance.[60] Thus, a stretching regime was incorporated after every core training session in this study.

Forearm and Grip Strength Training

Grip strength appears to be important in the transfer of energy from the distal lever, dominant arm, through the wrist and to the tennis racket. Force will be an extension of the arm instead of a separate entity. If the grip is not tight, forces could dissipate.[23 63]

One study suggests that wrist and forearm training does not indicate a positive correlation to increased ball velocity.[64] Twelve weeks of male high school baseball athletes underwent wrist and forearm training that did not significantly improve linear bat velocity, center of percussion velocity, or hand velocity.[64] This evidence suggests that forearm and wrist training for serving in tennis would not increase racket head speed, or lead to an increase in serve velocity. Contrarily, dominant wrist flexion and elbow flexion were found to be highly related to serve velocity in forty tournament-level state and professional tennis players.[43] Ball velocity has been shown to be correlated with grip strength.[64] This suggests that when the links in the kinetic chain are flexible and strong, instability is reduced, and force output is greater. In addition to grip strength, we analyzed several factors that could be related to serve velocity.

CHAPTER III

METHODOLOGY

Application Number: 2009X6803

The purpose of this study was to determine the effect of an eight week core training regime on serve velocity in regularly active tennis players. This study also analyzed the relationship between biometric variables that best predict serve velocity. All exercises were timed and monitored for proper and maximal effort.

Subjects

The subjects (n = 35), who completed the study, were healthy physically active adult aged student tennis players from Texas State University-San Marcos and adult aged tennis players from the local community (age = 25 ± 7 years). Volunteers were recruited from intermediate Physical Fitness and Wellness (PFW) tennis classes by granting access from the teacher(s) of record. The Personal Investigator (PI) personally discussed the research with these classes. Meetings were scheduled with the volunteers to explain the purpose and procedures of the study and request for volunteers. An informed consent form was provided to the volunteers to read and sign after explanation of the information from the PI. Participation was voluntary. For inclusion subjects must have had tournament experience. No previous musculoskeletal injury that would affect serving performance and participation during the testing and core-training were the criteria for exclusion. This information was ascertained via medical questionnaire, using the standard medical questioner for all students enrolled in PFW (Physical Fitness and Wellness) and PE (Physical Education) classes at Texas State. The participants in this study only had recreational weight training experience, if any at all. None were involved in a weight training program when they volunteered.

At time one maximal tennis serve velocity and core endurance of all participants were measured. Participants were then randomly assigned to one of two groups: the treatment group that received eight weeks of core training and the control group which received no such training.

At time two, tennis serve velocity and core endurance was again measured. It was expected that core endurance training would enhance one's maximal tennis serve velocity over and above the impact of physiological aspects contributing to tennis serve velocity measured at time one.

The measurements of core endurance at times one and two served as a manipulation check of sorts so as to determine the efficacy of the experimental treatment. That is, participation in core endurance training classes for eight weeks must show improvement in core endurance over time so as to minimize the internal threat to validity of a weakly implemented treatment effect.

Instrumentation

The pretesting for each subject was performed in one session and began at the Texas State University-San Marcos tennis courts. Serve velocity was measured using a Stalker Sport 2 radar gun (Applied Concepts Inc., Plano, TX). The rest of the measurements commenced in Jowers building. Grip strength was measured using a Hydraulic Hand Dynamometer (Fabrication Enterprises, Inc., White Plains, NY). Subjects' vertical jump was measured using a Vertec vertical jump tester (Jump USA, Sunnyvale, CA). Internal and external shoulder rotation was measured using the Biodex 4 Isokinetic Dynamometer (Biodex Medical Systems Inc., Shirley, NY). The PI conducted all measurements to ensure validity, accuracy and precision of all testing.

PROCEDURES

Pretest

This experiment collected data on participants at two points in time. At time one a host of physiological measurements was undertaken: Such measurements were non-intrusive and posed no risk of psychological harm. These measures included height, grip strength, leg strength, vertical, core plank hold time, lower back extension hold time, arm length, internal and external shoulder rotation. Max leg strength was measured with the squat by lifting the maximum weight possible for five repetitions (5RM). Upper body strength was measured with the bench press by lifting the maximum weight possible for five repetitions.

Both groups had their serve velocity measured on hard courts. Only serves within the service box counted. Before administering the test, subjects had a warm-up consisting of light groundstroke rallies and easy to moderate velocity serves, followed by all out serving at their discretion. Subjects were instructed to try to hit their fastest first serve.

Each subject underwent twenty-five service attempts, and given up to twenty seconds of rest between each serve. The top five fastest in serves were retained.

Subjects' height was measured with shoes on because they were wearing shoes while serving. Dominant arm length was measured from the acromioclavicular joint to the end of the longest finger.

After the serving subjects were taken to the Texas State University-San Marcos Athletic Training Lab to have their plank and lower back time assessed. These core endurance tests were performed on an athletic training table. Subjects began the plank lying chest down against the floor with their elbows directly under their shoulders, and toes under their heels. They were then instructed to raise their body off of the ground, keeping their core tight, and keeping their body straight. As soon as they raised their body off of the ground, timing started. When the subjects were no longer able to keep their body in a straight line, timing stopped. The lower back endurance was tested with the subjects lying with their torso off of the athletic training table with the hips at the edge of the table. Their ankles were held to keep the lower half of their body on the table. Subjects were instructed to fold their arms across their chest and extend their lower back until their torso was equal with their lower body. Timing began as soon as the subjects became straight. Timing stopped when the subjects were no longer able to hold their torso equal to their lower body.

Subjects' dominant arm was measured on the Biodex for flexibility. After the subject was strapped into the Biodex, he or she was instructed to internally rotate their dominant arm as far as they could without their shoulder coming off of the chair. External rotation was assessed in the same manner.

Next, subjects were taken to the Texas State University-San Marcos exercise physiology lab to test their grip strength and vertical. Upon completion they were taken to weight room to have their bench and squat five repetition max assessed. Both lifts were demonstrated to show proper form. Subjects were spotted during each lift. Subjects increased weight until the 5RM was determined, or increased to a weight where five repetitions could not be performed.

After the pretest was administered to the subjects, one group returned to their daily routine without further testing until after the eight week period. They then returned and had the initial test administered and checked for differences in velocity. During the eight week period, they were asked to refrain from any core training exercise unless they were previously engaged in it before the study.

The experimental group had a core training program outlined and supervised by the PI. The subjects underwent two core training workout sessions a week with rest days between them, and continued all other activity as normal, for eight weeks. Workouts lasted no longer than one hour, including stretching.

Core Training

Subjects were only given five seconds of rest between each set and each exercise. Having five seconds of rest seemed to help the subjects recover, and may have also kept workout sessions on a fast enough pace to exert the core musculature in the more advanced athletes.

The first two weeks of core training focused on stability and endurance. Core stability has been shown to improve force output and decrease the risk of injury, making it an ideal starting place.[32 47 53] Weeks three and four were progressively more difficult, including more sport specific variations of the exercises from the first two weeks .Weeks five and six incorporated more explosion and power based exercises that are biomechanically similar to the tennis serve. The final two weeks took the similar exercises from weeks five and six and added external resistance to the exercises. Weights lifted varied on the level of the subjects' performance. There was also a five-ten minute stretching time for the core muscles used during training. Stretches were performed twenty to thirty seconds per exercise for two to four reps.

The experimental group had a core training program outlined and supervised. The subjects had two core training workout days a week with rest days between them, but continued all other activity as normal. Workouts lasted no longer than one hour including stretching. A more in-depth description of the exercises has been provided below.

<u>Weeks One and Two</u>

The first two weeks of core training focused on stability and endurance. Core stability has been shown to improve force output and decrease the risk of injury, making it an ideal starting place. [32 47 53]

Planks were used for endurance and stability as they incorporated all of the core musculature.[50] Subjects began by laying face down on the floor with their elbows under their shoulders, and pointed their toes into the ground. From here they lifted their body off of the ground keeping their back in good alignment, spine in neutral position, and bellybutton pulled in towards their spine. Subjects completed three sets of planks for thirty seconds with five seconds of rest between each set.

Crunches were then administered. Crunches primarily focus on the abdominal musculature.[40] Subjects began lying on the floor, finger tips at the temples, with knees bent to reduce lower back stress. They then flexed their abdominal muscles to lift their torso until their shoulder blades came off of the ground. After slightly pausing in this position, they returned to the ground. Subjects again completed three sets for thirty seconds with five seconds between each set.

The next exercise was the leg raise. Subjects were instructed to lay their hands down next their sides, with the palms down. They then raised their legs off the ground and into the air to as close to a 90 degree angle as they could, and then back down to the ground. They continued this motion until thirty seconds were up. That was one set. Five seconds of rest was given, and they started again. This was repeated for three sets.

The final workout for weeks one and two were bird dogs. Bird dogs, like the plank, work the entire core.[50] Subjects started in table top position with shoulders directly over the wrists, and hips directly over the knees. Subjects were instructed to keep their belly button pulled in towards their spine, and to keep their head and back flat to reduce risk of injury. Subjects were then informed to raise their right arm straight out in front of their body while simultaneously raising their opposite leg straight out behind themselves. Subjects performed three sets of thirty seconds with five seconds of rest between each set.

Weeks Three and Four

Weeks three and four were progressively more difficult. The same exercises were kept from the previous weeks and some new ones were added.

The first exercise was again the plank, but only two sets were completed instead of three in the third week to reduce soreness. In the fourth week subjects performed three sets of crunches again. Instead of doing a third set in week three, subjects were instructed to now do a plank variation. Subjects started in the same position as before, but alternated bringing their knees in towards their elbow, as close to touching their elbows with their knees as possible. They were instructed to exhale as they brought their knees in, similar to exhaling while serving. This variation of the plank better mimics the twisting movement of serving than the normal plank.

The third exercise was the crunch, followed by sit-ups. Sit-ups have a larger range of motion than crunches and involve hip flexors; making them a more ideal choice than crunches after stability has been established. Because everyone has a different skeletal system, it was up to the subjects to make their own decision on whether or not to have bent knees, or straight legs. Keeping their back straight and core tight, they lifted their torso off of the ground and into the air, bringing their elbows towards their knees, and slightly paused there concentrating on abdominal contraction. Afterwards they returned the torso back down to the ground. This continued for three sets for thirty seconds with five seconds of rest in between. As with the planks, crunches were done for two sets in week three, and then increased back to three sets in week four.

The fifth exercise was the leg raise, but only two sets were completed in week three. The third set was replaced with hip thrusters, a variation of the leg raises. The only difference in form is that when the legs are up in a 90 degree angle, the subjects lifted their hips off the ground and into the air before returning their legs back to the ground. Again, three sets of thirty seconds were completed with five seconds of rest between each set.

The seventh exercise was again bird dogs. These were followed by back extensions. Back extensions work all of the back musculature in the core, but focus on the lower back. Subjects, depending on their level of performance put their feet on the ground (more difficult) or against a wall for more support. Subjects are instructed to lay with their stomach down, back straight, with finger tips on their temples. They then extended their back to rise off of the ground. Hands could have been dropped to the sides to make this exercise easier. The movements incorporated with back extensions are similar to the windup phase in serving.

Weeks Five and Six

Explosion and power based exercises were brought into the workouts to closely mimic the demands of the tennis serve.[51] Medicine balls were included as they allow for freedom of movement and may mimic the power needed in the tennis serve.[65]Planks and crunches were kept in as the first two exercises to warm the subjects up.

Sit-ups were replaced with suitcase crunches as they are even more biomechanically similar to serving. Subjects started on the ground in the crunch position with legs extended into the air in a 90-45 degree angle. They crunched their upper body up while trying to touch their right hand to their left foot. During each rep they alternated hands to feet. They performed three sets of thirty seconds with five seconds of rest between sets.

The next exercise was sit-ups to medicine ball throws against a wall. This exercise tried to simulate the power and explosion of the serve in the contact to follow through phases. Subjects started by lying on the floor with their arms in front of their face holding a medicine ball. Subjects were reminded to keep neutral back posture. They crunched their body in the same manner as performing a sit-up and threw the medicine ball to the wall. After the ball bounced off of the wall, subjects caught the ball and returned back to the starting position. This was continued for thirty seconds, with five seconds of rest, for three sets.

The fourth exercise performed was the bicycle crunch. Subjects began lying on the ground with their legs just off of the ground with the finger tips on the head. Subjects then brought their right elbow to their left knee, paused, and then alternated elbow to knee. This was done in a continuous motion. Bicycle crunches incorporate the natural twisting of the core musculature, activating the core musculature with an emphasis on the oblique's. This exercise was conducted for thirty seconds per set for three sets, with five seconds of rest between sets.

The fifth exercise performed was medicine ball cross body tosses. This exercise was performed standing perpendicular, one to two feet from a wall. Subjects twisted at their core keeping their hips stable, and threw the medicine ball into the wall at chest level. Subjects then caught the ball and repeated this motion for thirty seconds. Subjects alternated sides between sets, three sets per side, with five seconds of rest between sides. This exercise worked the abs, obliques, lower back, and also incorporates the same rotation found in the tennis serve. Subjects were reminded on all throws to keep their backs straight. In week six, three sets of leg raises with hip thrusters were added.

The final exercise performed was back extensions.

Weeks Seven and Eight

In the final two weeks subjects again performed three warm up sets of planks and crunches, with the addition of medicine balls to the crunches.

The third exercise was suitcase crunches using medicine balls. Weights varied based on subjects' strength. The subjects' started in the original position, legs in the air, and held a medicine ball at their chest. The subjects flexed upward toward their opposite foot, and brought the medicine ball from their chest toward their foot, then came back to the starting position with the medicine ball at their chest and repeated. This lasted thirty seconds for three sets with five seconds between sets.

The fourth exercise was sit-ups to medicine ball throws, the same as in the previous weeks, but for forty-five seconds. Weight of the medicine ball was dependent upon the subjects' strength.

The next exercises were three sets of standing medicine ball cross body tosses for thirty seconds, followed by leg raises with hip thrusters for fourty-five seconds.

The following exercise was seated medicine ball torso twists. Subjects started by sitting on the floor their legs out in front and their back at a 45 degree angle and a medicine ball in their lap. To start, subjects raised their feet one to two inches off of the floor and grasped the medicine ball with both hands. They then rotated their torso to one side with the medicine ball in hand, as far back as they could, touching the ball to the ground. Subjects then returned to the starting position and alternated sides. Seated torso twists work the obliques from moving the body from side to side, and keep tension in the back by keeping it off of the ground. They also work the upper and lower abdominals by keeping the legs off of the ground, creating more demands for stability.[3 8 41 58 66]

The final exercise performed were three sets of back extensions for forty-five seconds. Times were increased and medicine balls were included to progress the difficulty of exercises.

Cool Down and Stretch

After every workout session a stretching and cool down session was performed. This session included timed stretching posses for the core musculature. The first stretch performed was the yoga cobra pose. Subjects started by lying face down on the floor in push up position, hands directly under the shoulders. They then pushed their torso off of the ground leaving their knees and feet touching the ground. Subjects were instructed to breathe deeply and try to release the tension in the abdominal area. This position was held for thirty seconds with ten seconds of rest, and repeated once more.

The next stretch was the child's pose. This stretch aims to reduce tension in the lower back, hips, and neck. Subjects began by kneeling, toes together, with their knees at least hip distance apart. They then leaned forward with arms over head, chest over knees, and draped their body over the thighs so that their forehead rested on the floor (or as close as possible, depending on subject flexibility). This may also be performed with hands pulled back towards the toes. Subjects were instructed to breathe deeply and relax while focusing on releasing any tension that might be in the back, neck, or hips. This pose was held twice for one minute with fifteen seconds of rest in between.

The final stretch focused on the obliques and hip flexors. Subjects started in the lunge position, front foot under their outstretched knee at 90 degrees keeping the opposite knee on the floor. They were instructed to tilt their pelvis forward until they felt mild tension in the hips. They then raised the opposite arm of the outstretched knee overhead. This was held for twenty seconds, for a total of six sets, alternating legs and arms between sets.

Posttest

After the eighth training week, both groups returned and performed the posttest. This included serve velocity measures and core endurance measures.

Statistical Analysis

The effect of the core-training program was determined by a comparison of plank and lower back times (pretest versus posttest trials). The impact of being in the treatment group experiencing core strength training is predicted to improve tennis serve velocity. The data collection technique is a randomized pretest posttest control group experiment. The analysis was conducted with multiple regression. The independent variables analyzed were tennis serve velocity at time one, the treatment (training versus control groups), and the biometric measures at time one. The dependent variable was tennis serve velocity at time two.

Manipulation Check

The manipulation in this experiment was comprised of eight weeks of core strength training for the treatment group. The control group, of course, did not receive such core strength training. A manipulation check was performed using the 17 intermediate tennis players enrolled in Texas State University Intermediate PFW tennis classes and Austin league tennis players randomly assigned to the treatment group.

The efficacy of the manipulation was measured via changes in plank endurance and lower back endurance which was measured by subtracting the time one score from the time two score (change score). A *t*-test was used to examine whether or not the two groups, treatment and control, had a different change score. For the plank endurance test, the control group's mean change score was 22.78. The treatment group's change (mean score) was 51.85. The *t*-test of whether or not those two change scores are significantly different was -2.93 with 33 degrees of freedom ($p <.01$).

The other manipulation check involved the measurement of lower back endurance. The change in lower back endurance was computed by subtracting the time one lower back score from the time two lower back score. The change score for the control group was 13.95 and for the treatment group it was 32.56. The test of whether or not those two scores are significantly different resulted in a *t*-score of -1.58 with 33 degrees of freedom ($p > .05$, and therefore non-significant). Thus, while the difference was pronounced, it was not significantly different from 0. This may be due to the lack of statistical power as a result of a small sample size.

With these manipulation check results in mind, I therefore turn to an analysis of the experiment.

CHAPTER IV

RESULTS

Correlation Results

The experimental treatment group was coded as 1, and the control group was coded as 0. The manipulated variable was therefore membership in the treatment group with the dependent variable being serve velocity (mph) at time two. Other measured variables included vertical jump (in), grip strength (lbs), squat (lbs), bench (lbs), external rotation (degrees), internal rotation (degrees), height (in), arm length (in) from the acromioclavicular joint to the finger tips, and gender, all of which serve as covariates in the multiple regression analysis that follows.

Treatment Group Correlations

There were 17 subjects in the experimental group. In this group, the measured variable of the vertical jump had a mean of 19.03 inches with a standard deviation of 4.79. The vertical jump was significantly correlated with grip strength ($r = .820$, $p < .001$), squat ($r = .71$, $p < .01$), bench ($r = .71$, $p < .01$), height ($r = .61$, $p < .05$), change in lower back strength from time one to time two ($r = .56$, $p < .05$), time one speed ($r = .73$, $p < .01$), time two speed ($r = .81$, $p < .001$), and negatively correlated with external rotation ($r = -.24$, $p < .01$). Grip strength had a mean of 85.88 pounds with a standard deviation of 25. 08. Grip strength was significantly correlated with squat ($r = .63$, $p < .01$), bench ($r = .77, p < .001$), height ($r = .71, p < .01$), change in plank strength from time one to time two ($r = .55, p < .05$), change in lower back strength from time one to time two ($r = .52, p < .05$), time one speed ($r = .68, p < .01$), time two speed ($r = .79, p < .001$), and negatively correlated with external rotation ($r = -.51, p < .05$). Squat had a mean of 137.94 pounds with a standard deviation of 54.6. Squat was significantly correlated with bench ($r = .82, p < .001$), height ($r = .6, p < .05$), time one speed ($r = .66, p < .01$), and time two speed ($r = .72, p < .01$). Bench had a mean of 114.12 pounds with a standard deviation of 52.54. Bench was significantly correlated with height ($r = .66, p <.01$), time one speed ($r = .80, p < .001$), time two speed ($r = .85, p < .001$), and negatively correlated with external rotation ($r = -.61, p < .01$). External rotation had a mean of 143.53 degrees with a standard deviation of 11.16. External rotation was significantly negatively correlated with arm length ($r = -.5, p < .05$). Internal rotation had a mean of 82 degrees with a standard deviation of 7.95. Height had a mean of 69.92 inches with a standard deviation of 4.68. Height was significantly correlated with arm length ($r = .71, p < .01$), change in plank strength from time one to time two ($r = .59, p < .05$), time one speed ($r = .61, p < .01$), and time two speed ($r = .63, p <.01$). Arm length had a mean of 28.30 inches with a standard deviation of 2.7. Time one plank had a mean of 41.44 seconds, with a standard deviation of 25.41. Time one plank was significantly correlated with time two plank ($r = .55, p < .05$), and time two lower back ($r = .65, p < .01$). Time two plank had a mean of 93.3 seconds with a standard deviation of 26.12. Time two plank was significantly correlated with change in plank strength from time one to time two ($r = .5, p < .05$). Time one lower back had a mean of 62.66 seconds with a standard deviation of 42.88. Time one lower back was significantly correlated time two lower back ($r = .64, p < .01$). Time two lower back had a mean of 95.22 seconds with a standard deviation of 43.49. Change in plank strength from time one to time two had a mean of 51.8five seconds with a standard deviation of 24.48. Change in lower back strength from time one to time two had a mean of 32.59 seconds with a standard deviation of 36.85. Time one speed had a mean of 84.1 seconds with a standard deviation of 14.62. Time one speed was significantly correlated with time two speed ($r = .97, p < .001$). Time two speed had a mean of 86.26 seconds with a standard deviation of 16.28. See Table 1 for these statistics.

Control Group Correlations

There were 18 subjects in the control group. In this group, the measured variable of the vertical jump had a mean of 18.64 inches with a standard deviation of 4.45. The vertical jump was significantly correlated with grip strength ($r = .55, p < .05$), squat ($r = .67, p < .01$), bench ($r = .08, p < .001$), time one speed ($r = .65, p < .01$), time two speed ($r = .56, p < .05$). Grip strength had a mean of 89 pounds with a standard deviation of 28.8. Grip strength was significantly correlated with bench ($r = .58, p < .05$), time one speed ($r = .63, p < .01$), and time two speed ($r = .61, p < .01$). Squat had a mean of 135 pounds with a standard deviation of 61.53. Squat was significantly correlated with bench ($r = .89, p < .001$), and time one plank ($r = .59, p < .05$). Bench had a mean of 108.89 pounds with a standard deviation of 59.08. Bench was significantly correlated with height ($r = .49, p < .05$), time one speed ($r = .64, p < .01$), and time two speed ($r = .65, p < .01$). External rotation had a mean of 145.17 degrees with a standard deviation of 9.36. Internal rotation had a mean of 79.89 degrees with a standard deviation of 11.02 Internal rotation was significantly correlated with time one plank ($r = .49, p < .05$). Height had a mean of

68.61 inches with a standard deviation of 4.16. Height was significantly correlated with arm length ($r = .83, p < .001$), time one speed ($r = .58, p < .05$), and time two speed ($r = .72, p < .01$). Arm length had a mean of 28.71 inches with a standard deviation of 1.79. Arm length was significantly correlated with time one speed ($r = .49, p < .05$), time two speed ($r = .66, p < .01$). Time one plank had a mean of 59.62 seconds with a standard deviation of 26.23. Time one plank was significantly correlated with time two plank ($r = .56, p < .05$). Time two plank had a mean of 82.41 seconds with a standard deviation of39.72. Time two plank was significantly correlated with time two lower back ($r = .55, p < .05$), and change in plank strength from time one to time two ($r = .76, p < .001$). Time one lower back had a mean of 73.9 seconds, with a standard deviation of 40.02. Time one lower back was significantly correlated time two lower back ($r = .64, p <.01$). Time two lower back had a mean of 87.86 seconds with a standard deviation of 49.87. Time two lower back was significantly correlated with change in plank strength from time one to time two ($r = .73, p <.01$), and change in lower back strength from time one to time two ($r = .6, p < .01$). Change in plank strength from time one to time two had a mean of 22.78 seconds with a standard deviation of 33.23. Change in plank strength from time one to time two was significantly correlated with change in lower back strength from time one to time two ($r = .55, p < .05$). Change in lower back strength from time one to time two had a mean of 13.96 second with a standard deviation of 32.71. Time one speed had a mean of 85.06 mph. with a standard deviation of 18.65. Time one speed was significantly correlated with time two speed ($r = .95, p < .001$). Time two speed had a mean of 85.13 with a standard deviation of 17.04. See Table 2 for these statistics.

Complete Sample Correlations

There were 35 total subjects in this study. In the analysis of all of participants, gender had a mean of .6 with a standard deviation of .5. Gender was significantly correlated with the vertical jump ($r = .64, p < .001$), grip strength ($r = .66, p < .001$), squat ($r = .59, p < .001$), bench (r = .76, $p <.001$), height (r = .8, $p < .001$), arm length ($r = .61, p < .001$), time one speed ($r = .73, p < .001$), and time two speed ($r = .82, p < .001$). The vertical jump had a mean of 18.83 inches and a standard deviation of 4.55. The vertical jump was significantly correlated with grip strength ($r = .67, p < .001$), squat ($r = .69, p < .001$), bench ($r = .76, p < .001$), height ($r = .48, p < .01$), time one speed ($r = .67, p < .001$), time two speed ($r = .68, p < .001$). Grip strength had a mean of 87.49 pounds with a standard deviation of 26.71. Grip strength was significantly correlated with squat ($r = .45, p < .01$), bench ($r = .65, p < .001$), height ($r = .56, p < .001$), arm length ($r = .39, p < .05$), time one speed ($r = .65, p < .001$) time two speed ($r = .69, p < .001$). Squat had a mean of 136.43 pounds with a standard deviation of 57.43. Squat was significantly correlated with bench ($r = .86, p < .001$), height ($r = .42, p < .05$), time one speed ($r = .47, p < .01$), time two speed ($r = .52, p < .01$). Bench had a mean of 111.43 pounds with a standard deviation of 55.23. Bench was significantly correlated with height ($r = .57, p < .001$), arm length ($r = .41, p < .05$), time one speed ($r =.7, p < .001$), time two speed ($r = .74, p < .001$), and negatively correlated with time one lower back ($r = -.36, p < .05$). External rotation had a mean of 144.37 degrees with a standard deviation of 10.16. External rotation was significantly correlated with time one lower back ($r = .44, p < .01$), and negatively correlated with change in plank strength from time one to time two ($r = -.35, p < .05$). Internal rotation had a mean of 80.91 degrees with a standard deviation of 9.57. Height had a mean of 69.25 inches with a standard deviation of 4.4. Height was significantly correlated with arm length ($r = .72, p < .001$), time one speed ($r = .57, p < .001$), and time two speed ($r = .67, p < .001$). Arm length had a mean of 28.51 inches with a standard deviation of 2.25. Arm length was significantly correlated with time one speed ($r = .36, p < .05$), and time two speed ($r = .45, p < .01$). Time one plank had a mean of 50.79 seconds with a standard deviation of 27.07. Time one plank was significantly correlated with time two plank ($r = .45, p < .01$), and negatively correlated with experimental group ($r = -34, p < .05$) and change in plank strength from time one to time two ($r = -.37, p < .05$). Time two plank had a mean of 87.7 seconds with a standard deviation of 33.77. Time two plank was significantly correlated with time two lower back ($r = .5, p < .01$), change in plank strength from time one to time two ($r = .67, p < .001$), and change in lower back strength from time one to time two ($r = .38, p < .05$). Time one lower back had a mean of 68.44 seconds with a standard deviation of 41.22. Time two lower back had a mean of 91.4five seconds with a standard deviation of 46.34. Time two lower back was significantly correlated with change in plank strength from time one to time two ($r = .36, p < .05$) and change in lower back strength from time one to time two ($r = .52, p < .01$). Change in plank strength from time one to time two had a mean of 36.9 seconds with a standard deviation of 32.43. Change in plank strength from time one to time two was significantly correlated with change in lower back strength from time one to time two ($r = .37, p < .05$). Change in lower back strength from time one to time two had a mean of 22.99 seconds with a standard deviation of 35.59. Time one speed had a mean of 84.59 mph with a standard deviation of 16.57. Time one speed was significantly correlated with time two speed ($r = .95, p < .001$). Time two speed had a mean of 85.68 mph with a standard deviation of 16.44. See Table 3 for these statistics.

Regression Results

Hierarchical regression was used to examine the hypothesis. In step one of the regression analysis, time one speed was examined. The F-score was 325.64, with $df_1 = 1$ and $df_2 = 33, p < .001$. The Beta weight was $.95, p < .001$. $R^2 = .91$, meaning 91% of the variability in time two speed is explained by the independent variable.

In step two of the regression analyses, the overall F-score was 165.72 with $df_1 = 2$ and $df_2 = 32$ ($p < .001$). The Beta weight for the dummy coded variable of the Experimental Group was .06 ($p > .05$) and for Time one Tennis Serve Velocity it was .96 ($p < .001$). Thus, the overall equation resulted in $R^2 =.91$, meaning 91% of the variability in time two speed is explained by the two independent variables. Thus, the primary hypothesis of this experiment was not supported. In other words, being in the experimental group was not related to time two speed (dependent variable).

In step three of the regression analyses, all of the independent variables were entered into the equation. The overall F-score was 43.74 with $df_1 = 11$ and $df_2 = 23$ ($p < .001$). Thus, R^2 was .95; meaning 95% of variability in the dependent variable was explained by the independent variables. The Beta weight for time one speed was $.75, p < .001$. The Beta weight for Experimental Group was $.05, p >.05$. Gender had a Beta weight of $.27, p < .05$. The beta weight for the vertical jump was $.02, p < .05$. Grip strength had a Beta weight of $.02, p > .05$. Squat had a Beta weight of $.07, p > .05$. Bench had a Beta weight of $-.12, p > .05$. External rotation had a Beta weight of $-.11, p <.05$. Internal rotation had a Beta weight of -.01, $p > .05$. Height had a Beta weight of .04, $p > .05$. Arm Length had a Beta weight of -.03, $p > .05$. Only gender ($p < .05$), time one speed ($p < .001$), and external rotation ($p < .05$) were statistically significant predictors of the dependent variable. See Table 4 for the regression results.

<u>Analysis of Subject Mortality</u>

Among the many threats to the internal validity of an experiment is that of subject mortality.[67] To alleviate this concern an analysis of differences between those who completed the experiment and those who did not must be undertaken. Several *t*-tests were conducted to examine differences between these two groups. Assumptions of the *t*-test are that there are similar sample sizes in both groups and that the variances of the scores in both groups are similar. Because a visual inspection of the standard deviations in both groups (dropped and completed) showed potentially vast differences and because the sample sizes for the groups were vastly different, a likely contributing factor to the unequal variances in that there were only 3 people who dropped out and 35 who completed this experiment, *t*-tests were conducted where unequal variances are not assumed. This relaxation of the critical assumption makes adjustments to the ratio involved in the calculation of the *t*-score.

The *t*-test assuming unequal variance for the vertical leap was significant, with $t = 2.64$ ($p < .05$). The group who stayed in had a mean vertical leap of 18.83 inches. The subjects that dropped out had a mean group score of 15.5 inches. The *t*-test assuming unequal variance for internal rotation was significant, at $t = .3.64$ ($p < .01$). The group who stayed in had a mean internal rotation of 80.91 degrees. The subjects that dropped out had a mean score of 74.0 degrees. None of the other variables were significantly different for the two groups.

Table 1 Correlations, Means, Standard Deviations for Experimental Treatment Group

Variable	*Mean*	*SD*	1	2	3	4	5	6
1. Gender	.59	.51						
2. Vertical	19.03	4.79	.75**					
3 Grip Strength	85.88	25.08	.76**	.82**				
4. Squat	137.94	54.60	.67**	.71**	.63**			
5. Bench	114.12	52.54	.78**	.71**	.77**	.82**		
6. External Rotation	143.53	11.16	-.49*	-.24	-.51*	-.26	-.61**	
7. Internal Rotation	82.00	7.95	.17	.17	.15	.11	.17	-.20
8. Height	69.92	4.68	.85**	.61*	.71**	.60*	.66**	-.46
9. Arm Length	28.30	2.70	.53*	.38	.40	.42	.43	-.50*
10. Time One Plank Time	41.44	25.41	-.24	-.17	-.07	-.03	-.03	.19
11. Time Two Plank Time	93.30	26.12	.20	.26	.45	.25	.40	-.18
12. Time One Lower Back	62.66	42.88	-.33	-.24	-.28	-.07	-.35	.46
13. Time Two Lower Back	95.22	43.49	.05	.24	.16	.26	.04	.42
14. Time One Speed[a]	84.10	14.62	.80**	.73**	.68**	.66**	.80**	-.33
15. Time Two Speed[b]	86.26	16.28	.84**	.81**	.79**	.72**	.85**	-.42

Table 1 (Continued)

	7	8	9	10	11	12	13	14
7.								
8.	.21							
9.	.02	.71**						
10.	-.22	-.30	-.47					
11.	.16	.26	-.11	.55*				
12.	.07	-.20	.30	.42	.21			
13.	-.14	.05	-.32	.65**	.41	.64**		
14.	.15	.61**	.29	-.04	.36	-.23	.03	
15.	.19	.63**	.31	-.09	.36	-.32	.01	.97***

Note. $n = 17$

[a] Time One Tennis Serve Velocity

[b] Time Two Tennis Serve Velocity

*$p < .05$

**$p < .01$

***$p < .001$.

Table 2 Correlations, Means, Standard Deviations for Control Group

Variable	*Mean*	*SD*	1	2	3	4	5	6
1. Gender	.61	.50						
2. Vertical	19.03	4.79	.50*					
3. Grip Strength	85.88	25.08	.58*	.55*				
4. Squat	137.94	54.60	.52*	.67**	.33			
5. Bench	114.12	52.54	.75**	.80**	.58*	.89**		
6. External Rotation	143.53	11.16	.19	.00	-.04	-.06	-.04	
7. Internal Rotation	82.00	7.95	.12	.21	-.25	.43	.30	.20
8. Height	69.92	4.68	.77**	.34	.46	.26	.49*	.07
9. Arm Length	28.30	2.70	.77**	.24	.41	.22	.43	.11
10. Time One Plank Time	41.44	25.41	.18	.19	.05	.59**	.40	.21
11. Time Two Plank Time	93.30	26.12	-.12	-.03	-.17	.32	.11	-.14
12. Time One Lower Back	62.66	42.88	-.27	-.13	-.18	-.35	-.36	.39
13. Time Two Lower Back	95.22	43.49	-.33	-.40	-.35	-.35	-.44	.06
14. Time One Speed[a]	84.10	14.62	.69**	.65**	.63**	.35	.64**	-.18
15. Time Two Speed[b]	86.26	16.28	.79**	.56*	.61**	.35	.65**	-.22

Table 2 (Continued)

	7	8	9	10	11	12	13	14
7.								
8.	-.01							
9.	-.09	.83**						
10.	.49*	.03	.17					
11.	.21	-.00	.15	.56*				
12.	-.21	-.06	-.06	-.11	.31			
13.	-.27	-.06	.08	-.09	.55*	.76**		
14.	.00	.58*	.49*	-.10	-.29	-.30	-.36	
15.	-.03	.72**	.66**	-.10	-.16	-.31	-.28	.95**

Note. $n = 18$

[a] Time One Tennis Serve Velocity

[b] Time Two Tennis Serve Velocity

*$p < .05$

**$p < .01$.

Table 3 Correlations, Means, Standard Deviations for Complete Sample

Variable	*Mean*	*SD*	1	2	3	4	5	6
1. Experimental Group	.49	.51						
2. Gender	.60	.50	-.02					
3. Vertical	18.83	4.55	.04	.63**				
4. Grip Strength	87.49	26.71	-.06	.66**	.67**			
5. Squat	136.43	57.43	.03	.59**	.69**	.45**		
6. Bench	111.43	55.23	.05	.76**	.76**	.65**	.86**	
7. External Rotation	144.37	10.16	-.08	-.17	-.13	-.26	-.16	-.32
8. Internal Rotation	80.91	9.60	.11	.14	.19	-.11	.31	.26
9. Height	69.25	4.40	.15	.80**	.48**	.56**	.42*	.57**
10. Arm Length	28.51	2.25	-.09	.61**	.32	.39*	.32	.41*
11. Time One Plank Time	50.71	27.07	-.34*	-.01	-.00	.02	.29	.18
12. Time Two Plank Time	87.70	33.77	.16	.01	.09	.04	.29	.22
13. Time One Lower Back	68.44	41.21	-.14	-.29	-.19	-.22	-.22	-.36*
14. Time Two Lower Back	91.44	46.34	.08	-.16	-.10	-.14	-.09	-.23
15. Time One Speed[a]	84.59	16.57	-.03	.73**	.67**	.65**	.47**	.70**
16. Time Two Speed[c]	85.68	16.44	.04	.82**	.68**	.69**	.52**	.74**

Table 3 (Continued)

	7	8	9	10	11	12	13	14	15
8.	.01								
9.	-.23	.10							
10.	-.26	-.04	.72**						
11.	.21	.15	-.18	-.15					
12.	-.16	.21	.13	.01	.45**				
13.	.44**	-.10	-.15	-.19	.19	.24			
14.	.23	-.21	.01	-.14	.20	.50**	.68*		
15.	-.24	.05	.57**	.36*	-.06	-.09	-.26	-.21	
16.	-.32	.06	.67**	.45**	-.10	.04	-.31	-.15	.95**

Note. $n = 35$

[a] Time One Tennis Serve Velocity

[b] Time Two Tennis Serve Velocity[c]

$*p < .05$

$**p < .01$

Table 4 Hierarchical Regression Results for Time Two Serve Velocity as the Dependent Variable

	Time Two Serve Velocity								
	Step One (Control)			Step Two			Step Three		
Variable	B	s.e.	β	B	s.e.	β	B	s.e.	β
Constant	5.73	4.51		4.58	4.58		39.55	27.01	
Time 1 Speed	.95	.05	.95***	.95	.05	.96***	.74	.08	.75***
ExpGroup[a]				2.04	1.70	.06	1.66	1.62	.05
Gender[b]							8.90	3.58	.27*
Vertical							.07	.29	.02
Grip Strength							.01	.05	.02
Squat							.02	.03	.07
Bench							-.04	.04	-.12
External Rotation							-.18	.09	-.11*
Internal Rotation							-.02	.09	-.01
Height							.14	.36	.04
Arm Length							-.21	.52	-.03
F-score $_{(df1, df2)}$	$325.64_{(1, 33)}$ ***			$165.72_{(2, 32)}$***			$43.74_{(11, 23)}$***		
Δ F-score $_{(df1, df2)}$				$1.44_{(1, 32)}$			$2.38_{(9, 23)}$ *		
R^2	.91			.91			.95		
Δ R^2				.00			.04		

Table 4 (Continued)

Adjusted R^2	.91	.91	.93

[a]Coded as 0 = control group, 1 = treatment group.

[b]Coded as 0 = female, 1 = male

*$p < .05$

***$p < .001$

CHAPTER V

DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

Significant Relationships for Subject Mortality

By and large those who dropped out of the study showed only modest differences from those who remained in the study. Those who dropped out had less internal rotation and had a lower vertical leap than those who completed the experiment. However, these two results could both be due to the impact of gender. That is, females generally have lower vertical leaps and less internal rotation than do males. In this study two females and one male failed to complete the experiment after undergoing various biometric measurements at time one. Of course time two scores (plank and lower back endurance and tennis serve velocity) were not recorded for those who dropped out so it is impossible to examine the difference in these three scores between those who dropped out and those who remained in the study. There is little reason to believe that these three subjects who failed to complete the experiment were any different from those who, in fact, completed it given that only two of the numerous biometric tests were significantly different for the two groups. With these differences in mind, I now turn to an examination of the correlation between the variables in this study.

Discussion of Correlations

Variable Correlations for Entire Sample

Of most interest among the numerous correlations were the bivariate relationships between all of the predictor variables and the dependent variable (time two serve velocity). The strongest bivariate relationship with the dependent variable was gender (where $r = .82$). The biometric relationships between bench press strength ($r = .76$) and squat strength ($r = .59$) were both significantly correlated with time two tennis serve velocity, supporting research that total body strength training for intermediate level tennis players wanting to improve serve velocity should be implemented into workout routines for athletes.[35 36 39 43 51] This also supports the idea that stronger links in the kinetic chain may transfer energy through the body.[1 16 22] The vertical leap was also correlated with time two tennis serve velocity ($r = .64$). While this may be true, this is the first known study to analyze the correlation between the vertical jump and serve velocity. Grip strength was significantly correlated with time two tennis serve velocity speed ($r = .66$), supporting research that grip strength is positively correlated with ball velocity in tennis and baseball.[43 64] Height ($r = .56$) and arm length ($r = .39$) were both significantly correlated with time two tennis serve velocity. This correlation supports a higher contact point with the tennis ball creates a greater angle and direct line to hit the ball down into the service box. In addition, longer levers increase linear velocity of the racket while rotating at the same angular velocity. Aside from these biometric measures, time one speed was also significantly correlated with time two tennis serve velocity. The correlation was nearly perfect ($r = .95$), which explains that overall, time one tennis serve velocity was the greatest predictor for time two tennis serve velocity at the bivariate level in this study.

Among the non-significant bivariate correlations for the entire sample was the relationship between membership in the experimental group and the dependent variable of time two tennis serve velocity. Thus there is no support for the main hypothesis that eight weeks of core training would increase tennis serve velocity.

External and internal range of motion were also not significantly correlated with time two serve velocity, supporting previous research on junior players that flexibility is not related to ball velocity in tennis.[28 59] Yet, there is research suggesting that the act of throwing is greatly amplified by range of motion, where as the range of motion test in a non-dynamic movement setting may not be a valid measure of dynamic flexion on the ability of the shoulder joint to create shoulder flexibility in a dynamic setting.[62]

None of the core endurance training (time one plank or time two plank endurance, time one or time two lower back) were significantly correlated with time two tennis serve velocity, suggesting that core strength has a minimal effect on serve velocity in this study. It appears that core training alone does not significantly increase serve velocity in intermediate tennis players, but it is possible that it may in beginners. It is also possible that core training added to upper and lower body strength training may be beneficial. Core plank endurance changes from time one to time two did significantly increase ($p <$ .01), but were unable to transfer the improved core adaptations through the kinetic chain. This may be due to lack of improvement in the shoulder joint.

Variable Correlations for the Treatment Group

In the treatment group (analyzed separate from the control group), the strongest bivariate relationships with the dependent variable of time two tennis serve velocity were bench strength ($r = .85$), gender ($r = .84$), vertical leap ($r = .81$), grip strength ($r = .79$), squat ($r = .72$), and height ($r = .63$). Nevertheless, time one tennis serve velocity was still the most significantly correlated predictor with time two tennis serve velocity ($r = .97$). Thus in the treatment group, tennis serve velocity at times one and two were almost perfectly correlated.

Variable Correlations for the Control Group

The strongest biometric relationships for the control group (analyzed separate from the treatment group) with the dependent variable of time two tennis serve velocity were gender ($r = .79$), height ($r = .72$), arm length ($r = .66$), bench strength ($r = .65$), grip strength ($r = .61$), and vertical leap ($r = .56$). However, time one tennis serve velocity once again had the highest correlation with time two tennis serve velocity ($r = .95$). As in the treatment group, tennis serve velocity at times one and two were almost perfectly correlated.

Discussion of Regression Results

To examine the relationship of all the measured variables simultaneously and thus make a more accurate assessment of any one variable while controlling for the impact of the other variables, hierarchical multiple regression was used. In step one of the hierarchical regression the time one tennis serve velocity was the sole predictor of tennis serve velocity at time two. This was done to statistically control for the impact of time one serve velocity on time two serve velocity, a relationship seen above that is strong and positive. Since simple regression with only one predictor is identical to bivariate correlation, this relationship maintained its same magnitude and direction. This correlation was expected; however, the focal variable in this study was participation in the experimental treatment. So in step two of the hierarchical regression the experimental treatment group was entered (dummy-coded with 0 for the control group and 1 for the treatment group). The experimental group had a non-significant relationship with time two tennis serve velocity. Having collected a host of other biometric measures, an examination of their relationship in the prediction of time two speed above and beyond the predictive impact of membership in the experimental group and its concordant increase in core endurance and time one tennis serve velocity was undertaken. Gender and external rotation were the only biometric measures significantly related to time two tennis serve velocity. External rotation was negatively correlated with serve velocity. This is different from previous research.[61] This does support the idea that instability in the shoulder could cause weakness in power output of the shoulder through to the dominant arm as it is a weakness in the kinetic chain.

A closer examination of the regression coefficients shows that gender was a significant predictor above and beyond all other biometric measures. Therefore, it is possible that gender subsumed these other potentially collinear predictors. Males generally have more grip strength, can jump higher, have a stronger bench, have longer arms, are taller, and on average have a faster serve than females. If gender had not been measured and entered, several of these other biometric measures may have also been statistically significantly related to the dependent variable.

Limitations

Although the criterion for inclusion was intermediate level of tennis ability, experience level was not controlled. However, the groups were randomly assigned and showed no significant differences in tennis serve velocity. Some subjects had much more playing experience than did others. Many of the subjects had previous private one-on-one lessons while others had never received private coaching. In this study, the characteristics of the subjects were intermediate level tennis experience, while the majority had minimal weight training experience. Different results may be yielded from beginning and advanced players. This study may be slightly limited by subject mortality above and beyond that which was previously discussed. For example, six subjects who were scheduled to participate did not appear for the time one measures, or had to withdraw from the study due to illness, injury (outside the study), or other reasons. Due to this there is no way of knowing how they would have performed in this experiment. Because of these reasons, mortality threats still exist. On the other hand, there is no evidence to suggest that these subjects would have performed differently than the subjects that completed the experiment. This was an eight week study and most of the subjects were enrolled in classes at the university. Mortality rate and tennis playing time could have suffered for some subjects as the semester became more difficult. However, tennis playing time was not measured.

Additionally, the effect of serve proficiency was not measured. Similarly, exercise intensity was difficult to control. Subjects were allowed to take breaks during their exercises when they felt they were unable to continue working out. This freedom to take breaks may have lead to subjects not giving 100 percent in their workouts. However, all sessions were supervised by the principle investigator who emphasized the significance of training at a high intensity. All of the subjects appeared to train hard and were motivated to increase their serve velocity.

This study was also limited in the method used to measure strength. There is no definitive testing procedure for assessing core strength. It is possible that a medicine ball throw would be better to measure abdominal power, which may have been more strongly related to serve velocity than the plank test. However, when using ballistic movements with untrained subjects, injury and technique are always a concern. Rotational strength may have also been a better predictor than the core measures used in this study.

Another limiting factor that could have influenced the results of this study was actual tennis play. Subjects were instructed to play tennis at least two times per week to be considered an active tennis player. However, playing time was not recorded. It is possible that participants did not engage in regular tennis play, and if they did, they may not have practiced tennis serves.

Conclusion

This study investigated the effects of core endurance training on serve velocity in tennis. The hypothesis of this study was not supported by the results. While plank endurance did significantly increase for the treatment group, it is concluded that eight weeks of core training did not have a significant effect on tennis serve velocity. It is possible that the training program could have been effective to increase serve velocity given more time in the strength and power phases of the program. Tapering was not used in the program. It is also possible that one week of rest before conducting the posttest could have yielded higher serve velocities.

Future Research

More research is needed in tennis regarding the relationship between serve velocity and core endurance training. Future research could replicate this study with the suggestion to increase sample size and also log playing time. Playing time should include regular serving with match play.

Future research should also focus on the method used to assess core strength. As mentioned above, there is not one definitive test for assessing core, abdominal, and lower back endurance at the current time.

There is also not much research on upper and lower body resistance training regarding serve velocity in tennis. The predictor variables in this study did overlap, indicating that total body weight training could lead to faster serve velocities since bench, squat, vertical, and grip strength were significantly correlated with time two serving velocity.

Electromyography (EMG) is another area that could be researched. Seeing how much skeletal muscle activity is contributing and from where could help athletic trainers and coaches create better workouts for their tennis players looking to increase serve velocity.

It is also possible that too strong of a core could have caused serves to be inaccurate. Research could look at total body strength, core strength, and their correlation with serve speed and accuracy.

While there is research in baseball on sport specific exercises, [13 33 35 36 57] there is a scarcity of data in tennis. Future research should also look into serve specific exercises, core flexibility, and their effects on serve velocity. By identifying which types of exercises increase serve velocity, sports coaches and strength and conditioning coaches can incorporate them into their training programs and help tennis athletes reach their full serving potential.

APPENDIX A

IRB SYNOPSIS OF PROPOSAL

Every application submitted for review and approval shall have attached to it a page organized in numerical brief paragraph form as outlined below.

Title of Study

The Effects of Core Training on Serve Velocity.

1. Identify the sources of the potential subjects, derived materials or data. Describe the characteristics of the subject population, such as their anticipated number, age, sex, ethnic background, and state of health. Identify the criteria for inclusion or exclusion. Explain the rationale for the use of special classes of subjects, such as fetuses, pregnant women, children, institutionalized mentally disabled, prisoners, or others, especially those whose ability to give voluntary informed consent may be in question.

   Adult aged college students and adult aged members of the local community will be solicited for voluntary participation. The PI will personally go to the first Texas State Tennis club meeting of the fall semester and talk with them about participation in this study. The subjects who have a current or previous musculoskeletal injury that affects serving performance and participation during the testing and core-training will be the criteria for exclusion. This information will be ascertained via medical questioner, using the standard medical questioner for all students enrolled in HPER PFW and PE classes at Texas State University.

2. Describe the procedures for recruitment of subjects and the consent procedures to be followed. Include the circumstances under which consent will be solicited and obtained, who will seek it, the nature of information to be provided to prospective subjects, and the methods of documenting consent. (Include applicable consent form(s) for review.) If written consent is

3. not to be obtained, this should be clearly stated and justified.

The club tennis team will be provided with information explaining the study with contact information, and volunteers will be requested pending the first official meeting of the club this Fall semester. Volunteers will also be recruited from the intermediate PFW tennis classes by granting access from the teacher(s) of record and then discussing the research with the class. Meetings will be scheduled with the volunteers to explain the purpose and procedures of the study and request for volunteers. An informed consent form will be provided to the volunteers to read and sign after explanation of the information from the PI. A singed copy will be given to the subjects.

4. Describe the project's methodology in detail. If applicable, detail the data collection procedures, the testing instruments, the intervention(s), etc. If using a survey, questionnaire, or interview, please provide a copy of the items or questions.

The presented study will last eight weeks. Subjects will be broken into two equal groups. One group will not go through the core training after the initial testing, but will return for posttesting.

This experiment collects data on participants at two points in time. At time one a host of physiological measurements will be undertaken: Such measurements are non-intrusive and pose no risk of psychological harm. They include height, grip strength, leg strength, vertical, core plank hold time, arm length, and internal shoulder rotation on the isokinetic biodex. Max leg strength will be measured with the squat by lifting the maximum weight possible for 5 reps. Upper body strength will be measured with the bench press by lifting the maximum weight possible for 5 reps.

Additionally, at time one maximal tennis serve velocity and core endurance of all participants will be measured. Participants will then be randomly assigned to one of two groups: the treatment group that receives eight weeks of core training and the control group which receives no such training.

At time two, tennis serve velocity and core endurance will again be measured. It is expected that core strength training will enhance one's maximal tennis serve velocity over and above the impact of physiological aspects contributing to tennis serve velocity measured at time one.

The measurements of core endurance at times one and two serves as a manipulation check of sorts so as to determine the efficacy of the treatment condition. That is, participation in core strength training classes for eight weeks must show improvement in core endurance over time so as to minimize the internal threat to validity of less-than-full efforts by participants.

Both groups will have their serve velocity measured on hard courts. Only in serves will be counted. Before administering the test subjects will have a ten minute warm-up consisting of easy to moderate serves followed by all out serving at their discretion. Each subject will undergo 25 service attempts. Out serves will not be counted. Each subject will be given up to twenty seconds of rest between each serve.

Serve velocity will be measured using radar guns. The subjects will be asked to try to hit their fastest first serve. The serves will be recorded to check if questionable serves are in or out. The top 5 fastest in serves will be retained.

After the test is administered to the subjects, one group will return to their daily routine without further testing until after the eighth week period, where they will return and have the initial test administered and checked for differences in velocity. During this time, they are asked to refrain from any core training exercise.

The experimental group will have a core training program outlined and supervised. The subjects will have two core training workout days a week with rest days between them, but continue all other activity as normal. Workouts will last no longer than one hour, including stretching.

The first 2 weeks of core training will focus on stability and endurance. Core stability has been shown to improve force output and decrease the risk of injury, making it an ideal starting place. Weeks three and four will be progressively more difficult, including more sport specific variations of the exercises from the first two weeks. Weeks five and six will start to incorporate more explosion and power based exercises that are biomechanically similar to the tennis serve. The final two weeks will take the similar exercises from weeks five and six and add weight to the exercises. Weights will vary on the level of the subjects' performance. There will also be a 5-10 minute stretching time for the core muscles used during training. Stretched will be performed 20-thirty seconds per exercise for to 2-4 reps.

After the eight week training period is up, both groups will return and have the posttest administered. This will include serve velocity and core endurance.

Training. All exercises completed will be core specific, weight-bearing/balance/endurance exercises. The subjects will complete three sets of thirty seconds for the majority of the exercises. Training will take place 2 days/week. The intensity will increase every 2 weeks with emphasis going from endurance/injury prevention to strength based, explosiveness, and lastly more sport specific biomechanically specific exercises.

Statistical Analysis. The effect of the core-training program will be determined by a comparison of the highest five serves measure (pretest) versus the posttest trials. These measures will be compared using a randomized pretest posttest control group experiment. The analysis will be conducted with multiple regressions. The independent variables analyzed will be the treatment (training versus control groups) and the trials (pre- versus posttests). The alpha level for all comparisons will be .05.

5. Describe any potential risks — physical, psychological, social, legal or other — and state their likelihood and seriousness. Describe alternative methods, if any, that were considered and why they will not be used.

Mild muscle soreness may take place 24-48 hrs after the tests and training for those who have not participated in core endurance/strength exercises recently.

6. Describe the procedures for protecting against or minimizing any potential risks and include an assessment of the likely effectiveness of those procedures. Include a discussion of confidentiality safeguards, where relevant, and arrangements for providing mental health or medical treatment, if needed.

Warm ups and stretching will help to relieve muscle soreness and prevent the possibility of muscle strains and sprains. The serve velocity tests will include a warm up and twenty seconds of rest between each serve, and 5 minutes between sets. Each subject will undergo 5 sets of 5 service attempts out wide and 5 attempts down the middle. Core training will be completed with a minimum of 48 hrs of rest between the workouts to ensure complete muscle recovery takes place.

7. Describe and assess the potential benefits to be gained by the subjects, as well as the benefits that may accrue to society in general as a result of the proposed study.

Subjects will better understand factors that may increase serve velocity, and also strengthen, balance, and increase core endurance that may reduce your risk of injury while playing tennis. Hitting a serve five mph faster could mean the difference in an ace or a returned ball, a service winner or a return winner. With the serve being the most hit stroke in a service game, the benefits of core training and the data collected through this research could provide the edge needed in winning in match play

8. Clearly describe any compensation to be offered/provided to the participants. If extra credit is provided as an incentive, include the percentage of extra credit in relation to the total points offered in the class. Also, if extra credit is provided, describe alternatives to participation in your research for earning extra credit.

No incentives will be provided.

9. Discuss the risks in relation to the anticipated benefits to the subjects and society.

Minimal risk of injury exists while the significant benefits are possible. Core injury is rare in the tennis world. The core training program has been carefully compiled to incorporate endurance based exercises in the first two weeks, which have been shown through research to reduce the chance of injury. However, benefits may include enhanced endurance, faster serve velocity, a stringer core, and a greater power output in all tennis related strokes.

10. Identify the specific sites/agencies to be used as well as approval status. Include copies of approval letters from agencies to be used (note: these are required for final approval). If they are not available at the time of IRB review, approval of the proposal will be contingent upon their receipt.

    All tests and training will be conducted on the Texas State campus at the tennis courts (tests), and the core-training at Jowers.

11. If you are a student, indicate the relationship of the proposal to your program of work and identify your supervising/sponsor faculty member.

    This Proposal is for my master's thesis. My supervising faculty member is Dr. Kevin McCurdy.

12. In the case of student projects, pilot studies, theses, or dissertations, evidence of approval of Supervising Professor or Faculty Sponsor should be included. Thesis and dissertation proposals must be approved by the student's committee before proceeding to the IRB for review.

    Approved

13. If the proposed study has been approved by another IRB, attach a copy of the letter verifying approval/disapproval and any related correspondence. If the proposed study has not been reviewed/approved by another IRB, please state this explicitly.

    This study has not been submitted for review by another IRB.

14. Identify all individuals who will have access, during or after completion, to the results of this study, whether they be published or unpublished.

    Jason Smart, Graduate Student, Texas State

Kevin McCurdy, Professor, Texas State

Robert Pankey, Professor, Texas State

Dr. Brian K. Miller, Professor, Texas State

In addition to this synopsis, you are required to submit all relevant documentation for review. This may include, but is not necessarily limited to: 1) recruiting documents (e.g., flyers, letter, e-mails, brochures, etc.), 2) a consent form, 3) an assent form, 4) letters of approval from relevant organization(s), 5) surveys/instruments/questionnaires, esp. those created by the researcher, 6) a list of questions that the researcher may ask (e.g., focus groups questions, questions for qualitative studies, etc.), and 7) all documents in translated versions.

APPENDIX B

CONSENT FORM

Project Title: The Effects of Core Training on Serve Velocity

Investigator (**PI**): Jason Thomas Smart – Application Number: 2009X6803

You are being asked to participate in a research project conducted through Texas State University. The University requires that you give your signed agreement to participate in this research project. The principal investigator, Jason Thomas Smart, will explain to you in detail the purpose of the project, the procedures to be used, and the potential benefits and possible risks of participation. You are being asked to participate because you have pre existing knowledge of how the tennis serve is performed and have practiced and are comfortable with your serving technique. You may ask the investigator any questions you have to help you understand this research project. A basic explanation of the research is given below. Please read this explanation and discuss with the researcher any questions you may have. If you then decide to participate in the project, please sign on the last page of this form in the presence of the investigator who explained the project to you. You will receive a copy of this form to keep for your personal records.

1. Purpose of the Research – To find the effects of core training on first serve velocity in Tennis.

   Explanation of the procedures – You will be asked to complete a series of 5 sets of 5 service attempts out wide and 5 attempts down the middle hitting your fastest serve, before and after strength training. The pretest will be conducted Aug. 26th-Sept. 6th by appointment so participants have ample time available to participate in the testing. Serve velocity (mph) will be measured by radar gun. The top 10 fastest serves will be recorded. Core endurance and strength training will take place 2 days/wk for eight weeks using free weights. Sessions will be held in the Jowers building at 7pm, Monday-Friday, or if you unable to attend one or both of these sessions during the week, they may be made up by appointment. We will meet in foyer (employee parking lot entrance, red parking area) and proceed to a gym that does not have an assigned class in it for training. The gym may change due to classes scheduled (The class schedules as of right now that are going to be conducted in each gym has not yet been released). Exercise sessions should last no longer than 1 hour. Posttesting for serve velocity will be conducted October 22nd thru October 30th by appointment.

2. Discomfort and risks anticipated - Reasonable safeguards have been taken to minimize the risks of injury through training (i e endurance and strengthening exercises the first few weeks). In addition, muscle soreness may occur after the tests and training, therefore, you will be provided time to recover after each trial, test and training sessions and provided with a light warm-up and stretching exercises before participating in each session Mild muscle soreness may take place 24-48 hrs after the tests and training for those who have not participated in core endurance/strength exercises recently There is a possibility of muscle strain, muscle soreness, and in extreme cases muscle tears. However you will be encouraged to go at your own pace, stop during exercises, and rest to reduce the chances of injury during exercise. Work out sessions will be held Monday, Tuesday, Wednesday, Thursday, and Friday at 7pm, and may also be made up by appointment if missed during the same week. You are required to attend TWO sessions a week.

3. Benefits of participating in this research project- You will better understand factors that may increase serve velocity, and also strengthen, balance, and increase core endurance that may reduce your risk of injury while playing tennis. Participants serve may show an increase in velocity, have better balance on the court, increased serving endurance and playing endurance, and a reduction to risk of injury while serving and playing. Research suggests that shoulder work outs, internal rotation flexibility of your dominant shoulder (the shoulder of the arm you serve with), and wrist flexion of your dominant hand may also contribute to serve velocity. Similar effects of training these areas with weights and stretching exercise programs may yield the same benefits to serve velocity as the core training conducted in this research.

4. Confidentiality assurance – Participants will go through testing as a group, but results will not be given, only recorded. Two subjects who will be next in line to participate will be allowed to observe test trials to better under stand the procedures but will not be provided the scores of these subjects. Names and individual test scores will not be used in any report, presentation or published article. Subjects who go through testing will be assigned a number (ex: #1, #2, etc.) for pre and posttesting to compare scores. After the posttesting with data recorded, participants will be re-assigned numbers at random and not told what their number is This is for publication reasons to ensure confidentiality of the participants. The data will be stored on the computer while data recorded on hard copies will be locked in a filing cabinet in my office and stored for a minimum of 3 years. If requested, a summary of your findings will be provided to you upon completion of the study by contacting Jason Smart, at 903-240-3179, or Dr. Kevin McCurdy at 512-245-7137, Jowers, A152.

5 Right to refuse and/or withdraw with no penalty- Refusal to participate in this study will have no effect on any future services you may be entitled to from the University Anyone who agrees to participate is free to withdraw from the study at any time without penalty.

6. IRB Contact - Any questions regarding the conduct of this research or questions pertaining to your rights as a research subject or any research-related injury should be brought to the attention of the IRB chair, Dr Jon Lasser (512-245-3413 – lasser@txstate.edu), or to Ms. Becky Northcut, Compliance Specialist (512-245-2102).

7. IRB Approval - This project has been reviewed and approved by the Texas State IRB for the Protection of Human Subjects in Research and Research-Related Activities.

Participant Signature Date

Principal Investigator Signature Date

APPENDIX C

Health History and Agreement to Participate

If I have any physical limitations that would be compromised by my full participation I will list those limitations below and discuss with my instructor how this might affect my health and my safe participation.

Name ______________________________ Date ____________________

Circle any condition that applies. If further explanation is needed use the back of the form, all information given will be kept confidential.

1. Cardiovascular disease (heart, blood vessel, or stroke disease) Chest pain during exertion.
2. Elevated blood lipids (Cholesterol or Triglycerides)
3. Epilepsy
4. Shortness of breath, asthma, emphysema, or other respiratory problems.
5. Inner ear problems.
6. Elevated blood pressure and under medication or not
7. Often feel faint or have spells of severe dizziness
8. Diabetes that is affected by exercise
9. Any joint, bone, or muscle problems
10. An eating disorder (anorexia, bulimia)
11. Smoke cigarettes
12. Any other concerns that might affect your ability to participate safely in an exercise program. List and explain.

I have reviewed the consent form and have had the opportunity to ask questions related to the study, which I do not understand.

Print Name __________________________________

Sign Name ______________________________

APPENDIX D

SUBJECT INFORMATION SHEET

Date: __________

Subject #: ______

Vertical: _______ in.

Height: ________ in.

Grip Strength: ______ lbs.

Five Repetition Max Squat: _______ lbs.

Five Repetition Max Bench: _______ lbs.

External Rotation: ______

Internal Rotation: _______

Dominant Serving Arm: ______

Arm Length: ______ in.

Time one Plank: ______ sec.

Time two Plank: ______ sec.

Time one Lower Back: ______ sec.

Time two Lower Back: ______ sec.

Average Serve Speed Time one: ______ mph

Average Serve Speed Time two: ______ mph

APPENDIX E

Subject Specific Experimental Data

Subject	Vertical Jump (in)	Grip Strength (lbs)	Squat (lbs)	Bench (lbs)	External Rotation (deg)	Internal Rotation (deg)	Height (in)	Arm Length (in)	Plank Time 1 (sec)	Plank Time 2 (sec)
1	19.5	97	220	195	131	72	72.2	30.6	65.44	100.49
2	16.5	75	115	65	147	90	69	29	39.23	122.5
3	13	80	75	45	150	71	67.2	28.7	66.45	102.8
4	22.5	105	145	115	151	90	76	29.5	11.84	61.78
5	13	40	125	85	151	90	64.5	26	11	68.74
6	18	62	60	80	148	87	62 5	25.6	82.5	96.89
7	20	79	210	155	148	111	69	27.5	81.16	90.68
8	24	100	165	145	148	85	67.5	29.5	76.93	62.83
9	15.5	60	75	65	151	63	63	26	23.26	49 49
10	24	115	95	120	144	61	71.2	29 2	17 47	20.43
11	29	135	225	175	137	80	73.6	31	23.8	95.48
12	22.5	75	135	95	147	75	75.6	32.6	19.45	84.6
13	28	120	245	210	138	89	72	29.45	42.43	115.56
14	17	105	135	185	116	88	78	32	26.25	114.05
15	19.5	115	95	120	154	79	72.2	28.7	34.88	35.7
16	22 5	111	155	145	151	81	71.9	22.5	84.71	156.2
17	19 5	101	95	115	121	88	69	28.2	22.23	81 25
18	20	87	155	145	151	81	71.6	29.5	41.83	104.17
19	15	74	75	55	151	83	65	25.4	33.19	88.17
20	14.5	61	55	45	151	85	65	27.2	24.53	36.9
21	15	75	95	65	110	72	66 5	27.5	25.15	100.4
22	19	78	165	95	148	87	71.8	29.3	27.34	61.2
23	20	90	105	95	148	83	78.8	32	52.38	73.73
24	15.5	58	45	35	148	85	61	27	52.07	54.48
25	19.5	114	155	135	148	69	71	31.6	50.43	104.06
26	21.5	144	185	185	141	70	70.5	28.5	46.06	66.95

Subject Specific Experimental Data (Continued)

Subject	Vertical Jump (in)	Grip Strength (lbs)	Squat (lbs)	Bench (lbs)	External Rotation (deg)	Internal Rotation (deg)	Height (in)	Arm Length (in)	Plank Time 1 (sec)	Plank Time 2 (sec)
27	20	42	235	175	146	86	69	29	62.43	78.12
28	21	109	165	85	147	79	63.4	26.2	66.72	75.06
29	13	55	145	70	151	79	65.8	25.8	83.56	82.66
30	12.5	97	105	75	147	73	70	30.2	53.63	80
31	15	69	115	55	147	71	63	26	79.78	80.53
32	15	62	105	60	147	77	68	27.5	65.15	76.92
33	29.5	124	275	255	140	94	71.4	30.1	111.68	145.37
34	15.5	47	90	40	151	79	66	27.9	63.15	189 41
35	13.5	101	135	115	148	79	71.5	31.2	109.58	11.73

Subject Specific Experimental Data (Continued)

Subject	Lower Back Time 1 (sec)	Lower Back Time 2 (sec)	Average Serve Speed Time 1 (mph)	Average Serve Speed Time 2 (mph)
1	1.57	79.72	96	101
2	135.02	85.2	77	77
3	55.12	81.6	67.6	68.25
4	37.22	88.5	92.4	93.25
5	27.3	30.5	67	68.6
6	56.44	114 78	75.4	74.4
7	39.34	62.53	90.6	88.8
8	89.58	60.78	108.8	102.4
9	50.27	59.54	81.8	78.6
10	81.84	85.42	111.2	103.8
11	45.53	138.78	81.6	94.6
12	45.13	98.8	83.6	83.2
13	52.31	87.32	118	122
14	35.28	54 5	91	91.8

Subject Specific Experimental Data (Continued)

Subject	Lower Back Time 1 (sec)	Lower Back Time 2 (sec)	Average Serve Speed Time 1 (mph)	Average Serve Speed Time 2 (mph)
15	116.25	60.9	107.4	101
16	86.82	181.95	101.33	105.4
17	21 34	26.42	85	93.4
18	103 99	116.87	95	94.4
19	55.28	96.1	63.2	66
20	73.48	76 3	69	68
21	35.07	102.23	93.8	95.6
22	82.68	96.41	90.2	94.8
23	58.43	72.16	96.6	103.4
24	48.52	63.76	69 4	67.2
25	92 77	164.52	93.8	97
26	37 63	46.28	101.4	102.6
27	30.88	55.54	87	89.8
28	70 33	61.5	77.8	69.4
29	173.98	181.78	63.6	59.8
30	72.02	79.02	59.4	73.8
31	60.91	60.66	55.2	54.66
32	131.78	154.54	62.2	60.2
33	55.82	36.25	94.2	93.6
34	189 58	234.29	57 6	65.4
35	46.02	104.8	95.6	95.6

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VITA

Jason Thomas Smart was born in West Monroe, Louisiana, on February 19, 1981, the son of Sherry Lileete Smart and William Thomas Smart. Jason completed his Bachelor of Arts in Photography and Bachelor of Fine Arts in Art History at The University of Texas, Austin, in 2004. In 2005 he moved to Tokyo, Japan to teach English for 2 years. In the fall of 2007 he entered the Exercise Sports Science Graduate Program at Texas State University-San Marcos. Throughout his time at Texas State, Jason taught Physical Fitness and Wellness classes, worked at the Texas State Student Recreation Center, and conducted his thesis research. After graduate school, he plans on one day returning to academia to further his education.

Permanent Address: 2702 Patio Street

Longview, TX 75605

This thesis was typed by Jason Thomas Smart.