A CORRELATION BETWEEN CORE STRENGTH AND SERVE VELOCITY IN COLLEGIATE TENNIS PLAYERS

A THESIS

Submitted to the Faculty of the School of Graduate Studies and Research of California University of Pennsylvania in partial fulfillment of the requirements for the degree of Master of Science

By
Renee E. Zingaro

Research Advisor, Dr. Robert Kane
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CALIFORNIA UNIVERSITY of PENNSYLVANIA
CALIFORNIA, PA

THESIS APPROVAL

Graduate Athletic Training Education

We hereby approve the Thesis of

Renee Elizabeth Zingaro
Candidate for the degree of Master of Science

Date                      Faculty
4-20-08                    Robert H. Kane, Jr., EdD, ATC, PT
                                      (Chairperson)
4-28-08                    Jamie Foster, DPT, ATC
4-28-2008                  Bruce D. Barnhart, EdD, ATC, PTA
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First, I would like to recognize God. I thank Him for choosing this path for me. I thank Him for laying a hand of calmness and comfort on me when I was stressed throughout this process. He is my strength and perseverance and without Him I could not accomplish anything. Above all, I thank Him for my life.

Not only so, but we also rejoice in our sufferings, because we know that suffering produces perseverance; perseverance, character; and character, hope. And hope does not disappoint us, because God has poured out his love into our hearts by the Holy Spirit, whom he has given us. Romans 5:3-5

Next, I would like to thank my family. They have shown so much support throughout this process and I appreciate it. I also thank my step-mom, Susan, for the many revisions she did on my paper to make it sound more professional.

I would like to thank my friends. They have had to endure my complaining about being tired of doing schoolwork since the second month of school. I appreciate them listening
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I thank my thesis committee. I would like to thank Jamie Foster you for finding the errors in my writing that no one else was able to find. Also, I would like to thank Bruce Barnhart helping me with my statistics. Lastly, I would like to thank Bob Kane for helping me keep everything in AMA format. Overall, thank you for your efforts on revising my thesis, giving advice and overall helping me complete this project. Without all of you, I would not be graduating on time.

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INTRODUCTION

There are a variety of elements required by a tennis player in order to have a complete and highly competitive game. The athlete has to perfect the many aspects of their game, such as the serve, a mixture of strokes, footwork, ball placement, strength, endurance and strategy, in order to have an inclusive game. The serve, specifically, is a key component in competing at a high level such as college or professional and it is difficult to win matches with an inadequate service game. Thus, proper instruction, technique and practice are imperative. If this is not enough, though, then what can be done to enhance this component of a tennis match?

An athlete’s core is the foundation of all functional movements within the body and consists of abdominal and back musculature. Muscles from the cervical spine to the hamstrings have been labeled as core muscles, though, there has not been a universally agreed upon definition of the core musculature. The functional ability of the core could affect performance of the serve.

Core stability and core strength are both necessary for daily activities and sport movement. This is because the core
serves as the center of the kinetic chain\textsuperscript{1}. Therefore motion starts at the proximal segment (core) to distal segments (arm).\textsuperscript{2,11} Core stability allows force and motion to transfer from the core to a distal segment needed for an athletic activity.\textsuperscript{2} However, core strength is the ability to endure or produce a force not its ability to stabilize a motion.\textsuperscript{1,5}

There is much debate on how to measure core strength. A reliable and/or valid test for core strength has not been found. Several authors have favored the double leg-lowering test to measure core strength.\textsuperscript{9,12,13} This test has been found to be reliable, but not a valid test.\textsuperscript{14} Other tests have also been used to find the correct way to measure core strength, but unfortunately have not been both a reliable and valid test.

Muscular strength and stability from the lower extremity to the upper extremity is needed to make a good, competitive tennis player. One of the most dominating parts of the game has become the serve. This action transfers force from the lower extremity to the upper extremity. To be competitive, a player must have the ability to serve with strength, speed and accuracy. The serve can be improved in numerous ways, including the selection of rackets or balls, but the core musculature is also an important component in the service game. The quickest way a player can increase the velocity of
his or her serve is as fast as technology can develop lighter and faster rackets. The player's height also is a factor. However, if core strength is increased, the velocity of the serve may also be increased.

In summary, the core is very important in daily living as well as sport-related activities. This is because the core is the connection between the proximal and distal segments during most bodily movements. In tennis, the serve is a set of movements that requires great skill and strength, which includes core strength, to achieve the fastest velocity possible. Thus, is there a direct correlation between core strength and serve velocity? If so, can a player improve the speed of the serve by strengthening his or her core?
METHODS

The primary purpose of this study was to determine how core strength correlates with the velocity of a tennis serve. In the methods section the design of the study is explained along with details of the subjects, tools, preliminary research and procedures. In addition, the hypothesis and data analysis will be discussed.

Research Design

This research is a non-experimental, correlational study. The variables were the tennis serve velocity and the recorded core strength. The assets of the study will be the ability to control certain variables that would affect the results of the serve velocity. This included skill level, weather, age, height, racket string tension and tennis ball condition. Limitations of the study included the inability to control for the kinetic function of an individual, such as the knee bend that occurs during the service motion, and the contact point between the racket and the ball.
Subjects

Seventeen subjects for this study were volunteer male and female tennis players from NCAA Division Two and Three colleges; California University of Pennsylvania and Messiah College. All players must have played at least four years of competitive tennis prior to entering college and have no injuries that have hindered performance in the past month.

Each athlete was required to participate in one 45-minute testing session. All subjects in the study signed an Informed Consent Form (Appendix C1) prior to participation in the study. The study was approved by the Institutional Review Board (Appendix C2) California University of Pennsylvania. This approval was also accepted at Messiah College, along with approval from the athletic director and Dean of Students. Each participant’s identity remained confidential and was not be included in the study.

Preliminary Research

There was a pilot study conducted with this research project. An athletic subject, with tennis experience, was used to review the protocol. The athlete was tested on the modified double leg-lowering test and then taken though the
tennis protocol. The researcher looked for the athlete’s ability to understand directions, the amount of time used to complete the tasks and if the warm-up protocol before service testing was accurate. Data was collected on the data collection sheet (Appendix C3).

**Instruments**

The instruments used in this study were a goniometer, sphygmomanometer, two radar guns and a demographic questionnaire. A 12-inch, 360 degree universal goniometer was used to obtain all joint angle measurements during the core strength testing. The sphygmomanometer was used to measure the pressure of the back during the abdominal strength testing. The radar guns that were used are SpeedChek and Stalker Sport and they were used to measure the velocity of the tennis ball during service. Stalker Sport’s spec sheet can be seen in Appendix 4. Unfortunately, SpeedChek’s spec sheet is unavailable at this time. The demographic questionnaire (Appendix C5) was used to identify information that might have affected the service of a player during testing (i.e.: height, type of racket, string tension).
Procedure

Subjects were tested over one day. The testing day took approximately 45 minutes to complete. First, the subjects completed the demographic sheet, were informed of the testing protocol and signed the informed consent. After this was completed, the modified double leg-lowering test for core strength was explained and demonstrated for the athlete.

The modified double leg-lowering test began with the athlete in a supine position. A sphygmomanometer was centered beneath the umbilicus and aligned with the length of the spine. Once the sphygmomanometer was in the correct position, the athlete raised his or her legs into a hip flexion position of 90 degrees with full knee extension and arms laid along the side of the body with the palm of the hands down. The sphygmomanometer was set to 20 mmHg with the abdominal muscles relaxed. The athlete was told to ‘flatten out his or her back,’ in a drawing-in motion, to stabilize the lumbar spine and induce a posterior tilt of pelvis until 40 mmHg pressure is reached. The athlete was instructed to lower his or her legs slowly, keeping the knees in full extension and maintaining the posterior pelvic tilt until the sphygmomanometer drops below 20 mmHg. At this point the test
is stopped. A second researcher that voluntarily helped in this process, held the feet of the athlete so he or she did not have to keep contraction of the abdominal muscles and hold the leg position while the goniometer measurement was taken. The goniometer was placed at the hip joint. The stationary arm was parallel to the mid axillary line of the trunk (parallel to the table) and the moveable arm was parallel to the longitudinal axis of the femur (aligned with the greater trochanter and the lateral epicondyle of the femur). This process was performed three times with a 30 second rest in between each trial. The measurements were recorded and an average was determined for the data analysis.

After this was completed, the athlete was taken to an indoor facility that had a tennis court set up for the athletes. The athletes had a seven-minute warm-up before the serve velocity portion of the test was completed. The warm-up consisted of two minutes of jogging, three minutes of ground strokes hits (the researcher hit balls to the athletes that incorporated forehand, backhand, volley and overhead shots), and then the athlete had two minutes to practice the flat serve.

The researcher, depending on the radar gun, stood at the baseline of the court that was served into (Stalker Sport) or the radar gun was placed at the net (SpeedChek) to measure the
velocity of the serve. The athlete hit a flat serve into the deuce court. The athlete had to serve into the service box, which did not hit the net, nor commit a foot-fault, in order for the serve to count. The velocity of the first three good serves that made it into the service box were recorded. The average velocity of the serves was determined for the data analysis.

Hypothesis

The following hypothesis was based on the researcher’s intuition of the study.

1. Core strength will positively correlate with tennis serve velocity.

Data Analysis

All data was analyzed by SPSS version 14.0 for Windows at an alpha level of 0.05. The research hypothesis was analyzed using the Pearson Product-Moment Correlation.
RESULTS

The following section analyzes the data collected from the study conducted using Division II and III intercollegiate tennis players. The purpose of this study was to determine if there was a correlation between core strength and serve velocity in a collegiate tennis player. Each group of athletes performed a modified double leg-lowering test, warmed-up prior to serving and then performed the serves. This section is divided into demographic data, hypothesis testing and additional findings.

Demographic Data

The demographic data allowed the researcher to have a better understanding of the subjects who participated in the study. Each subject was required to complete a demographic questionnaire that provided information regarding year in school, height, weight, years participated in competitive tennis including high school, string tension and any previous injury to his or her shoulder. The total number of subjects
in this study was seventeen. Eleven women and six men participated in this study. Seven subjects were from the California University of Pennsylvania Division II women’s tennis team. Ten subjects were from the Messiah College Division III women and men’s tennis team (6 men, 4 women). The athletes ranged from a first year student to a graduate student. The subjects’ height ranged for the women between 61 to 72 inches (M = 66 ± 3.73) and the men ranged from 68 to 80 inches (M = 72 ± 4.57). The athletes’ weight for the women ranged between 104 to 159 pounds (M = 135 ± 16.07) and the men ranged from 140 to 205 pounds (M = 168 ± 23.80). Both genders have competed in competitive tennis for between 5 and 8 years since beginning high school (women: M = 6.09 ± 1.30, men: M = 6.83 ± 1.47). The subjects’ string tension ranged for the women between 55 to 72 pounds (M = 60.18 ± 4.56) and the men ranged from 60 to 64 pounds (M = 62.50 ± 1.38). No participants experienced any shoulder pain during testing.

Hypothesis Testing

The following hypothesis was tested for the study. The hypothesis was tested at the 0.05 level.
**Hypothesis:** Core strength will positively correlate with tennis serve velocity.

Core strength was measured by having subjects perform a modified double leg-lowering test. When analyzing the data for the core strength, it must be realized that the lower the number for the hip angle, the stronger the core. The mean score for core strength in women was $55.61 \pm 11.55$ and the men’s mean score was $51.78 \pm 7.51$. The serve velocity was measured via a radar gun. The mean serve velocity for the women was $80.97 \pm 5.60$ and the men’s mean score was $109.00 \pm 9.27$. A Pearson Product-Moment Correlation test was performed utilizing SPSS version 14.0 for Windows on male, female and both genders (Figure 1). A Pearson $r$ was calculated for the relationship between subjects’ core strength and tennis serve velocity (Table 2). A strong positive correlation was found ($r(9) = 0.665, p < 0.013$), indicating a significant linear relationship between the two variables only for the women. Thus, women who have a strong core tend to serve with more velocity. There was no correlation between the men’s core strength and serve velocity (men: $r(4) = 0.279, p > 0.296$). There was not a significant correlation between core strength and serve velocity in both genders ($r(15) = 0.044, p > 0.867$).
Table 1: Modified Double Leg-Lowering (MDLL) Test (deg) and Serve Velocity (mph)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>54.25</td>
<td>90.86</td>
<td>51.78</td>
<td>109.00</td>
<td>55.61</td>
<td>80.97</td>
</tr>
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</table>

Table 2: Correlational Statistics for Core Strength Test and Serve Velocity

<table>
<thead>
<tr>
<th></th>
<th>Both</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson r</td>
<td>0.044</td>
<td>0.279</td>
<td>0.665</td>
</tr>
<tr>
<td>P</td>
<td>0.867</td>
<td>0.296</td>
<td>0.013</td>
</tr>
<tr>
<td>N</td>
<td>17</td>
<td>6</td>
<td>11</td>
</tr>
</tbody>
</table>

* Correlation is significant at the .05 level (2 tailed)

Additional Findings

Tests were done to determine if additional findings were present. Pearson correlations were performed between the serve velocity average and height, weight, body mass index (BMI), years playing competitive tennis since first year in high school and string tension (Table 3).
Table 3: Correlational Statistics for Serve Velocity and Additional Measurements

<table>
<thead>
<tr>
<th></th>
<th>Both</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Height</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearson r</td>
<td>0.638</td>
<td>0.258</td>
<td>0.278</td>
</tr>
<tr>
<td>P</td>
<td>0.006</td>
<td>0.311</td>
<td>0.204</td>
</tr>
<tr>
<td>N</td>
<td>17</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearson r</td>
<td>0.773</td>
<td>0.635</td>
<td>0.409</td>
</tr>
<tr>
<td>P</td>
<td>0.000</td>
<td>0.088</td>
<td>0.106</td>
</tr>
<tr>
<td>N</td>
<td>17</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td><strong>String</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearson r</td>
<td>0.293</td>
<td>0.052</td>
<td>0.654</td>
</tr>
<tr>
<td>P</td>
<td>0.254</td>
<td>0.461</td>
<td>0.014</td>
</tr>
<tr>
<td>N</td>
<td>17</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td><strong>BMI</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearson r</td>
<td>0.384</td>
<td>0.85</td>
<td>0.216</td>
</tr>
<tr>
<td>P</td>
<td>0.128</td>
<td>0.016</td>
<td>0.262</td>
</tr>
<tr>
<td>N</td>
<td>17</td>
<td>6</td>
<td>11</td>
</tr>
</tbody>
</table>

* Correlation is significant at the .05 level (2 tailed)

** String = String Tension
BMI = Body Mass Index

When both genders were analyzed together, there were positive correlations between the serve velocity average and height (r(15) = 0.638, p < 0.006) and weight (r(15) = 0.773, p < 0.000). This shows that when both genders are combined, both height and weight are variables related to a higher serve velocity (Tables 4 and 5).

Table 4: Serve Velocity (mph) and Height (inches)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Both: Serve</th>
<th>Both: Height</th>
<th>Men: Serve</th>
<th>Men: Height</th>
<th>Women: Serve</th>
<th>Women: Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>90.86</td>
<td>68.19</td>
<td>109.00</td>
<td>72.08</td>
<td>80.97</td>
<td>66.06</td>
</tr>
</tbody>
</table>
Table 5: Serve Velocity (mph) and Weight (pounds)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Both: Serve</th>
<th>Both: Weight</th>
<th>Men: Serve</th>
<th>Men: Weight</th>
<th>Women: Serve</th>
<th>Women: Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>90.86</td>
<td>146.77</td>
<td>109.00</td>
<td>168.33</td>
<td>80.97</td>
<td>135.00</td>
</tr>
</tbody>
</table>

A Pearson correlation coefficient was calculated for the relationship between serve velocity average and string tension. A strong positive correlation was found with the women (r(9) = 0.654, p < 0.014), indicating a significant linear relationship between the two variables (Table 6). Thus, increased string tension tends to enhance the serve velocity.

Table 6: Serve Velocity (mph) and String Tension (pounds)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Both: Serve</th>
<th>Both: String</th>
<th>Men: Serve</th>
<th>Men: String</th>
<th>Women: Serve</th>
<th>Women: String</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>90.86</td>
<td>60.88</td>
<td>109.00</td>
<td>62.50</td>
<td>80.97</td>
<td>60.00</td>
</tr>
</tbody>
</table>

In the men, a positive correlation was found between the serve velocity average and BMI. A strong positive correlation was found (r(4) = 0.850, p < 0.016), indicating a significant linear relationship between both variables (Table 7). This suggests that a male athlete with a higher BMI has a faster serve velocity.
For both genders, a multiple linear regression was preformed. The dependent variable was the average serve velocity and the independent variables were height, weight, body mass index (BMI), string tension and modified double leg-lowering test. A significant regression equation was found (F(5,11) = 5.010, p < 0.012), with an $r^2$ of 0.695. However, none of the variables were significant predictors of serve velocity.
DISCUSSION

The following discussion section consists of three subsections: discussion of results, conclusion and recommendations.

Discussion of Results

The purpose of this study was to determine if there was a correlation between core strength and serve velocity in a collegiate tennis player. It is already known that the core plays an important role as the center of all functional movements within the kinetic chain. However, to what effect does strength have on the game of tennis, in particular the serve? This study enhances the knowledge on the tennis service game by introducing new literature to the topic.

It was hypothesized that there would a positive correlation between core strength and serve velocity. The study by Chow, Shim and Lim showed a direct relationship between several of the core muscles, the rectus abdominis, internal oblique, external oblique and the erector spinae. The researchers used electromyography (EMG) on a tennis player
during the service motion. They found activation of all four core muscles tested during one or more parts of the serve. In this study, statistical analysis demonstrated that only the women participants had a correlation between core strength and serve velocity, thus the hypothesis was supported. When the men then and both genders together were tested, the hypothesis was not supported.

Previous literature has suggested that the trunk and lower quarter muscles accounts for 54% of the forces generated during a tennis serve. It was also stated that shoulder velocities generate up to 47 mile per hour hand speed during the serve. This could indicate that more of the service power in men is from the upper extremity versus the women who use their entire kinetic chain to provide power for the serve. Therefore, the women activate more of the core musculature to enhance the velocity of the tennis ball. Whereas the men produce more velocity in their serve by producing more shoulder velocity. The men could be reaching up to the 47 mile per hour hand speed and using less core strength. But, the women would be producing less than 47 mile per hour hand speed, thus using more core strength. This could have resulted in the difference between correlation of core strength and serve velocity in women versus the no correlation
in men. However, it should be noted that due to the low number of male participants, the results may be skewed.

A multiple linear regression was performed on all seventeen participants. It showed that there was a significant regression between the serve velocity average and height, weight, body mass index (BMI), modified double leg-lowering average and string tension. However, there were no individual regressions that were significant. This suggests that all the variables that were analyzed increase the serve velocity, but no variable by itself has a significant impact on the serve.

This explains that when both genders are analyzed together, core strength and serve velocity are not significantly related. However, when core strength is compared with height, weight, BMI and string tension, these variables make an impact on the serve velocity. This is not a surprise since serving incorporates multiple variables for success. It was seen in previous literature that racket head speed and height of a player enhances the serve velocity.\textsuperscript{15-20} Hitting the ball on the ‘sweet spot’ of a racket will increase the velocity of a serve.\textsuperscript{18} Therefore, a taller player will increase the height of the ‘sweet spot,’ due to the racket being higher, thus producing a serve with more velocity.
When analyzing the correlational statistics, there were several additional findings. A positive correlation was found between the men’s serve velocity and their body mass index (BMI). This shows that a male with higher BMI will have a faster serve. This suggests that overall BMI of the male tennis player corresponds to the speed of the ball. The reasoning for this result is difficult because the BMI can be due to either high muscle mass or a high fat content. In this study, muscle mass versus fat content was not measured.

When men and women were compared together, there was not a correlation between the modified double leg-lowering test and body mass index (BMI). This can be due to the fact that the females did not have a correlation between these two variables, although the men did. When the women were added into the calculation, they altered the amounts that the men had, thus eliminating the correlation when both genders were analyzed together.

Another correlation in the women’s statistics was found between the tennis serve velocity and the string tension. This proposes that the tighter the strings are strung that the velocity of the ball during the serve will increase. However, when there is an increase in string tension there is a loss in accuracy. This compares to a lightweight racket, which produces a more powerful serve than a heavier racket because
there is extra upper arm rotation and wrist snap that moves the ‘sweet spot’ up the racket head.⁷,⁸ Even though this helps to increase the speed of a serve, top competitors in tennis today prefer heavier rackets. They rather have more control of a ball than more speed.⁶

Further correlations were found when both genders were analyzed together. A positive correlation was found between serve velocity and both, height and weight. This suggests that a taller and heavier tennis player would have a greater serve velocity.

Height helps increase serve velocity because the contact angle between the racket and ball is higher. It has been seen that taller tennis players have an increase in height of the ‘sweet spot’ on the racket. Thus, a taller player would naturally have a more powerful serve, due to the increase in the window of angular acceptance that produces a higher service speed.⁹,¹⁰

Conclusions

Based on the results, it can be concluded that core strength does have a correlation to serve velocity in women. However, the men, who did not have a correlation between core strength and serve velocity, seem to produce most of their
force from upper body strength versus core strength. However, this could have been altered by the small male sample.

It has been previously stated that 54% of the tennis serve speed comes from the trunk and lower extremity\(^2\) and the activation of core musculature through all the phases of a serve.\(^{14}\) It has also been shown that other variables also induce a higher serve velocity such as height of a player, racket head speed and hitting the 'sweet spot.'\(^{15,17,18,20}\) Even though multiple variables help increase serve velocity, core strength is still important in the service game.

Though all of the results were not as expected, this study contributes to the limited research done on the relationship between core strength and serve velocity. The study points shows that there is a correlation between core strength and serve velocity to make it a relevant variable to continue to improve.

Results may be different for high school or professional level players. This is due to high school players still learning the technique of the serve, thus having a lower level of play. At the professional level, they have more defined form and higher level of training. For these reasons, results from this study may differ for these two groups.

In conclusion, the serve has many components, which include form, strength from extremities and the core and type
of equipment used. It is a multifactorial movement in the sport of tennis and should be treated as such. Thus, one should attempt to improve all of the factors associated with the serve and not one single component.

Recommendations

It is recommended that core strength training should be implemented into conditioning programs for tennis players along with their daily routines.

Future studies could shed much light on the factors associated with increasing velocity of the tennis serve. Physical performance factors such as body mass index, muscle verse fat mass, core strength and upper and lower extremity strength should be examined in both men and women in large sample studies.

Also, in future studies, a different warm-up protocol should be used. In this study, the athlete was ready to serve before the seven-minute warm-up was finished. Perhaps a shorter warm-up will be as beneficial as a longer one. Determine if there is a core strength test that is both valid and reliable. Another study could focus on a string tension analysis to see at what pressure does a player actually start to transfer from accuracy and control to power and loss of
control. All of these studies should be done with a large sample size and on subjects of different levels of tennis experience to see if there is a difference in the role that each of these factors could play into the service game.
REFERENCES


APPENDICES
APPENDIX A

Review of Literature
REVIEW OF LITERATURE

Introduction

There are many components a tennis player needs in order to have a complete and highly competitive game. The athlete has to perfect many aspects of their game, such as the serve, a variety of strokes, footwork, ball placement, strength, endurance and strategy, in order to have an inclusive game. The serve, specifically, is a key component in competing at a high level, such as college or professional, and it is difficult to win matches with an inadequate service game. Thus, proper instruction, technique and practice are imperative. If this is not enough, though, then what can be done to enhance this component of a tennis match?

An athlete’s core consists of abdominal and back musculature and is the foundation of all functional movements within the body. The strength of this body component is key for any athlete because of its involvement in all controlled motions in sport. This is because the core serves as the center of the kinetic chain.\(^1\) It has also been shown that motion should start at the proximal segment (core) to distal segments (example: arm).\(^2,3\) Therefore, the question arises, if
a tennis player has a stronger core, would their serve velocity be faster?


The Core

The overused body term, core, is a very undefined and unclear label. Many authors have tried to explain this concept, but have left readers confused because of the several interpretations given while attempting to find its correct meaning. Not only are there differing opinions on the musculature that comprises the core, but there are multiple definitions for core stability and core strength.\textsuperscript{1,3-7}

Core musculature has included muscles from the cervical spine to the hamstrings.\textsuperscript{1,3-5,8-13} However, there has not been a universally agreed upon definition of what should be considered the core. The following is a review on the descriptions of the core and the anatomical structures that authors include in the core and their potential contribution to core function.\textsuperscript{1,3-5,8-12}
Abdominal Musculature

The abdominal muscles within the core consist of the rectus abdominis (RA), transverse abdominis (TA), internal oblique (IO) and external oblique (EO). The RA, IO and EO are trunk flexors and control extension. The IO also is an ipsilateral rotator, controls contralateral rotation, is a contralateral flexor and controls ipsilateral flexion of the trunk. The other functions of the EO is a contralateral rotator, controls ipsilateral rotation, ipsilateral flexor and controls contralateral flexion of the trunk. The TA increases inter-abdominal pressure (IAP), stabilizes sacroiliac joint and the coactivation with internal oblique limits translation and rotation.

Quadratus Lumborum

Many authors consider the quadraus lumborum (QL) part of the core musculature, like the abdominals. The QL originates on the iliac crest and iliolumbar ligament and inserts on the transverse processes of the lumbar vertabae and the twelfth rib. Thus, there are three major parts of this muscle, the inferior oblique, superior oblique and longitudinal fascicles. The longitudinal and superior components of the muscle act to stabilize the twelfth rib during respiration. However, the inferior oblique fibers are
an isometric lumbar stabilizer and, like the external oblique is also an ipsilateral trunk flexor.\textsuperscript{1,3,5,8,10}

**Paraspinals**

Only five muscles within the paraspinal group have been mentioned in literature as being part of the core.\textsuperscript{1,4-5,8-11} The paraspinals consist of the multifidus, longissimus, iliocostalis and intertransversarii. The multifiduii are multisegment stabilizers of the spine.\textsuperscript{1,3,8} The longissimus and iliocostalis are both lumbar extensors.\textsuperscript{1,8,10} The intertransversarii is an ipsilateral trunk flexor.\textsuperscript{1,8}

**Hip and Pelvis**

The muscles included in this section are psoas major,\textsuperscript{3,4-5,8-10} gluteus maximus,\textsuperscript{3,4-5,8,10} and gluteus medius.\textsuperscript{3,4-5,9-10} When lower extremities are stationary, the psoas major is a trunk flexor and ipsilateral rotator and the gluteus maximus is a trunk extensor.\textsuperscript{1,3,8} The gluteus medius is an abductor of the trunk when it is in extension.\textsuperscript{12}

**Diaphragm and Pelvic Floor**

The diaphragm and pelvic floor are considered the roof and floor of the core, respectively.\textsuperscript{1,3,8} The diaphragm increases the intra-abdominal pressure (IAP) before the limb movements begin, thus assisting in spine/trunk stability.\textsuperscript{1,3,8} The pelvic
floor helps to modulate the IAP and is coactivated with the transversus abdominis contraction.\textsuperscript{1,8}

**Thoracolumbar Fascia**

The thoracolumbar fascia unites the upper limb to the lower limb by the latissimus dorsi and gluteus maximus respectively. This connection of the limbs causes some authors to include this in their description of the core.\textsuperscript{1,3} The connection helps with stabilization by forming a ‘ring’ around the abdomen from the lumbar spine to the internal oblique and transverse abdominis.\textsuperscript{3}

**Thoracic and Cervical Spinal Muscles**

Hedrick\textsuperscript{9} also included thoracic and cervical spine musculature in the definition of the core. These muscles include in the thoracic spine: lower and middle trapezius, rhomoid major and minor, and serratus anterior. The cervical spine muscles comprise of the scalenes, sternocleidomastoid and longus coli and capitis.

**Lumbo-Pelvic-Hip Complex**

Some authors consider the whole lumbo-pelvic-hip complex to be the core.\textsuperscript{4-5,10-11,13} The lumbo-pelvic-hip complex consists of the abdominals, quadratus lumborum, paraspinals and hip and pelvis musculature. It also includes all three erector spinae
muscles (iliocostalis, longissimus and spinalis), latissimus dorsi and the hamstrings.

The core is a complex term to define. For example, some authors include the diaphragm and pelvic floor in their definition of the core\(^1,3,8\) and other authors comprise the core of the entire lumbo-pelvic-hip complex.\(^4-5,10-11,13\)

Core Stability

The indecisiveness about how the core should be defined muscularly carries over to the definitions of core strength and core stability. The inability to find a singular definition can be detected in various writings on this topic. The puzzlement continues as core strength and stability have been described as the same.\(^8\)

Core stability, simply stated, is the functional stability of the trunk.\(^6,7\) This definition can be extended to the ability to maintain trunk-controlled motion while there are forces attempting to change its position.\(^3,7\) This depiction of core stability can continue as trunk stability that is kept while a position is being modified. Core stability allows force and motion to transfer to a distal segment needed for an athletic activity.\(^3\) This characterization can become very specific as well. Core
stabilization is the “product of motor control and muscular
capacity of the lumbo-pelvic-hip complex.”

The term, core stability, can be defined as simply or
complex as needed for an individual author’s purpose. Core
stability will be defined as the ability of the trunk to
maintain (stabilize) its positioning while forces are being
applied to it.

Core Strength

A definition used for strength is the “ability of a
muscle to exert or withstand force.” Stability, on the other
hand, is the ability of the body to control motion of a
joint. Thus, it has been stated the core strength is the
muscular control around the lumbar spine needed to uphold
functional stability. However, core strength, itself, is the
ability to endure a force whether it is on a single repetition
to a maximum force or an extended stay in the neutral
position, not its ability to control (stabilize) a motion.

Core strength does not have many different explanations.
Core strength will be defined as the ability of the
musculature to endure a single force exerted upon it.
Core Strength in Sports

Strength, or the “ability of a muscle to exert or withstand force,” is quite beneficial to everyday living. For example, the strength of the leg muscles assists the body going from a sitting position to a standing position. This is why it is difficult for the elderly to stand from a sitting position because they have lost strength in their muscles. Core strength has the same effect and is extremely significant in athletics. Its importance is shown through the new focus on core exercises that have been implemented into athletic training.

The core has been described as a muscular corset that works to stabilize the spine during movement and non-movements. It transfers force between the upper and lower limbs, thus demonstrating that it is the center of the kinetic chain. Therefore, proximal stability is needed for distal mobility in order to produce the largest possible speed. If the muscles that control the extremities are strong and the core weak, then the transfer of forces will be difficult, and there will be an inability to perform efficient movements. Accordingly, if an athlete does not have a strong core base it will be difficult for him or her to achieve the great extremity movements needed for sport.
Testing Core Strength

There are many ideas about how to measure core strength. Similar to defining the core, there is much debate on how to measure core strength. A reliable and valid test for core strength has not yet been found. However, there have been many attempts to determine the correct way to measure core strength. Several authors have favored the double leg-lowering test to measure core strength.\textsuperscript{12,15-17} Other tests have transpired to find the correct way to measure strength, but unfortunately have not been both a reliable or valid test.

The series of three tests will be described first in this literature review to measure core strength. This test includes a one-leg standing balance, one leg squat and three-plane core testing. After this series of tests, the double leg-lowering test will be explained.

One-Leg Standing Balance Ability

To measure one-leg standing balance ability the athlete would be requested to stand on one leg and would not be given any other verbal cues. The evaluator would look for any deviations, such as the Trendelenburg or an internal or external rotation on the weight bearing leg. If any of this is evident, then it is thought that there is a lack of control
in posture, thus suggesting that there is a proximal core weakness.³

One-Leg Squat

If the previous test is completed correctly then, the one-leg squat is performed. The athlete is in the same position as before, balancing on one leg, but is told to do repetitive quarter to half squats with no other verbal cues. The evaluator will be looking for similar dysfunctions as in the previous test. However, the use of arms to help with balance should also be noted or the athlete may go into an exaggerated flexed or rotated posture. This will try to compensate for weaker muscles.³

Three-Plane Core Testing

This test consists of three parts, testing the core musculature in the sagittal, frontal and transverse planes. Each of the tests is done with the patient standing eight centimeters away from the wall. The sagittal plane test has the athlete standing with his or her back to the wall on a single leg. The patient should slowly lean backward toward the wall while keeping the foot flat on the ground and stop when his or her head barely touches the wall. This part of the test eccentrically activates the abdominals, quadriceps and hip flexors and the hip and spine muscles should be
concentrically activated. The frontal plane portion of the test has the patient standing sideways to the wall standing on his or her inside leg. They are to barely touch the wall with their inside shoulder. This tests the eccentric loading on the quadratus lumborum, hip abductors and a few long spinal muscles. Lastly, the transverse plane test will start the athlete with his or her back to the wall. However, the patient will try to barely touch the opposite shoulder (from the leg that he or she is balancing on) to the wall. The transverse plane tests the abdominals, hip rotators and spinal extensor muscles.\(^3\)

**Double Leg-Lowering Test**

The double leg-lowering test has the patient in a supine position on a hard flat surface. A sphygmomanometer is placed under the lumbar back placed at the L4/L5 level. Once this is complete, the patient will raise his or her legs into hip flexion of 90 degrees and the sphygmomanometer is inflated to 40 mmHg. The patient is instructed to lower his or her legs slowly and is stopped when the 40 mmHg decreases. At this point the angle of the hip is measured with a goniometer. The lower the patient can lower his or her legs correlates to a stronger core.\(^{12,15-16}\)
There is a modified double leg-lowering test, which has reliability. This test has the athlete lying supine. A sphygmomanometer will be centered beneath the umbilicus and aligned with the length of the spine. Once the sphygmomanometer is in the correct position, the athlete will raise his or her legs into a hip flexion position of 90 degrees with full knee extension and arms laid along the side of the body. The sphygmomanometer was set to 20 mmHg with the abdominal muscles relaxed. The athlete will also be told to draw in the abdominals to stabilize the lumbar spine and have a posterior tilt of pelvis until 40 mmHg pressure is found. The athlete will be instructed to lower his or her legs slowly and is stopped when the sphygmomanometer drops below 20mmHg. This is unlike the double leg-lowering test, which takes a measurement at 40 mmHg. At this point the angle of the hip is measured with a goniometer.17

Several tests have been presented and none of them have been shown to be both reliable and valid. However, the double leg-lowering test has been used in several studies.12,15-16 This is a typical method to measure core strength. The modified test has shown to be reliable.
The Game of Tennis

Tennis is a sport that involves upper and lower extremity activity. Also, muscular stability and strength is needed to make a good competitor. The many components of the sport include, but are not limited to, the serve, different strokes, footwork, agility and endurance. One of the most dominating parts of the game has become the serve. To become a high-level tennis player, one must be able to have a hard, fast paced service. There are several factors that go into serving, such as the type of racket used, the height of the player, the form used and the strength of the core.

Importance of the Serve

The success of a player, at a high level, is dependent on the post impact ball speed especially during a power serve (ie: flat serve). The power serve is a flat serve with a lot of speed and little to no spin (spin slows down a serve). There are three types of serves a player can choose from: flat, topspin or sidespin. A high-speed first serve (flat serve) has become a dominant factor in a match. Many players today are hitting hard, fast serves. Currently, Andy Roddick holds the fastest men’s serve at 155 mph, recorded in 2004.
The fastest women’s serve recorded was by Venus Williams, who served 127.3 mph in 1998.

Factors in Serving

There are many factors that come into play during the serving motion, such as the racket head speed, height of a player, type of ball used and core strength. Most literature has focused on racket head speed. Hitting the ball on the ‘sweet spot’ of a racket will increase the velocity of a serve. A lightweight racket, as opposed to a heavier one, also makes a serve more powerful. This is because of the increase in racket head speed. Internal rotation of the upper arm produces the racket head velocity at the time of ball impact during the serve. This means, with extra upper arm rotation and wrist snap that the ‘sweet spot’ during the serve can be moved up by 0.05 – 0.10 meters thus increasing the serve velocity. This is only possible with the newer, lighter rackets being produced. However, the top competitors in tennis today are still using the rackets that they are most comfortable with, which is usually an older style, heavier racket. The heavier racket equates to more control over the ball; therefore, the top current players are sacrificing speed for control.
The increase in height of the ‘sweet spot’ on the racket correlates to why a taller player would naturally have a more powerful serve. In both of these instances, there is an increase in the window of angular acceptance that produces a higher service speed.\textsuperscript{18,23}

The type of ball used during competition also helps the pace of a serve. The pressure and the size of the ball are both congruent with producing high velocity serves. There is concern over the increase of service speed in tennis because of the entertainment value of the sport is beginning to decrease with shorter rallies. Thus, the size of the ball has been looked at to slow down the game by increasing the pressure (ball rebound speed decreases) and making larger balls (increase in air resistance).

However, to be competitive, a player must have the ability to serve with strength, speed and accuracy. A player can only increase the velocity of his or her serve as fast as technology can develop lighter and faster rackets or he or she is tall. But if core strength is increased, the velocity of the serve can also be amplified.

Activation of Core Musculature during the Serve

It has been suggested that the trunk and lower quarter muscles generates 54\% of the forces generated during a tennis
serve. Also, it has been alluded that when there is a 34% increase in shoulder rotation there is a 20% decrease in hip and trunk force production.\textsuperscript{24} Shoulder velocities generate up to 47 mile per hour hand speed during the serve,\textsuperscript{24} thus if the trunk does not provide the proximal stability needed for the service there can be problems in the distal mobility. Chow, Shim and Lim (2003) did a study on the trunk muscles during the different phases of a tennis serve. The trunk muscles that they looked at through electromyography (EMG) activity were the rectus abdominis (RA), internal oblique (IO), external oblique (EO) and the erector spinae (ES). They found that for a right-handed player, during the ball release there was an initiation of the left lateral trunk flexors, extension (via ES), and toward the end of the phase there was activation of the right ES and the EO.\textsuperscript{25}

The next phase was between the backward swing of the racket to the ball contact. The EMG showed, during the backward fall of the trunk, that the IO muscles on both sides were going through eccentric contractions. The left RA and EO were active since the trunk was flexing to the left and rotating to the right as well as falling backward. When the arm swung upward to make contact with the ball, there was moderate activation of the ES. All muscles showed high
activity during the acceleration phase as all the subjects in this study left the ground to make contact with the ball. After ball impact, all of the abdominal muscles, RA, IO and EO, decreased in activity greatly while the ES increased. During the follow-through phase, both of the IO and ES activated, which made the authors think that they were stabilizing the trunk. The EO had greater activity on the right side over the left side, which suggests that the trunk was rotating, left and the right EO was counteracting gravity during the follow-through phase.

The game of tennis consists of many variables that are needed, such as footwork or mastery of a variety of strokes, to have a great game. One of the biggest factors is the serve. The serve can be improved in numerous ways, including the selection of rackets or balls, but the core musculature, also, is an important component of the power serve.

Measuring Velocity

Radar (speed) guns have been used in many ball sports, such as baseball and tennis, to measure the velocity of the ball. There has not been any literature found on a comparison on radar guns used in any sports. However there have been a
couple studies that have used radar guns to assess the velocity of a tennis ball off of a serve.\textsuperscript{18,26}

One radar gun was the Stalker ATS, MN. When it recorded the velocity of a tennis ball during a serve, it was set up 2 meters behind the player on a 2.5-meter high tripod.\textsuperscript{18} The other radar gun, which is a hand held gun, found that was used to measure a tennis serves’ ball velocity was a \textit{MuniQuip} Model T-3S.\textsuperscript{26}

Even though there are not any comparison articles on radar guns for sports, some have been used to measure serve velocity before. There are a variety of ways to use a radar gun to measure the velocity of a serve. The hand held gun would be the preferred method for testing in the field because it does not have to be as accurate in placement compared to having a tripod. Thus, the researcher’s placement does not have to be precise making this method most effective.

\textbf{Summary}

In summary, many researchers have come up with numerous definitions of the core, but all have found that the core is very important in daily living activities as well as sport related activities. In tennis, the serve is a movement that requires great skill and strength, which includes core
strength, to achieve the fastest velocity possible. Unfortunately, there is still not a great method for testing core strength, but for this research project, the modified double leg-lowering test will be used. Though some controlled variables, such as skill level, ball and playing surface conditions, measuring the modified double leg-lowering test and the velocity of a tennis serve through a radar gun will hopefully show if there is a correlation between core strength and the velocity of a tennis serve.
APPENDIX B

The Problem
THE PROBLEM

The purpose of the study is to examine the correlation between the core strength of tennis players and the velocity of flat tennis serves. It is important to examine this relationship because with the advancement in power and speed in the game of tennis it is becoming harder to obtain an ‘edge’ over another player. The service game has been the greatest noticeable and measurable enhancement in performance over the years. Players can enhance their tennis serve by working on their mechanics, however, increasing core strength can help progress their game through the serve as well. Therefore, the development of increased velocity of a player’s tennis serve is important to assist improvement of the overall tennis game.

Definition of Terms

The following are definitions of key terms:

1. Core – The core will be considered the axial muscles: abdominals, paraspinals, quadratus lumborum and diaphragm. Also included would be the pelvic floor and the thoracolumbar fascia.¹

2. Core Stability – the ability of the trunk to maintain (stabilize) its positioning while forces are being applied to it.³,⁷
3. Core Strength - the ability of the musculature to endure a single force exerted upon it or to produce a force against a resistance.¹⁴

4. Deuce Court - the right side of the court for both the receiver and server

5. Flat Serve - a low, fast, straight shot with little to no spin

**Basic Assumptions**

The following are basic assumptions of this study:

1. The subjects will be honest when they complete their demographic sheets.

2. The subjects will perform to the best of their ability during testing sessions.

3. The modified double leg-lowering test measures core strength.

**Limitations of the Study**

The following are possible limitations of the study:

1. The subjects are only from Division II or Division III Colleges.

2. Limited number of participants for male tennis players.

3. The needle on the sphygmomanometer jumping when posterior pelvic tilt is difficult to maintain.
Significance of the Study

In the game of tennis it is believed that the serve is the hardest stroke to master; therefore, it needs to be practiced consistently to get a quality stroke. There are three types of serves: flat (minimal to no spin), topspin and slice (sidespin). Chow, Shim and Lim (2003) found that during all three serves the racquet movement and contact location with the ball relative to the body are different.\textsuperscript{25} Thus, it is a common thought that advancing arm movement will also progress the serve, however core strength is quite important as well.

Kibler (1995) showed that in a tennis serve, 54\% of the forces generated are from the core and the lower quarter.\textsuperscript{24} The core refers to the trunk muscles, which consist of abdominal and lumbar musculature. The transverse abdominis (TA) and the multifidus are considered the ‘ring of stability’ for the core. This term is used due to the fact that when the TA contracts, the multifidus co-contracts. For example, if the abdominal area is pulled inward, the TA is contracting while the multifidus is co-contracting. When this movement occurs other muscles considered part of the core are relaxed such as the external and internal obliques and the rectus abdominis.
In order for the limbs to do their specific function, the core must work properly. Kibler, Press and Sciascia (2006) found that the spine and pelvis help the function and transfer of energy from large to small body parts during many sport activities. If the core is not working properly, adjustments will have to be made in the extremity itself. Kibler and Chandler (1995) suggest that, during a tennis serve, if the trunk and hip decrease force production by 20%, there would be a 34% increase in rotational velocity in the shoulder. Over time this extra shoulder rotation could cause an injury to the athlete. Therefore it is important to have a strong core to keep extremities working properly.

To enhance the velocity on a player’s serve it cannot be from just the arm itself, but must be from the core muscles as well. A study was done by Chow, Shim and Lim (2003) which measured core activation by electromyography (EMG) during a tennis serve. This showed that there is much activation in the rectus abdominis, external oblique, internal oblique and erector spinae during the serve. This supports the premise that a tennis player cannot only strengthen upper extremity muscles to improve their serve velocity, but they must also increase the strength of their core muscles. This study will examine how much core strength contributes to the development of a player’s serve velocity.
APPENDIX C

Additional Methods
APPENDIX C1

Informed Consent Form
Informed Consent Form

1. "Renee Zingaro, who is a graduate student at California University of Pennsylvania and a certified athletic trainer, has requested my participation in her research study at this institution. The title of this research is "The Correlation between Core Strength and Serve Velocity in Collegiate Tennis Players."

2. "I have been informed of the purpose of this research study is to find if there is a direct correlation between core strength and the velocity of a flat tennis serve. Volunteers from the tennis team are being included."

3. "My participation will include performing the double leg-lowering test (to test core strength), a warm-up program before serving and completing a maximal velocity flat serve. This session will take approximately 45 minutes to complete."

   **Double Leg-Lowering Test:** The double leg-lowering test will begin with the athlete lying on his or her back. A BP cuff will be centered beneath the belly button and aligned with the length of the spine. The athlete will raise his or her legs into a hip flexion position of 90 degrees with knee straight and arms laid along the side of the body. The athlete will also be told to ‘flatten out his or her back,’ in a drawing-in motion. The athlete will be instructed to lower his or her legs slowly, keeping the knees straight and stomach flattened while the researcher watches the BP cuff for it to lower to a certain number. When that number is reached, the athlete will hold the position he or she is in while the researcher takes a measurement with a goniometer (ti measures angles) of the hip angle. This will be repeated three times.

   **Warm-Up:** The athlete will have a seven-minute warm-up before the serve velocity portion of the test will be complete. The warm-up will consist of two minutes of jogging, three minutes of ground strokes hits (the researcher will hit balls to the athletes that will incorporate forehand, backhand, volley and overhead shots), and then the athlete will have two minutes to practice the flat serve.

   **Maximal Serve:** The athlete will hit a flat serve into the deuce court. The athlete must get the serve into the service box, not hit the net, nor commit a foot-fault, in order for the serve to count. The velocity of the first
three good serves that make it into the service box will be recorded.

4. “I understand that there are foreseeable risks and discomforts if I agree to participate in this study. The possible risks and/or discomforts are to the shoulder during maximal velocity testing. The researcher’s knowledge of a proper warm-up before testing will minimize these risks.”

5. “There are no feasible alternative procedures available for this study.”

6. “I understand the possible benefits of my participation is to progress an alternative method (ie: increasing core strength) of improving the velocity of a flat tennis serve. Also, I understand that there are no benefits to me personally for my participation.”

7. “I understand that the results of this study may be published but my identity will remain confidential. To maintain confidentially Renee Zingaro will assign each participant a number and all documents will be stored in a secure location, which access will only be to the student researcher and research advisor.”

8. “I have been informed that I will not be compensated for my participation.”

9. “I have been informed if I have any questions or concerns about this research study before or after it is conducted, they will be answered by Renee Zingaro, zin2946@cup.edu, 361 California Road, Apt. 311, Brownsville, PA 15417, (412) 965-9542 and/or Dr. Robert Kane, Kane@cup.edu.”

10. “I understand that written response may be used in quotations for publication but my identity will remain anonymous.”

11. “I have read the above information. The nature, demands, risks, and benefits of the project have been explained to me. I knowingly assume the risks involved, and understand that I may withdraw my consent and discontinue participation at any time without penalty or loss of benefit to myself. In signing this consent form, I am not waiving any legal claims, rights, or remedies. A copy of this consent form will be given to me upon request.”
Subject’s signature____________________________ Date__________

12. “I certify that I have explained to the above individual the nature and purpose, the potential benefits, and possible risks associated with participation in this research study, have answered any questions that have been raised, and have witnessed the above signature.”

13. “I have provided the subject/participant a copy of this signed consent document upon request.”

Investigator’s
Signature ________________________________ Date__________
APPENDIX C2

Institutional Review Board –

California University of Pennsylvania
Institutional Review Board (IRB) approval is required before beginning any research and/or data collection involving human subjects

(Reference IRB Policies and Procedures for clarification)

Project Title _A Correlation Between Core Strength and Serve Velocity in Collegiate Tennis Players_

Researcher/Project Director _Renee E. Zingaro_

Phone # 412 965 9542  E-mail Address zin2946@cup.edu

Faculty Sponsor (if required) _Dr. Robert H. Kane_

Department _Health Science and Sport Studies_

Project Dates January 2007 to April 2007

Sponsoring Agent (if applicable)

Project to be Conducted at _California University of Pennsylvania, Washington and Jefferson College & Messiah College_

Project Purpose:  ☒ Thesis  ☐ Research  ☐ Class Project  ☐ Other

Keep a copy of this form for your records.
**Required IRB Training**

The training requirement can be satisfied by completing the online training session at [http://cme.nci.nih.gov/](http://cme.nci.nih.gov/). A copy of your certification of training must be attached to this IRB Protocol. If you have completed the training at an earlier date and have already provided documentation to the California University of Pennsylvania Grants Office, please provide the following:

*Previous Project Title*  
*Date of Previous IRB Protocol*
Please attach a typed, detailed summary of your project AND complete items 2 through 6.

1. Provide an overview of your project-proposal describing what you plan to do and how you will go about doing it. Include any hypothesis(es) or research questions that might be involved and explain how the information you gather will be analyzed. For a complete list of what should be included in your summary, please refer to Appendix B of the IRB Policies and Procedures Manual.

2. Section 46.11 of the Federal Regulations state that research proposals involving human subjects must satisfy certain requirements before the IRB can grant approval. You should describe in detail how the following requirements will be satisfied. Be sure to address each area separately.

   a. How will you insure that any risks to subjects are minimized? If there are potential risks, describe what will be done to minimize these risks. If there are risks, describe why the risks to participants are reasonable in relation to the anticipated benefits.

   b. How will you insure that the selection of subjects is equitable? Take into account your purpose(s). Be sure you address research problems involving vulnerable populations such as children, prisoners, pregnant women, mentally disabled persons, and economically or educationally disadvantaged persons. If this is an in-class project, describe how you will minimize the possibility that students will feel coerced.

   c. How will you obtain informed consent from each participant or the subject’s legally authorized representative and ensure that all consent forms are appropriately documented? Be sure to attach a copy of your consent form to the project summary.

   d. Show that the research plan makes provisions to monitor the data collected to insure the safety of all subjects. This includes the privacy of subjects’ responses and provisions for maintaining the security and confidentiality of the data.

3. Check the appropriate box(es) that describe the subjects you plan to use.

   - Adult volunteers
   - Mentally Disabled People
   - CAL University Students
   - Economically Disadvantaged People
   - Other Students
   - Educationally Disadvantaged People
   - Prisoners
   - Fetuses or fetal material
   - Pregnant Women
   - Children Under 18
   - Physically Handicapped People
   - Neonates

4. Is remuneration involved in your project? □ Yes or ☑ No. If yes, Explain here.

5. Is this project part of a grant? □ Yes or ☑ No. If yes, provide the following information:
   - Title of the Grant Proposal
   - Name of the Funding Agency
   - Dates of the Project Period

6. Does your project involve the debriefing of those who participated? □ Yes or ☑ No
If Yes, explain the debriefing process here.

7. If your project involves a questionnaire interview, ensure that it meets the requirements of Appendix __ in the Policies and Procedures Manual.
1. The purpose of the study is to examine the correlation between the core strength of tennis players and the velocity of flat tennis serves. This research is a non-experimental, correlational study. The dependent variable will be the tennis serve velocity. The independent variable will be the recorded core strength. Thirty subjects for this study will be volunteer male and female tennis players from NCAA Division Two and Three colleges; California University of Pennsylvania, Washington and Jefferson College and Messiah College. My hypothesis is that tennis players with higher core strength will have a faster serve velocity.

Subjects will be tested over one day. The testing day will take approximately 45 minutes to complete. The time will be adjusted given the results of the Preliminary Research. The athlete will be explained and demonstrated how to perform the double leg-lowering test for core strength. They will complete this test 3 times. Then, the athlete will be taken to a gymnasium that has a tennis court set up for the player. The athlete will have a seven-minute warm-up before the serve velocity portion of the test will be complete. The warm-up will consist of two minutes of jogging, three minutes of ground strokes hits (the researcher will hit balls to the athletes that will incorporate forehand, backhand, volley and overhead shots), and then the athlete will have two minutes to practice the flat serve. The researcher will be standing at the net with the radar gun measuring the velocity of the serve. The velocity of the first three good serves that make it into the service box will be recorded.

2. a. There are foreseeable risks and discomforts in this study. The possible risks are to the shoulder during maximal velocity testing. The risk of any shoulder injury is very minimal because tennis players are used to hitting at maximum velocity during the serve and other shots. However, the researcher’s knowledge of a proper warm-up before testing will minimize these risks further. The benefits to this testing session to the minimal risk is that if the hypothesis is proven correct, then improving core strength for the service game will decrease the stress placed on the shoulder during the serve, thus reducing the risk of injury.

b. The athletes will be volunteers from the three schools mentioned previously.

c. The athlete will be given time before the testing session to read over and sign the informed consent form.

d. The subjects will be given a number for collection of all data. All data sheets will be stored in a secure
location, which only the student researcher and research advisor will have access to.
Project Director’s Certification

Program Involving HUMAN SUBJECTS

The proposed investigation involves the use of human subjects and I am submitting the complete application form and project description to the Institutional Review Board for Research Involving Human Subjects.

I understand that Institutional Review Board (IRB) approval is required before beginning any research and/or data collection involving human subjects. If the Board grants approval of this application, I agree to:

1. Abide by any conditions or changes in the project required by the Board.
2. Report to the Board any change in the research plan that affects the method of using human subjects before such change is instituted.
3. Report to the Board any problems that arise in connection with the use of human subjects.
4. Seek advice of the Board whenever I believe such advice is necessary or would be helpful.
5. Secure the informed, written consent of all human subjects participating in the project.
6. Cooperate with the Board in its effort to provide a continuing review after investigations have been initiated.

I have reviewed the Federal and State regulations concerning the use of human subjects in research and training programs and the guidelines. I agree to abide by the regulations and guidelines aforementioned and will adhere to policies and procedures described in my application. I understand that changes to the research must be approved by the IRB before they are implemented.

Professional Research

Project Director’s Signature

Department Chairperson’s Signature

Student Class Research

Student Researcher’s Signature

Supervising Faculty Member’s Signature if required

Department Chairperson’s Signature

ACTION OF REVIEW BOARD (IRB use only)
The Institutional Review Board for Research Involving Human Subjects has reviewed this application to ascertain whether or not the proposed project:

1. provides adequate safeguards of the rights and welfare of human subjects involved in the investigations;
2. uses appropriate methods to obtain informed, written consent;
3. indicates that the potential benefits of the investigation substantially outweigh the risk involved.
4. provides adequate debriefing of human participants.
5. provides adequate follow-up services to participants who may have incurred physical, mental, or emotional harm.

[Check box for Approved or Disapproved]

Chairperson, Institutional Review Board  Date

02.14.08
Appendix C5

Individual Data Collection Sheet
<table>
<thead>
<tr>
<th>DLL angle 1</th>
<th>DLL angle 2</th>
<th>DLL angle 3</th>
<th>AVG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SERVE 1</th>
<th>SERVE 2</th>
<th>SERVE 3</th>
<th>AVG</th>
</tr>
</thead>
</table>
Appendix C6

Spec Sheet for Radar Gun
# Specifications

## STALKER Sport

### PERFORMANCE SPECIFICATIONS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed Range</td>
<td>5 - 250 MPH, 8 - 400 KPH</td>
</tr>
<tr>
<td>Accuracy</td>
<td>+ / - 0.1 MPH</td>
</tr>
<tr>
<td>Target Acquisition Time</td>
<td>0.046 Seconds (Ball Modes)</td>
</tr>
<tr>
<td></td>
<td>0.08 Seconds (Vehicle Modes)</td>
</tr>
<tr>
<td>Sample Rate</td>
<td>25 Speed Updates per Second</td>
</tr>
<tr>
<td>Max. Clocking Distances (Estimated)</td>
<td>4000 Feet - Passenger Car</td>
</tr>
<tr>
<td></td>
<td>1500 Feet - Snowmobiles</td>
</tr>
<tr>
<td></td>
<td>1000 Feet - Watercraft</td>
</tr>
<tr>
<td></td>
<td>200 Feet - Baseballs</td>
</tr>
</tbody>
</table>

### MICROWAVE SPECIFICATIONS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Frequency</td>
<td>24.150 GHz (K Band)</td>
</tr>
<tr>
<td>Polarization</td>
<td>Circular Polarization</td>
</tr>
<tr>
<td>3 db Beamwidth</td>
<td>11 Degrees Nominal</td>
</tr>
<tr>
<td>Microwave Source</td>
<td>Gunn-Effect Diode</td>
</tr>
<tr>
<td>Receive Type</td>
<td>Schottky Barrier Mixer Diode</td>
</tr>
<tr>
<td>Power Output</td>
<td>15 Milliwatts Nominal</td>
</tr>
</tbody>
</table>

The STALKER SPORT Complies with Part 15 and Part 90.101 of the FCC rules. FCC ID #IBOACM1003.

### GENERAL SPECIFICATIONS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Type</td>
<td>Stationary Doppler Radar</td>
</tr>
<tr>
<td>Computer Processor</td>
<td>40 MHz Motorola 56002 DSP</td>
</tr>
<tr>
<td>Display Type</td>
<td>Backlighted Liquid Crystal</td>
</tr>
<tr>
<td>Operating Temperatures</td>
<td>-20F to + 120F</td>
</tr>
<tr>
<td>Storage Temperatures</td>
<td>-40F to + 140F</td>
</tr>
</tbody>
</table>

### ELECTRICAL SPECIFICATIONS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery Handle</td>
<td>7.5 VDC, 1.5 Ah, Ni-Cad</td>
</tr>
<tr>
<td>Corded Handle Input</td>
<td>13.8 VDC (9.0 - 16.0 VDC)</td>
</tr>
<tr>
<td>Current Requirements (At 7.5 Volts DC)</td>
<td>Transmitting - 0.66 Amps</td>
</tr>
<tr>
<td></td>
<td>Standby - 0.20 Amps</td>
</tr>
<tr>
<td></td>
<td>Sleep Mode - 0.04 Amps</td>
</tr>
</tbody>
</table>

### PHYSICAL SPECIFICATIONS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (Battery Handle)</td>
<td>2.5 Pounds</td>
</tr>
<tr>
<td>Weight (Corded Handle)</td>
<td>2.2 Pounds</td>
</tr>
<tr>
<td>Dimensions</td>
<td>9.25” H x 3.5” W x 10.2” L</td>
</tr>
<tr>
<td>Housing Material</td>
<td>High Impact Polycarbonate</td>
</tr>
</tbody>
</table>

### WARRANTY

- On Radar Gun: 2 Years, Parts and Labor
- On Batteries: 90 Days Replacement

### SERIAL COMMUNICATIONS PROTOCOL

A Display Handle or Corded Interface Handle is required for data communications to speed display boards, computers, and other electronic devices. The data connector is on the bottom of these handles. The display handle requires that the radar gun be powered through the data connector. The corded interface handle includes a cigar lighter plug for powering the radar gun.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connector on Handles</td>
<td>3 Pin Switchcraft TA3ML</td>
</tr>
<tr>
<td>Mating Connector</td>
<td>Switchcraft TA3FL</td>
</tr>
<tr>
<td>Pin Order</td>
<td>Pin 1 - Data</td>
</tr>
<tr>
<td></td>
<td>Pin 2 - 12 VDC Power</td>
</tr>
<tr>
<td></td>
<td>Pin 3 - Ground</td>
</tr>
<tr>
<td>Data Type</td>
<td>TTL Format</td>
</tr>
<tr>
<td></td>
<td>+ 5V for Logic High</td>
</tr>
<tr>
<td></td>
<td>0V for Logic Low</td>
</tr>
<tr>
<td>BAUD Rate</td>
<td>1200 BAUD</td>
</tr>
<tr>
<td>Data Format</td>
<td>8 Data Bits</td>
</tr>
<tr>
<td></td>
<td>No Parity</td>
</tr>
<tr>
<td></td>
<td>2 Stop Bits</td>
</tr>
</tbody>
</table>

Data is sent in packets of four ASCII characters followed by a carriage return. A new data word is sent every time the speed changes (up to 25 samples per second) and/or every 1/3 of a second if the speed remains the same.

Example for 59.8 MPH (Vehicle Mode with Tenth Units)

| Data Byte 1, ASCII 0               |
| Data Byte 2, ASCII 5               |
| Data Byte 3, ASCII 9               |
| Data Byte 4, ASCII 8               |
| Data Byte 5, ASCII CR              |

Example for 105 MPH (Ball Mode with Whole Units)

| Data Byte 1, ASCII 1               |
| Data Byte 2, ASCII 0               |
| Data Byte 3, ASCII 5               |
| Data Byte 4, ASCII : (Colon)       |
| Data Byte 5, ASCII CR              |

Peak Mode - if Peak Hold is ON, the speed information transmitted will be only the peak speeds. With Peak Hold OFF, the data will be based on the continuously updated speed information.

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Appendix C7

Demographic Information
Demographic Information

College: __________________________

Year in college: ________________

Gender: __________________________

Height: __________________________

Weight: __________________________

Years participating in competitive tennis (starting freshman year of high school): ___________

Type of racket: ____________________

String tension: ____________________

Preferred serving style (ie: flat, slice, topspin, other): ______________________________________

Have you had any injuries to your serving shoulder within the past year? _______________________

If so, do you still have pain or problems with that shoulder? ________________________________
REFERENCES


ABSTRACT

Title: A Correlation between Core Strength and Serve Velocity in Collegiate Tennis Players

Researcher: Renee E. Zingaro

Advisor: Dr. Robert Kane

Date: May 2008

Research Type: Masters’ Thesis

Purpose: The purpose of this study was to determine if there was a correlation between core strength and flat serve velocity in a collegiate tennis player.

Problem: To find if core strength is a vital aspect to help a player gain more velocity on his or her flat serve.

Method: Eleven female and six male colligate tennis players from Division II and III were tested. Each player performed a modified double leg-lowering test for core strength and flat serves for velocity.

Findings: There was a positive correlation between core strength and serve velocity for the women participants, but not the men.

Conclusion: Core is an important part of a training regimen for tennis players. However, the serve is a multifactorial movement and should be treated as such. Thus, one should attempt to improve all of the factors associated with the serve and not one single component.