The Effects of a 12 Week Conditioning Program on Fitness in Female Collegiate Tennis Players

Thesis

Presented to the Graduate Council of
Southwest Texas State University
In Partial Fulfillment of
The Requirements

For the Degree

Master of Education

By

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San Marcos, Texas
August, 2000

ACKNOWLEDGEMENTS

Thanks to my parents for giving me the love and support that I needed through out all my years in school.

Thanks to my Chair, Dr. John Walker for all of his help with this project. He kept me going through all the rough spots.

Thanks to Dr. Murray, and Dr. Lloyd for being supportive and patient through out this project.

Thanks to Coach Brenda Burgess for all of her ideas and help during this project.

Thanks to the SWT women's tennis team for being so cooperative with the testing and the off-season workout program.

Thanks to Dr. Walker's measurement and evaluation class for their help in this project.

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ABSTRACT

The Effects of a 12 Week Conditioning Program On Fitness in Female Collegiate Tennis Players

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Previous research has failed to show the effects of a specific training program for tennis players. The purpose of this study was to determine the effects of a 12-week off-season training program on cardio-respiratory endurance, flexibility, muscular strength, agility, power, and body composition in collegiate female tennis players. The subjects were 6 female tennis players and 15 female college students in assorted P.E. classes served as a control group. The subjects performed the 1.5-mile run, vertical jump, medicine ball chest pass, push-ups, sit-ups, grip strength, flexibility and three agility tests pre- and post- training. The tennis players completed a 12-week training program specifically designed to prepare for tennis competition, while the

control group participated in various physical education classes. The treatment group showed improvements in the fitness components (1.5 mile run, sit-up test, push-up test, sit-and-reach) and two of the three agility tests but did not show any improvement in body weight, percent fat, grip strength or power tests. The control group showed no improvement on any of the tests. These data suggest that a 12-week specific training program may improve aerobic fitness, muscular endurance, lower-back & hamstring flexibility, and agility in female collegiate tennis players. However, the length of this 12-week program may not have been sufficient to cause improvement in grip strength or upper and lower body power.

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The Effects of a 12 Week Conditioning Program on Fitness in Female Collegiate Tennis Players

Off-season conditioning has become a vital component to the success of current tennis programs (United States Tennis Association, 1998). Today's tennis players are larger in stature, quicker, and stronger. As a result of their strenuous off-season training regimens that focus on muscular strength, muscular endurance, cardiovascular endurance, and flexibility, the speed of the serve has increased, body control has increased, and placement of tennis shots has become more precise (USTA, 1998). This has led to an increased overall level of play (USTA, 1998).

Success in tennis requires specific tennis practice, but also muscular strength, muscular endurance, cardiovascular endurance, flexibility, and agility training. Strength is very important to the tennis player because it allows the muscles to contract more forcefully, which produces more power (Jorgensen, 1976), resulting in explosive speed and harder shots. Strength training for tennis players should be comprehensive. It should include upper and lower body exercises as well as exercises that work the right and left sides of the body, equally to help off-set the differences between dominant and non-dominant body parts. This balance improves the consistency of the player's strokes (Groppel & Roetert, 1992).

The ability of the tennis player to participate in matches of long duration and to be able to play well throughout the entire match is based on endurance training and anaerobic power. Cardiovascular training includes aerobic (with oxygen) activities such as jogging, and walking, and anaerobic (without oxygen) training (NSCA, 1994). This includes high intensity activities of short duration such as sprints and plyometrics. Both aerobic and anaerobic forms of training are needed for tennis since a tennis match consists of a mixture of short bursts of activity, long rallies, and short recovery periods (USTA 1998).

Flexibility may be the most important training component for tennis (NSCA, 1994, p.44). Tennis requires movement across a broad range of motion; consequently, the body must be flexible enough to exert force at a variety of joint angles (Cooper & Fair, 1977).

Muscular strength, muscular endurance, cardiovascular endurance, and flexibility have a large impact on a player's overall tennis game. Not only are they essential for tennis performance but they also may help prevent injury while playing tennis (USTA, 1998). Most tennis injuries are caused by overuse as well as increased strain on the muscle, resulting in the over-stretching of a muscle beyond its limit. This type of injury can be prevented by strength and flexibility training (Copley, 1980). Strength training will help make movement more efficient, which will reduce the number of overuse injuries (Cooper & Fair, 1977). Flexibility will increase the range of motion that muscles must be stretched for any movement, thus decreasing the likelihood of pulled muscles. Strength, endurance, and flexibility are crucial because they are the basis for improving performance and reducing the risk of injury in the tennis player.

Although programs are available for athletes in general on strength and endurance training, previous research has failed to determine the effect of specific workout programs for tennis players. There is a need for research that specifically defines an effective off-season tennis program.

Purpose of the Study

The purpose of this investigation was to determine the effects of a 12-week off-season training program on cardio-respiratory endurance, flexibility, muscular strength, muscular endurance, agility, power, and body composition in collegiate female tennis players.

Hypotheses

It was hypothesized that:

1. The cardio-respiratory fitness of the athletes would improve during the 12-week training program.
2. The athlete's power would increase as a result of the 12-week training program.
3. The agility of the athletes would improve after the 12 weeks of training.
4. The athletes' flexibility would increase due to the 12-week training program.
5. The strength measures of the athletes would increase during the 12-week training program.
6. The body composition of the athletes would improve over the course of the 12-week training program.

Delimitations

This study is delimited to:

1. Females
2. Collegiate tennis players
3. 12 week training program

4. Field tests of fitness (sit-ups, push-ups, 1.5-mile run, sit-and-reach), power (vertical leap, medicine ball toss), agility (shuffle, spider, hexagon), and grip strength (isometric grip, handgrip dynamometer).

Definition of Terms

1. USTA - United States Tennis Association
2. Shuffle test - an agility test in which the subjects start on the middle service line and then shuffle without crossing their feet to one doubles line, then to the other doubles line and back to the middle.
3. Hexagon test - an agility test in which the subjects start in the middle of a hexagon which is taped to the court. They must jump out of the hexagon and back into the middle of it over each side while always facing forward. One trial is complete when the subject has finished three revolutions of the hexagon.
4. Spider test - an agility test in which the subject starts in the center of the court on the baseline. A tennis ball is placed in each corner at the baseline, each intersection of

the service line and the out of bounds line, and at the center service line and service line. There are five tennis balls used in all. The subject must run and retrieve one tennis ball and return it to the starting point before retrieving the next ball. When all five balls are returned to the starting point then one trial is completed.

Significance of the Study

Results from this study will be used to determine the effects of various training methods on the overall performance of female collegiate tennis players. Such information can be used to determine the most optimal and time-efficient training protocol for collegiate female tennis players.

Literature is limited to investigations on the effects of various types of training on male athletes. However, women's athletics are becoming more popular. With the increased emphasis on Title IX, schools are required to offer more women's sports. This will increase the number of women competing in athletics. As a result, there is an increased need for sport specific training for women athletes.

Chapter 2

Review of the Literature

Competitive tennis requires athletes to train a variety of skills in order to be successful. Bergeron (1988) identifies these skills as strength, fitness, and agility. The tennis player should strengthen the legs because they are the basis for the athletes movement and power, along with the upper body, specifically the arms and shoulders. The arms and shoulders are important because they help the tennis player control the racket to execute the various strokes. Another important aspect of training for tennis players is both aerobic and anaerobic fitness. This is very important because a tennis match can last for several hours, with a short amount of time for the athlete to recover. Finally, tennis requires considerable agility, because the athlete must often react quickly and move into position to return the previous shot.

The purpose of this review of literature is to discuss various aspects of conditioning for competitive tennis players. This review will also discuss some of the common injuries experienced by tennis players, as well as how training may prevent these injuries. This review will include a brief discussion on overall fitness, as well as the five basic physical requirements needed to play tennis effectively. These include muscular strength, power, muscular endurance, cardiovascular endurance, flexibility, and agility.

Strength Training

De Vries (1980) defines muscular strength as the maximum force that a muscle group can exert over a brief period. Isometric strength is defined as the maximum force that can be exerted over a brief period of time without movement. An isotonic contraction is one that lifts a constant load as the muscle shortens with varying tensions (Fox, Bowers, & Foss, 1993, 160).

Many physiological changes occur in the body as a result of strength training. These changes take place on two different levels. The first change is a neurological one, which can be seen within the first two weeks of training (McArdle, Katch & Katch, 1996, p.440). In other words, because of increased neural input to muscle fibers and golgi tendon organs, athletes may feel stronger and may have more energy (Staron, 1994). The physiological adaptations to strength training begin to occur after 3 -

6 weeks (Komi, 1986). These may include increases in muscle size (hypertrophy), ligament strength, and tendon strength (McArdle et al, 1996, 440). Hypertrophy occurs primarily because of an increased number and size of myofibrils per muscle fiber (Goldspink, 1964), increased total amount of contractile protein in the myosin filament (Penman, 1969), and increased capillary density per fiber. Increased amounts and strength of connective, tendinous, and ligamentous tissues is another reason that hypertrophy occurs (Tipton, Matthes, Maynard, & Carey, 1975).

The force of a tennis stroke is influenced by strength that is generated by the sequential summation of forces (Bergeron, 1988). This begins with the ground reaction forces and then moves to the forces produced by the muscles and ends with the follow through after the racquet makes contact with the ball.

Strength training can have a profound affect on an athlete's performance in competition (Roetert, Ellenbecker, Chu, & Bugg, 1997). Chandler, Kibler, Stracener, Ziegler & Pace (1992), mention that strength training as well as endurance training can also help to keep an athlete free of injury.

Strength Training for Tennis

Strength training brings out such beneficial physiological adaptations as hypertrophy, and increases in both ligament and tendon strength. Therefore, strength training should be implemented in the training of tennis players (USTA, 1998). Tennis players sometimes mistakenly believe that the increase in muscle size due to strength training may cause them to become too bulky (Behm, 1987). However, this will not be the case if the athlete participates in a strength training program that is specific to tennis (USTA, 1998, p.68). Since tennis matches can go on for a prolonged period of time, strength training would allow a tennis player to be able to hit the ball at the end of the match just as hard as he/she did at the beginning of the match (USTA, 1998, p.61).

Contrary to previous reports that have indicated tennis to be primarily an upper body sport (Behm, 1987), strength training of the lower body should also be emphasized. There are many different exercises that can be done for the legs, such as, squats, leg press, hamstring curls, leg extensions, and leg abduction/adduction (Bergeron, 1988).

The reason for the shift in emphasis from upper body to lower body strength training may be attributed to the fact that the leg strength provides tennis players with greater power (Spassov, 1989). In addition, the legs provide stability and support to the athlete while at the same time providing for lateral movement (Bergeron, 1988). This will allow the player to get to the ball more quickly and have time to set up for the shot. Bergeron (1988) reports that the leg muscles are probably the most important group of muscles for the tennis player to specifically strengthen through a training program since the upper body will naturally strengthen from playing tennis.

Although Bergeron (1988) de-emphasizes the importance of upper-body strength in tennis, Groppel and Roetert (1992) report that the athlete's upper body strength needs to also be specifically trained in order to achieve optimum stroke potential and to prevent injury. For instance, strength training is very important for a tennis players' grip strength. Behm (1988) asserts that grip strength is essential for a tennis player to control his/her racket throughout the full range of motion. In addition, since tennis players tend to develop major differences in strength between their dominant and non-dominant arms (Ellenbecker, 1992), strength training is needed to off set such imbalances.

The shoulder also needs to be strengthened because of its constant use. Zorbas and Karpovich (1951), found that weight lifters had a faster rotary arm motion than non-weight lifters did. These authors also concluded that the faster the arm could rotate, the more torque would be produced. Greater torque produces more power and velocity at the racquets point of impact with the ball (Zorbas & Karpovich, 1951), which results in faster more powerful shots.

Power

In order to allow the arm to rotate faster, the muscles of the shoulder need to be stronger. Therefore, generation of power in conjunction with strength is crucial for a tennis player (Chandler et al, 1992). Power is defined as "the time rate of doing work" (Meriam, 1978). It can also be stated as the "amount of work per unit of time, and be thought of as the explosiveness of a muscle or muscle groups" (USTA, 1998, p.62). Since tennis is such a dynamic sport, the athlete should participate in strength and power training programs that are specific to tennis (USTA, 1998, p.65). These specific training protocols consist of exercises that are performed with fast, dynamic movements and low resistance instead of slower dynamic movements with heavier resistance. An example of such a protocol is performing groundstrokes with rubber exercise bands or dumbbells (Treiber, Lott, Duncan, Slavens & Davis, 1998).

According to the USTA (1998), body movement during tennis competition requires a broad range of motion; consequently, tennis players should avoid static training. Static movements do not allow the joints and muscles to move through their full range of motion like dynamic movements. Using dynamic types of training methods will allow the tennis player to increase both strength and power, which will contribute to an improved performance level.

Aerobic Training

The aerobic process is one that uses molecular oxygen to generate energy from fuel (NSCA, 1994, p.68). There are many physiological changes that occur during aerobic training. Some of these changes include increases in heart size (Mitchell & Raven, 1994), stroke volume, and cardiac output. Aerobic training also causes a decrease in resting and submaximal heart rate.

The increase in heart size during aerobic training is seen by a minor thickening of the walls in the left ventricular cavity (Mitchell & Raven, 1994). Stroke volume increases due to the increase in heart size as well as an enhanced ventricular contractility (Spina, 1992). McArdle et al (1996), mention that cardiac output is the most significant change due to aerobic training. It increases directly from an improved stoke volume. The decrease in resting and submaximal heart rate is due primarily to the increased efficiency of the heart muscle.

Aerobic training should include training that provides a sufficient cardiovascular overload to stimulate increases in stroke volume and cardiac output. This should be accomplished by performing sport specific exercises. Most of these physiological changes occur in the cardiovascular system. For instance, with aerobic training, heart rate decreases, stroke volume increases, cardiac output increases, and blood pressure decreases. All four of these adaptations will not only allow an athlete to perform at a greater capacity but also to recover faster after exercise. As a result of aerobic training, these adaptations will allow an athlete to perform at a higher degree of efficiency (Barnard, 1975).

With aerobic training, body composition improves, i.e. body fat decreases, and thus performance typically improves (Bouchard, 1990). More specifically, aerobic training not only increases caloric expenditure, but it also increases the rate at which the muscles burn fat. As a result of such an activity, percent body fat decreases while percent lean body mass increases (Tanaka, 1993). In most instances, accompanying physiological changes due to aerobic exercise cause a noticeable increase in performance (McArdle et al, 1996, p.401).

Measuring Aerobic Fitness

Aerobic fitness is dependent on the body's ability to deliver oxygen to contracting muscles in order to maintain continuous, rhythmic, steady movement for extended periods of time (ACSM, 1990). The most valid index of aerobic fitness is VO_2max (Astrand and Rodahl, 1970, p.314), and is accepted as an indicator of a person's exercise capacity (ACSM, 1991). VO_2max is the maximum volume of oxygen a person uses during exhaustive exercise (Mitchell & Blomquist, 1971). Laboratory assessment of VO_2max requires the subject to exercise at a gradually increasing workload while their expired oxygen and carbon dioxide levels are measured. VO_2max is the rate of oxygen consumption at the maximal workload at which VO_2 has peaked and begins to level off, or an increase in the workload does not result in an increase in oxygen consumption (Noakes, 1988).

VO_2max is age-dependent. It steadily increases during childhood and peaks in early adulthood, at about age 25, after which it slowly declines (Buskirk & Hodgson, 1987). This decline can be slowed by regular exercise, and maintaining a physically active lifestyle and an optimal level of body composition (Pollock et al., 1987; Plowman et al., 1979; Rogers et al., 1990). Furthermore, maintaining an appropriate level of aerobic fitness has been shown to be a strong indicator of good health and a reduced risk of chronic lifestyle diseases (Blair & Minocha, 1989; Hagberg, 1990; Haskell, 1994).

The measurement of VO_2max in a clinical laboratory setting for research data collection is usually accomplished through a method known as "indirect calorimetry" (Consolazio, Johnson, & Pecora, 1963; Jones & Campbell, 1982). This technique involves the analysis of the volume and gasious content of the subject's expired air, requiring expensive oxygen and carbon dioxide analysis equipment. The use of such equipment is limited to well-trained technicians, and may not be practical for assessing large numbers of subjects. For this reason, alternative methods for estimating VO_2max have been developed. The most commonly used methods for estimating VO_2max clinical assessment are based on a subjects total exercise time during a maximal exercise test (Balke, 1963; Bruce, Kusumi, & Hosmer, 1973; Foster, Jackson, & Pollock, 1984). Since some adults may have a low tolerance for exercise, especially at a maximal workload, other methods have been developed for estimating VO_2max based on the subject's performance of a submaximal exercise protocal (Golding, Myers, & Sinning, 1989). Such procedures can require the subject to exercise on a cycle ergometer (Astrand & Rhyming, 1954; Bruce, 1973) or treadmill (Mahar, Jackson, & Ross, 1985; Ross & Jackson, 1990), or engage in bench stepping (Brouha, 1943; Sloan, 1959).

Clinical estimation of VO_2max requires little equipment for varying the exercise workload of the subject; however, these methods are usually inappropriate for a field setting such as a physical education class or athletic facility where exercise equipment is not available for mass testing. For this reason, field tests of aerobic capacity have been developed and validated. These tests require almost no equipment and are useful for testing large numbers of subjects at the same time, two aspects that characterize the measurement of physical fitness in a field setting. Some field tests have been developed which require the subject to walk (Kline, Porcari, Hintermeister, Freedson, Ward, McCarron, Ross, & Rippe, 1987) or jog (George, 1993) for one mile. The subject's performance time, as well as heart rate, body weight, and age are used to estimate their VO_2max.

Distance run tests are the most commonly used field tests for determining aerobic capacity. Cooper (1968) developed models for estimating VO_2max from 12-minute or 1.5 mile run performances. Since then, the following distance runs have been validated as field tests of aerobic capacity: 1-mile run (Cureton, 1977), 1800 yard run (Gutin, 1976), 9 - minute run (Jackson & Coleman, 1976), and 20 - minute steady-state jog (Murray, Walker, Jackson, Morrow, Eldridge, & Rainey, 1993). Baumgartner and Jackson (1995) report that distance run tests have been shown to have high correlations with VO_2max when the running distances are at least one mile in distance or 9 minutes in duration.

Anaerobic Training

Anaerobic metabolism results in the production of energy from carbohydrates in the absence of molecular oxygen (Brooks & Fahey, 1984). During the first 2 - 3 minutes of exercise, anaerobic metabolism supplies the majority of the energy for exercise (Karlsson & Saltin, 1970). More specifically, in the first 6 - 10 seconds, this energy comes from stored adenosine triphosphate (ATP) in the muscle and ATP regenerated from stored phosphocreatine (Saltin, 1973). Then the energy is usually derived for up to 3 minutes from generation of ATP from the anaerobic metabolism of carbohydrates (Karlsson, 1971). Therefore, in order to train the muscles anaerobically, the athlete needs to perform short, quick exercises that last no more than two minutes (NSCA, 1994, p.410).

Muscular endurance has been defined as the ability to continuously contract the same muscle groups and to resist muscular fatigue (deVries, 1980). Baumgartner and Jackson (1995) distinguish between two types of muscular endurance: 1) absolute endruance, where all subjects must lift the same weight or move the same resistance, and 2) relative endurance, where the weight lifted or resistance moved varies among subjects, depending on each subject's body size or absolute muscle strength. Most field tests of muscular endurance involve lifting the subject's own body weight (which varies among subjects), and can be considered measures of relative muscle endurance.

Tests of abdominal muscle endurance require the subject to use the abdominal muscles to move the body's upper extremity to exhaustion. Sit-up tests are the most common technique for measuring abdominal muscle endurance and are included on most physical fitness and motor ability test batteries (Morrow, Jackson, Disch, & Mood, 1995, p.234). The traditional method for performing sit-ups required the subject to keep their legs straight throughout the test. Kendall (1965) noticed that this method usually causes the subject to arch or hyperextend their lumbar spine. This indicates that the abdominal muscles do not have sufficient strength to prevent the hip flexor muscles from increasing the subject's pelvic tilt. Kendall (1965) claimed that such hyperextension may result in injury to the lower back. This problim has been resolved by the use of bent-knee sit-ups (or curl-ups) for most modern physical fitness test batteries (Baumgartner & Jackson, 1995). The risk of injury is reduced in the bent knee position because the hip flexor muscles are not extended, and the abdominal muscles act as the flexors of the lumbar spine. This technique enables the subject to better isolate their abdominal muscles for moving their torso, and is considered a more valid measure of abdominal muscle endurance than the straight-leg sit-up (Golding et al., 1989).

Arm and shoulder girdle muscle endurance is also a common test of physical fitness. Johnson and Nelson (1974) have shown that push-up tests have high reliability (Rxx=.93) when standardized test procedures are followed. Push-up test results are measures of relative muscle endurance because subjects must push against the gravitational resistance of their own body weight, and the results of push-up tests are negatively correlated with the subjects' body weight (Pate, Slentz, & Katz, 1989).

Cardiovascular and Muscular Endurance For Tennis

Dawson et al (1985) reported average rally times of 10 seconds in college tennis matches. This finding suggests the need for a concentration on anaerobic training, specifically on the immediate energy systems, which would allow a tennis player to perform at very high levels for short periods of time (Behm, 1987). In that same study, Dawson et al (1985) also showed that the recovery ratio was 1:2 for every 10 seconds of work, 20 seconds of recovery is needed. It was suggested that improvements in the cardiovascular system through aerobic training might assist the athlete in the recovery process from anaerobic exercise.

The USTA (1998) guidelines for tennis conditioning suggest that the tennis player train both aerobic and anaerobic energy systems. There are many different types of aerobic exercises that a tennis player can perform, such as running, swimming and cycling. The USTA (1998), also suggests implementing types of exercises that help train muscular endurance because tennis is performed primarily in short work: rest intervals, i.e. the athlete performs short bouts of work followed by slightly longer rest periods. A tennis player's primary training should consist of interval training and drills that include short multidirectional movement patterns (USTA, 1998, p.109). These drills may include wind sprints and side shuffles.

Both aerobic and anaerobic types of training will stimulate the muscles and joints to adapt by causing local and general physiological changes that will improve aerobic endurance, anaerobic power, and rates of recovery from each bout of work during a tennis match (Chandler, Kibler, Uhl, Wooten, Kiser & Stone, 1990).

Flexibility

Flexibility is the range of possible motion in a joint and its surrounding muscles (Cornelius, 1980, deVries, 1974, Getchell, 1979). Flexibility can be used to: 1) increase the performance of an athlete; 2) relieve soreness from participation in sports (Prentice 1983); 3) reduce injuries from hyperextension of a muscle or joint (Cooper, 1977).

Flexibility is determined by three main factors: 1) Heredity, 2) Neuromuscular components, 3) Muscle temperature. Heredity is determined by genetic factors (Peterson, 1983). Neuromuscular components such as muscle spindles and golgi tendon organs also affect flexibility. These keep the muscles from hyperextending by inducing the stretch reflex system (Fox, 1979). The stretch reflex is a naturally occurring event in the body that occurs when a muscle spindle is quickly stretched (Fox, 1979). This causes a sensory neuron in the muscle to activate a motor neuron in the spinal column, which causes the muscle to then contract (NSCA, 1994, p.291). Lastly flexibility is also affected by muscle temperature. Stretching before activity will cause an increase in muscle temperature because of an increased blood flow. This will then facilitate an increase in range of motion due to an increased muscle temperature (Prentice, 1984).

Flexibility training is very important for the tennis player because of the ranges of motion required of the athletes' body during competition (Cooper, 1977). Many tennis players ignore flexibility training for various reasons. These include: 1) it doesn't feel good and 2) the athletes do not realize the benefits of this type of training (USTA, 1998, p.33).

Chandler et al (1990) suggests that tennis is a sport that requires an extended range of motion. Therefore, the athlete should be flexible enough to move easily through the full range of motion required to perform each stroke (NSCA, 1994, p.44). Chandler et al. (1990) compared the level of flexibility between 86 junior elite tennis players and 139 athletes from other sports. They measured the flexibility of the hamstrings, quadriceps, gastrocnemius, and shoulder. It was concluded that the muscles of the tennis players were tighter overall in the sit-and-reach and shoulder internal rotation, but were more flexible in shoulder external rotation.

Cooper (1977) suggests that stretches should be done in a slow (static) manor and held for 15 to 25 seconds at point if mild discomfort. Specific areas that should be trained for tennis are the muscles that allow for lateral movement, such as the hip flexors and the groin muscles, the stabilizing muscles of the abdominal area, shoulder muscles and leg muscles.

The measurement of flexibility, or joint range of motion, is an important aspect of assessment for athletes, as well as patients recovering from orthopaedic injuries. Because flexibility is specific to a joint and its surrounding tissues, there are no valid tests of general flexibility (Miller, 1985). Measurement of hamstring flexibility by use of a goniometer has been shown to be reliable (Rxx=.90) in clinical trials (Jackson & Baker; Jackson & Langford, 1989). Lower back flexibility is usually measured with tests of trunk flexion and extension. The sit-and-reach test is the most commonly used measure of trunk flexion, although it actually measures the flexibility of the hamstring muscles (Morrow et al., 1995).

Injuries

Tennis players suffer from both chronic (over time) and acute (occur instantly) injuries. According to Roetert et al., (1997), most injuries in tennis are chronic injuries including the shoulder and lower back.

Shoulder injuries as well as lower back injuries are mostly derived from the repetitive swinging motion of a racket with every shot. For instance, repeated swinging motion causes momentum in axial rotation that leads to hyperextension of the back (Roetert et al, 1997).

Chronic injuries experienced in tennis may be prevented with the incorporation of flexibility exercises (Cooper, 1977). If performed correctly, flexibility exercises may be effective in the lengthening of muscles and enhancing the effects of strength training and thus the prevention of injuries (deVries, 1974).

Critique & Summary

The body, specifically muscles, joints, and tendons, of a tennis player are constantly under stress while playing tennis. Therefore, muscular strength, aerobic endurance, anaerobic power, agility and flexibility training become very important to the tennis player. Improving all of these components will not only improve an athlete's performance, but it will also reduce the risk of injury.

Previous research has validated general workout protocols for athletics but has not validated a sport specific program for tennis players. There is a need for research to develop a specific training program for tennis.

Chapter 3

Methods

The purpose of this investigation was to determine the effects of a 12-week off-season training program on cardio-respiratory endurance, flexibility, muscular strength, muscular endurance, agility, power, and body composition in collegiate female tennis players.

Subjects

The subjects of this study included an experimental group of six female tennis players from Southwest Texas State University. Each of these athletes compete regularly in intercollegiate tennis matches. This study also included a control group of 15 female college students from various physical education classes at Southwest Texas State University, and represented active, healthy females that were not varsity athletes.

Instruments

The instruments used in this study included:

1. A Physicians' scale to measure height and weight.
2. Hand Grip Dynamometer to measure grip strength.

3. A Sit and Reach box to measure flexibility.
4. Lafayette Instruments Isometric HandGrip system (Jackson System).
5. Skin fold calipers to determine body composition.

Procedures

Each subject was administered several different tests individually, over the course of one week. These tests were administered to the athletes at the beginning of an off-season practice and again after 12 weeks of conditioning.

The first test given was the 1.5-mile run. The subjects performed this test on a 400M track. They began with 15 minutes of stretching and warm-up exercises. The subjects then ran the 1.5 miles in one group and were timed by their coach.

Each subject's body composition was estimated by skin fold analysis using skin fold calipers. Skin fold measurements were taken at the triceps, supraillium, and thigh. According to Baumgartner and Jackson (1995, p.313) skin fold measurements at the triceps are measured by a vertical fold on the posterior midline of the upper arm halfway between the acromion and olecranon processes; the elbow should be extended and relaxed. The suprailium measurements are done by measuring a diagonal fold above the crest of the ilium at the spot where an imaginary line would come down from the anterior axillary line. Skin fold measurements on the thigh are measured by a vertical fold on the anterior aspect of the thigh midway between hip and knee joints (Baumgartner & Jackson, 1995, p.313). The subjects' height and weight were measured using a physicians' scale.

Flexibility

After 5 minutes of stretching, the subjects were tested for flexibility on a sit and reach box. The subjects were instructed to sit with their legs extended straight in front of them with their feet flat against the box. The subjects were then asked to place one hand on top of the other and lean forward as far as possible while keeping their legs straight. The subjects' maximum stretch was held for at least 1 second. They were given three practice trials and the result of the fourth trial was recorded (Baumgartner & Jackson, 1995, p.263).

Power

Lower body power was determined by a vertical jump test. The subjects started by standing next to the wall with a piece of chalk in their dominant hand and made a mark as high on the wall as they could reach, while keeping their feet flat on the floor. The subject then jumped straight up and made another mark on the wall. The subject started from a standing position and took no steps before jumping. The subject was given three chances to jump as high as possible. The difference in the starting mark and the highest mark made by the subject was measured and recorded (Baumgartner & Jackson, 1995, p.231).

Upper body power was measured by a medicine ball toss. Once again the subject was instructed to sit with their back flat against the wall and their legs extended straight out in front of them. A 2kg medicine ball was used in this test. The subject was instructed to toss the ball, like a chest pass in basketball, as far as she could. Each subject received three attempts and the greatest distance was recorded (USTA Video, 1990).

Muscle Endurance

Arm and Shoulder girdle muscle endurance was measured by a push-ups test. The subjects were then asked to get in a push-up position (legs straight, body being supported by the hands and toes) on a tumbling mat. Once the tester said go, the subjects did push-ups to volitional fatigue.

Abdominal muscle endurance was measured by a bent knee curl-up test. The subjects were paired up with a partner and while one subject got in a sit-up position (lying flat on back, knees bent) the partner would hold her feet flat on the floor. The subject would then be instructed to cross their arms across their chest. Once the time was started the subjects would curl-up to a sitting position and return their lower shoulder blades to the mat. The subject must not raise their hips off of the floor during the test. This test lasts for 60 seconds or until the subject can not do any more curl-ups (Fit Youth Today, 1986, p.78).

Grip Strength

The subjects were also tested for grip strength. This was done in two different ways. One of these tests was done using a hand grip dynamometer. The subject held the dynamometer by her side in her dominant hand. The subject was then instructed to squeeze the apparatus as hard as possible while keeping her arm by her side. Each subject was given three trials and the best score was recorded.

The other hand grip strength test was done using an electronic Isometric grip strength system. The testing machine was set up on a table and the subject was asked to sit in a chair on the other side of the table. The subjects grip the apparatus with their dominant hand, palm up, and set their free hand on the table. At this point the tester would push the start button. One beep will be heard and three seconds after that a second beep will be heard. The subject was instructed to grip the apparatus as tightly as possible on the first beep and release pressure on the second beep. This test was done three times with the best score being recorded (Baumgartner & Jackson, 1995, p.210).

Agility

The subjects performed three agility tests specific to tennis skill. They performed some warm up exercises before we began testing. These three tests were recommended by the USTA (United States Tennis Association) as tests for agility. They include the Shuffle test, the Hexagon test, and the Spider test.

The shuffle test begins in the center of the court at the service line. The subject then was instructed to shuffle from the middle of the court to the doubles line on one side, to the doubles line on the other side, and back to the middle. The object of the test is to do it as quickly as possible. The subjects were given three trials and the quickest time was recorded (USTA Video, 1990).

The hexagon test is executed by taping a hexagon shape on the court. Each side of the hexagon is 24 inches long. The subject was instructed to start in the middle of the hexagon and jump out of and back into the hexagon over each of the six sides. A trial is finished when the subject has completed 3 revolutions of the hexagon. The subjects were once again given three trials with their fastest time being recorded (USTA Video, 1990).

The final test was the spider test. For this test, five tennis balls are used and placed in each of the baseline corners, as well as one in the center of the court at the service line, and one on each sideline at the service line. An 8-inch by 8-inch box is taped in the center of the court at the baseline. The object of the test is for each subject to start at the box, run and get a tennis ball, starting with the right baseline, and returning it back to the box. When the subject returns the ball to the box, the ball must be set in the box so that it does not roll away. The subject then does the same thing with the other four tennis balls. Each subject was given three trials and the fastest time was recorded (USTA Video, 1990).

Training Program

The training program was broken down into four separate phases. The first phase was the Pre-competitive phase, and went from Aug. 30 - Sept. 28. This phase consisted of aerobic type activities, coupled with weight training. In the weight room the athletes completed 2-4 sets, of 8-10 reps, 2 to 3 times a week. For aerobic activity the athletes completed 1.5 mile runs, as well as doing aerobics for 20-30 minutes. The women also participated in on court drills to help prepare them for off-season tournaments.

The next phase was the Competitive phase (Sept. 29 through Oct. 16). During this phase of training the athletes decreased the number of sets in the weight room from 2-4, to 1-2. However, the number of reps increased to 10-15. At this point the athletes turned their focus to the rotator cuff and forearms. There was no aerobic conditioning during this phase, and a greater emphasis was put on anaerobic training. They performed on court sprints, as well as other drills aimed at improving speed and quickness.

The third phase lasting from Oct. 18, to Nov. 7, was called the Maintenance phase. This phase is aimed at maintaining the fitness level gained in the first two phases. The athletes continued to lift weights and performed endurance activities such as jogging. They also continued their on court drills for speed and quickness, but, with a little less frequency.

The final stage went from Nov. 8, to Nov. 19, and was called the Active rest stage. This stage was implemented to allow the athletes to perform other activities than tennis. This phase is also used to help prevent the athlete from becoming burned out on the sport. During this phase the athletes worked out on their own, with no instruction from the coach.

Design & Analysis

The Dependent Variables are:

1. Muscular Strength
   - A. Isometric Grip
   - B. Hand Grip Dynamometer
2. Muscular Endurance
   - A. Push-ups
   - B. Curl-ups
3. Power
   - A. Medicine Ball Toss
   - B. Vertical Leap
4. Flexibility: Sit & Reach
5. Agility
   - A. Shuffle test
   - B. Hexagon test
   - C. Spider test
6. Cardiovascular Endurance: 1.5 mile run

The Independent Variables are:

1. The Training program (Athletes vs. Control)
2. The Performance trials (Pre & Post tests)

A 2X2 Factorial ANOVA with repeated measures was used to determine the significance of the differences between the pre-tests and the post-tests.

Chapter 4

Results

<u>Body Size & Composition Measurements</u>

Table 1 reports the subjects' body size and body composition measurements. The sample appears to be representative of college-aged females that are in good health, active, and moderately fit.

Table 1				
Variables	Athletes		Control	
	Pretest	Post Test	Pretest	Post test
Body Weight (lbs)	142±38.8	140.4±40.5	144.6±20.2	145.1±21.1
Skinfold Sum (mm)	59.6±38.4	55.4±43	80.1±25.5	80±23.6
Percent Fat (%)	27.1±17.3	25.4±19.5	36.2±11.9	36.1±11

The treatment group (tennis athletes) and control group did not differ in height ($F1,18 = 0.12$, $p > .05$), body weight ($F1,18 = 0.07$, $p > .05$), sum of 3-site skinfold fat ($F1,18 = 0.15$, $p > .05$), or percent fat ($F1,18 = 0.17$, $p > .05$). During the training period, no change was observed in either the treatment group or control group for height ($F1,18 = 0.02$, $p > .05$), body weight ($F1,18 = 0.46$, $p > .05$), sum of 3-site skinfold fat ($F1,18 = 0.11$, $p > .05$), or percent fat ($F1,18 = 0.14$, p >

.05). Sample mean differences in sum of 3-site skinfold fat and percent fat can be attributed to random variation, and one subject in the treatment group whose body weight and percent fat exceeded the other subjects in the treatment group by 57-286%.

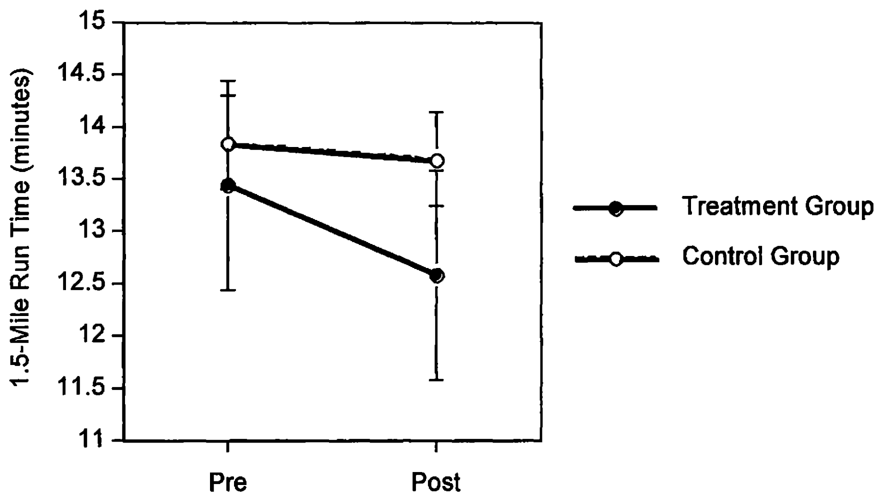
Fitness Measurements

Table 2 reports the subjects' physical fitness measurements. MANOVA revealed significant differences between the treatment (tennis athlete) and control groups for the performance variables of interest (Wilk's Lambda = 0.06, $F_{15,24} = 24.08$, $p < .05$).

Table 2				
Variables	Athl etes		Con trol	
	Pretest	Post test	Pretest	Post test
1.5 mile run (min)	11.2±5.8	12.6±1.9	13.7±1.7	13.7±1.8
Sit & Reach (In)	13.6±1.7	14.7±1.6	12.5±1.1	12.6±1.2
Sit-Ups (#)	30.8±4.1	37.4±5.7	28.1±4.8	29.5±5.6
Push-Ups (#)	13.8±7.1	21.8±10.6	16.4±3.6	17.1±2.9

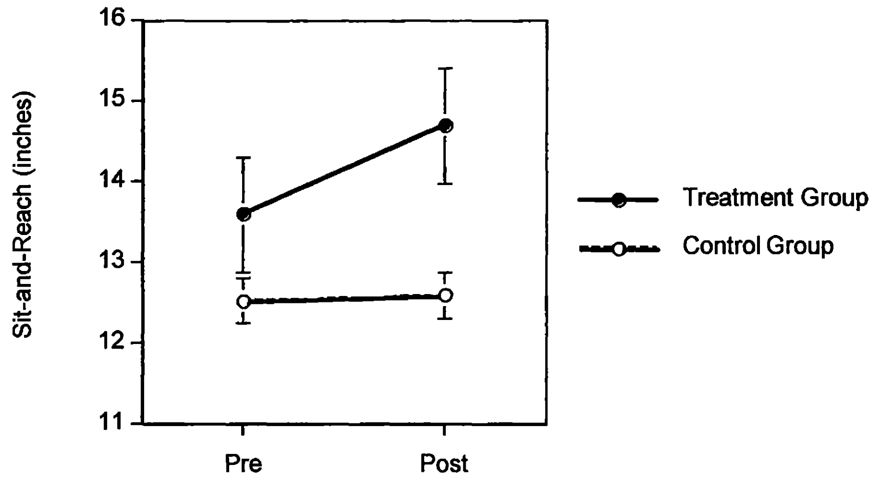
For the 1.5-Mile Run, the treatment and control groups did not differ in pre-test performance ($F_{1,18} = 0.61$, $p > .05$), but the treatment group improved more than the control group ($F_{1,18} = 13.12$, $p < .05$). Figure 1 demonstrates the group difference in 1.5-Mile Run.

Figure 1. 1.5-Mile Run Performance Difference Between the Treatment and Control Groups.



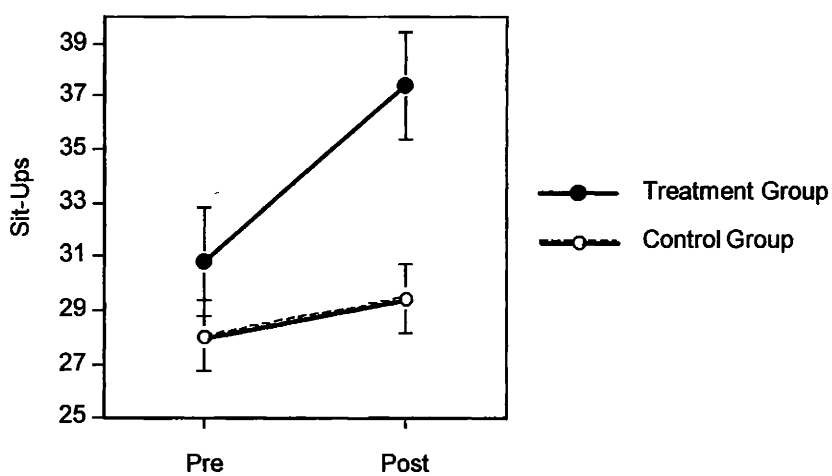
For the Sit-and-Reach test, the treatment group was more flexible overall ($F_{1,18} = 6.12$, $p < .05$), and also improved more than the control group ($F_{1,18} = 23.00$, $p < .05$).). Figure 2 demonstrates the group difference in the Sit-and-Reach test.

Figure 2. Sit-and-Reach Performance Difference Between the Treatment and Control Groups.



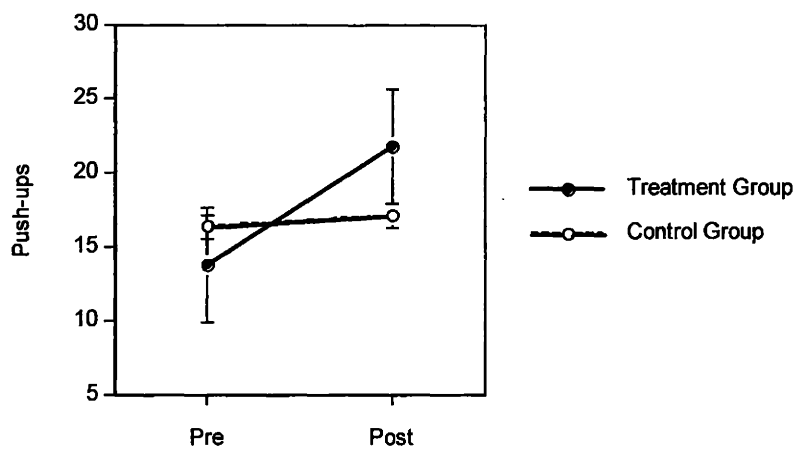
For the Sit-up test, the treatment and control groups did not differ in pre-test performance ($F1,18 = 4.41$, $p = .05$), but the treatment group improved more than the control group ($F1,18 = 10.32$, $p < .05$).). Figure 3 demonstrates the group difference in the Sit-up test.

Figure 3. Sit-up Performance Difference Between the Treatment and Control Groups.



Finally, for the Push-up test, the treatment and control groups did not differ in pre-test performance ($F1,18 = 0.17$, $p > .05$), but the treatment group improved more than the control group ($F1,18 = 21.35$, $p < .05$).). Figure 4 demonstrates the group difference in the Push-up test.

Figure 4. Push-up Performance Difference Between the Treatment and Control Groups.

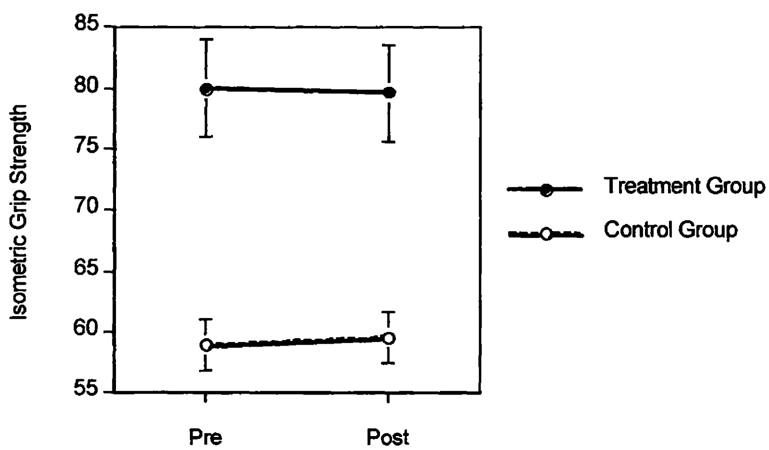


Strength & Power Measurements

Table 3 reports the subjects' muscle strength and power measurements. For the Isometric Grip Strength test, the treatment group (athletes) had a significantly stronger grip than the control group ($F1,18 = 22.36$, $p < .05$), but neither group improved more than the other ($F1,18 = 2.98$, $p > .05$). Figure 5 demonstrates the group difference in the Isometric Grip Strength test.

Table 3				
Variables	Athl Etes		Con Trol	
	Pretest	Post test	Pretest	Post test
Medicine Ball Toss (ft)	13.6±.6	13.8±.9	11.3±1.0	11.5±1.0
Vertical Leap (In)	12.7±3.1	13±2.8	10.6±1.7	10.5±1.9
Isometric Grip(lbs)	80±9.3	79.6±8.8	58.9±8.3	59.6±8.2
Peak Iso Grip (lbs)	82±9.4	81.3±8.7	61.4±9.7	61.7±9.6
Dynamometer (lbs)	36.6±2.7	34.6±5.9	36.5±2.5	36.7±3.1

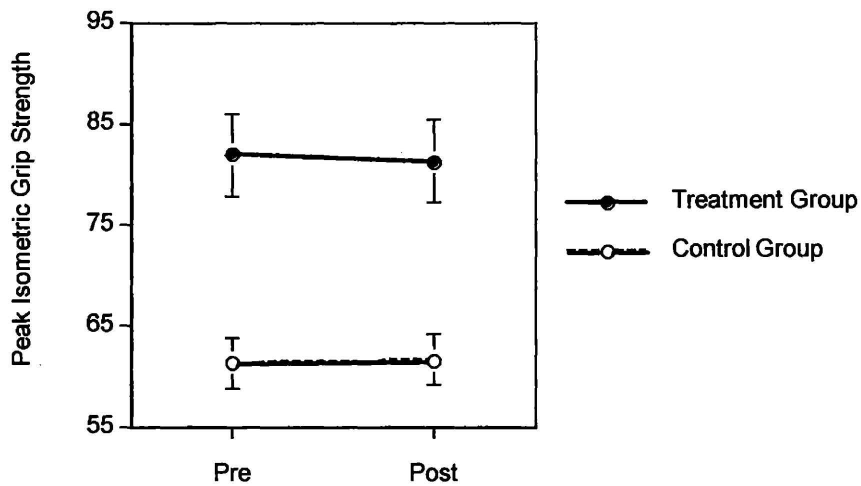
Figure 5. Isometric Grip Strength Performance Difference Between the Treatment and Control Groups



The same result was observed for the Peak Isometric Grip Strength test. The treatment group (athletes) had a significantly stronger peak isometric grip than the control group ($F1,18 = 16.74$, $p < .05$), but neither group improved more than the other ($F1,18 = 3.12$, $p > .05$).

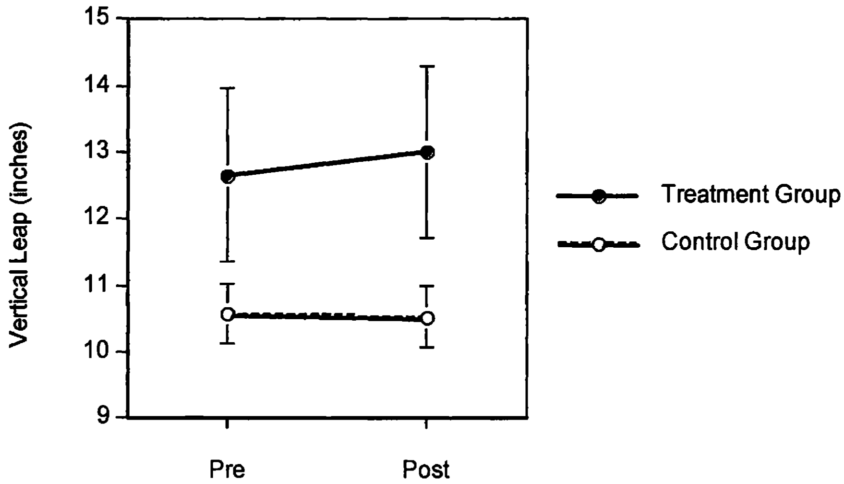
Figure 6 demonstrates the group difference in the Peak Isometric Grip Strength test. Group differences were not observed for the Dynamometer test. For this test, the treatment and control groups did not differ(F1,18 = 0.42, p > .05), and neither group improved (F1,18 = 1.73, p > .05).

Figure 6. Peak Isometric Grip Strength Performance Difference Between the Treatment and Control Groups



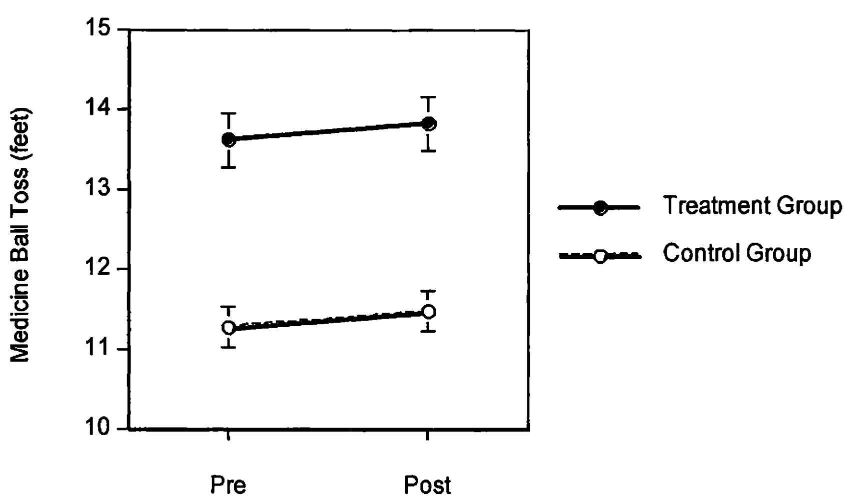
For the Vertical Leap test, the treatment group (athletes) had a significantly higher vertical leap than the control group (F1,18 = 4.49, p < .05), but neither group improved more than the other (F1,18 = 2.23, p > .05). Figure 7 demonstrates the group difference in Vertical Leap.

Figure 7. Vertical Leap Difference Between the Treatment and Control Groups



Finally, for the Medicine Boll toss, the treatment group (athletes) had a significantly farther toss than the control group ($F1,18 = 24.27$, $p < .05$), but neither group improved more than the other ($F1,18 = 0.01$, $p > .05$). Figure 8 demonstrates the group difference in the Medicine Ball toss.

Figure 8. Medicine Ball Toss Difference Between the Treatment and Control Groups.

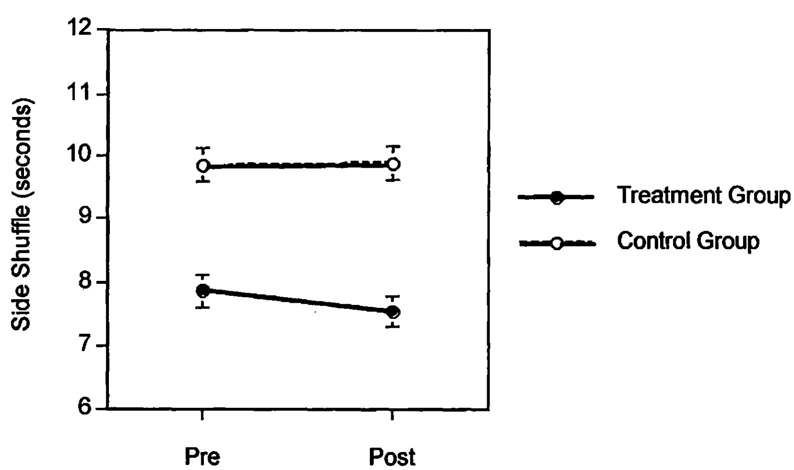


<u>Agility Measurements</u>

Table 4 reports the subjects' quickness and agility measurements. For the Side-Shuffle test, the treatment group (athletes) performed significantly faster than the control group ($F1,18 = 21.87$, $p < .05$), but neither group improved more than the other ($F1,18 = 3.72$, $p > .05$). Figure 9 demonstrates the group difference in the Side Shuffle test.

Table 4				
Variables	Athl etes		Con trol	
	Pretest	Post test	Pretest	Post test
Shuffle (lbs)	7.9±.3	7.5±.2	9.8±1.1	9.9±1
Hexagon (lbs)	11.0±.4	10.7±.3	13.8±1	13.6±1.1
Spider (lbs)	20.5±1	19.3±.8	24.4±1.2	24.3±1.3

<u>Figure 9</u>. Side Shuffle Performance Difference Between the Treatment and Control Groups.



For the Hexagon test, the treatment group (athletes) also performed significantly faster than the control group ($F_{1,18} = 27.87$, $p < .05$). The treatment group also improved more than the control group on this test ($F_{1,18} = 8.99$, $p < .05$). Figure 10 demonstrates the group difference in the Hexagon test. The same result was observed for the Spider test. The treatment group performed significantly faster ($F_{1,18} = 53.67$, $p < .05$) and improved more ($F_{1,18} = 24.66$, $p < .05$) on this test than the control group. Figure 11 demonstrates the group difference in the Spider test.

Figure 10. Hexagon Performance Difference Between the Treatment and Control Groups.

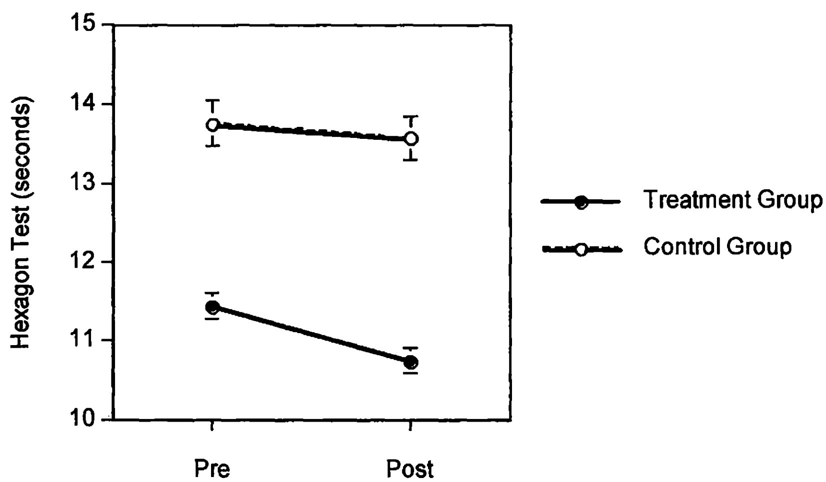
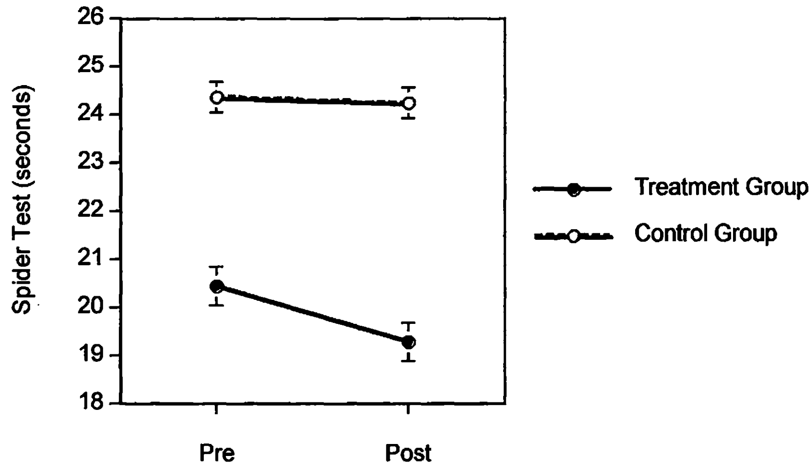


Figure 11. Spider Performance Difference Between the Treatment and Control Groups.



Chapter 5

Discussion, Summary & Conclusions

This study found that there was no improvement in height, body weight, body composition, grip strength or power for either the treatment or control groups. There were however, differences in the strength and power measurements between the treatment and control group. There was improvement on two of the agility variables for the treatment group but not the control group. The treatment group improved on the fitness measurements while the control group stayed the same.

Body Size & Composition Measurements

This study found no change in the body size and composition as determined by body weight, sum of skinfolds, and percent fat of the treatment group or the control group from pre to post tests. The differences seen can be attributed to random variation. This result may have occurred for two reasons. First, neither diet nor caloric intake was controlled or measured for either sample. Even though the athletes were on a specific workout program designed by their coach, they could eat whatever they wanted regardless of quantity (Moody, Kollias & Buskirk, 1969). The other reason there may not have been any change in body weight or percent fat is the length of the study. The training program under consideration in this study, only lasted for 12 weeks. This short time may be too short to see any major changes in body weight, skinfold sum, and percent fat (Kilbom, 1971).

Fitness Measurements

This study found a significant improvement in the fitness levels of the treatment group, but no change in the control group. The treatment group improved in the 1.5 mile run, the sit and reach test, sit-up test, and push-up test. This improvement is probably due to the fact that the training program required these types of exercises 3-4 times per week. The treatment group did aerobic conditioning at least twice a week during this study. Flexibility was a part of their warm up and cool down for each workout. Sit-ups and push-ups were done at least three times a week.

The control group, on the other hand, had no established training program. Some of them were enrolled in physical education activities requiring some moderate to vigorous exercise, while some may have been sedentery. The improved fitness of the athletes and lack thereof for the control group relates to the principle of specificity of training (Pechar, McArdle, Katch, Magel & DeLuca, 1974).

Specificity matches the mechanical similarities of training activities and a sport (NSCA, 1994, p.417). Training programs should be relevant to the demands for each sport. These demands may include the most important energy systems along with the movement patterns and major muscle groups used (Fox et al., 1993, p.171). Specific exercise elicits specific adaptations, creating specific training effects; runners should run, swimmers should swim, etc. (Kohrt et al, 1989).

Strength & Power Measurements

This study found no improvement in the grip strength and power measurements for either group of subjects. The treatment group was stronger in the grip strength tests than the control group. This is most likely due to the fact that the tennis players have a naturally strong grip from constantly holding on to the racquet (Spassov, 1989). There was no improvement between the pre-and-post tests for the athletes. In fact, the treatment group had a lower sample mean on the post test than on the pre test. This result occurred most likely because one of the tennis players had injured her dominant hand. The control group also showed no change from pre to post test. However, the control group was weaker on these measurements to begin with. This result is most likely due to the fact that the control group did not play tennis on a regular basis; and handgrip is not a common exercise in physical education activities. This result also relates to the specificity of training.

The treatment group showed no improvement on either the vertical leap or medicine ball toss. The control group also showed no improvement on these tests. As with the grip strength, the treatment group was better than the control group. This result can be attributed to the practice and competition of the athletes requiring both lower and upper body power. The weight program included bench press and shoulder exercises, while, the plyometrics included cone jumps, leaps and bounds. These drills do not seem specific for training vertical leap.

Agility Measurements

This study found that the treatment group improved on two of the agility measurements, while the control group showed no improvement. This improvement may have occurred because of the training program that the athletes completed. Part of the training program included shuffles and sprints. Another reason this occurred is because of the specificity of these measurements. All three of these drills are a little ackward at the beginning, but scores tend to get better the more the person practices. Once again the treatment group had better scores on these measurements. This occurred possibly because the tennis players have probably performed these drills on a regular basis.

Summary

The purpose of this investigation was to determine the effects of a 12-week off-season training program on cardio-respiratory endurance, flexibility, muscular strength, muscular endurance, agility, power, and body composition in collegiate female tennis players.

This investigation found no improvement in body weight, body composition, grip strength or power. The athletes did improve on the fitness tests, and two of the three agility tests, based on the 12 week training program that they were put on. The athletes performed better on the grip strength, power, and agility tests than the control group because they had developed these abilities from previous years of training and practice.

These results may have appeared as they did for a couple of reasons. First, the duration of the training program was only 12 weeks long. This may not be enough time to see a significant difference in some of these measures. The other reason we saw the results that we did is the actual training program. It was not geared toward grip strength, or some of the specific tests that were done in this study. The program overall, was good for cardiovascular endurance, flexibility, muscular endurance, and agility.

Conclusions

Based on the results of this study the following conclusions can be made:

1. This 12 week training program did not have an affect on body size and composition.
2. This 12 week training program caused improvement in the athletes' fitness levels specifically: sit and reach, push-ups, sit-ups and 1.5 mile run times.
3. This 12 week training program caused no improvement in grip strength or lower or upper body power measurements.

4. College female tennis players demonstrate greater grip strength, lower body power, and upper body power than non-athletes.
5. This 12 week training program resulted in improvement on two of the three agility measurements.
6. College female tennis players demonstrate greater agility, measured by the shuffle, hexagon, and spider tests than non-athletes.

References

American College of Sports Medicine (1990). Position statement on the recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness in healthy adults. Medicine and Science in Sports and Exercise, 22, 256-274.

Astrand, P. & Rhyming, I. (1954). A nomogram for calculation of aerobic capacity (physical fitness) for pusle rate during submaximal work. Journal of Applied physiology, 7, 218-221.

Astrand, P. & Rodahl, K. (1970). Textbook of work physiology. New York: McGraw-Hill.

Balke, B. (1963). A simple field test for assessment of physical fitness. Civil Aeromedical Research Institute Report, 1, 63-66.

Barnard, R.J. (1975). Long-term Effects of Exercise on Cardiac Function. In Wilmore, J.H., and Keough, J.F. (eds.), Exercise and Sport Sciences Reviews New York: Academic Press, pp. 113-133.

Baumgartner, T., Jackson, A. (1995). Measurement for Evaluation in Physical Education and Exercise Science. Dubuque, IA: Brown & Benchmark.

Behm, D. (1987). Strength and Power Conditioning for Racquet Sports. National Strength and Conditioning Journal, 9(1), 37-41.

Bergeron, M. F. (1988). Conditioning the Legs for Tennis. National Strength and Conditioning Journal, 10(3), 40-41.

Blair, S. & Minocha, H. (1989). Physical fitness and all-cause mortality: A prospective study of healthy men women. Journal of the American Medical Association, 262, 2395-2401.

Brooks, G.A., Fahey, T.D. (1984). Exercise Physiology: Human Bioenergetics and Its Applications. New York:Wiley.

Brouha, L. (1943). The step tests: A simple method of measuring physical fitness for muscular work in young men. Research Quarterly, 14, 31-36.

Bruce, R., Kusmi, F., & Hosmer, D. (1973). Maximal oxygen intake and nomographic assessment of functional aerobic impairment in cardiovascular disease. American Heart Journal, 85, 546-562.

Bouchard C. et al. (1990). Long-term exercise training with constant energy intake. I: Effect on Body Composition and Selected Metabloic Variables. International Journal of Obesity. 14:57.

Buskirk, E. & Hodson, J. (1987). Age and aerobic power: The rate of change in men and women. Federation Proceedings, 46, 1824-1829.

Chandler, T. J., Kibler, B. W. Stracener, E. C., Ziegler, A. K., Pace, B. (1992). Shoulder Strength, Power, and Endurance in College Tennis Players. The American Journal of Sports Medicine, 20(4), 455-458.

Chandler, T. J., Kibler, W. B., Uhl, T. L., Wooten, B., Kiser, A., Stone, E. (1990). Flexibility Comparisons of Junior Elite Tennis Players to Other Athletes. The American Journal of Sports Medicine, 18(2), 134-136.

Consolazio, L., Johnson, R., & Pecora, L. (1963). Physiological measurements of metabolic functions in man. New York: McGraw-Hill.

Cooper, D. L., Fair, J. (1977). Flexibility for Tennis and Racquetball. Physician and Sports medicine, 5(9), 21-22.

Cooper, K. (1968). A means of assessing maximal oxygen intake. Journal of the American Medical Association, 203, 201-204.

Cornelius, W.J., Hinson, M.N. (1980). The Relationship between Isometric Contractions of Hip Extensors and Subsequent Flexibility in Males. Sports Medicine, Physical Fitness, 20 : 75 - 80.

Copley, B.B. (1980). A Morphological and Physiological Study of Tennis Players with Special Reference to the Effects of Training. South African Journal for Research in Sport Physical Education and Recreation.

Cureton, K. (1977). Determinants of distance running in children: Analysis of a path model. Research Quarterly, 48, 270-279.

deVries, H.A. (1974). Evaluation of Static Stretching Procedures for Improvement of Flexibility. Research Quarterly, 33 : 222 - 228.

deVries, H.A. (1980). Physiology of exercise for physical education and athletics. Dubuque, IA: Wm. C. Brown.

Ellenbecker, T. S. (1992). Shoulder Internal and External Rotation Strength and Range of Motion of Highly Skilled Junior Tennis Players. Isokinetics and Exercise Science, 2(2), 65-72.

Fit Youth Today, (1986). FYT Program Manual. American Health and Fitness Foundation, Inc.

Foster, C., Jackson, A., & Pollock, M. (1984). Generalized equations for prediction functional capacity from treadmill performance. American Heart Journal, 107, 1229-1234.

Fox, E.L. (1979). Sports Physiology. Philadelphia : Saunders.

Fox, E., Bowers, R., Foss, M. (1993). The Physiological Basis for Exercise and Sports. Madison, Wisconsin : Brown & Benchmark.

George, J. (1993). VO2max estimation from a submaximal 1-mile track jog for fit, college-age individuals. Medicine and Science in Sports and Exercise, 25, 401-406.

Getchell, B. (1979). Physical Fitness : A way of life. New York : Wiley.

Golding, L., Myers, C., & Sinning, W. (1989). The Y's way to physical fitness, 3rd edition. Chicago: National Board of YMCA.

Goldspink, G. (1964). The Combined Effects of Exercise and Reduced Food intake on Skeletal Muscle Fibers. Journalof Cell Comp. Physiology. 63:209-216.

Groppel, J. L., Roetert, E. P. (1992). Applied Physiology of Tennis. Sports Medicine, 14(4), 260-268.

Gutin, B. (1976). Relationship among submaximal heart rate, aerobic power, and running performance in children. Research Quarterly, 47, 536-539.

Hagberg, J. (1990). Exercise, fitness, and hypertension. In Exercise, Fitness and Health: A Consensus of Current Knowledge, C. Bouchard, R. Shepherd, T. Stevens, J. Sutton, & B. McPherson Eds. Champaign, IL: Human Kinetics.

Haskell, W. (1994). Health consequences of physical activity: Understanding the challenges regarding dose response. Medicine and Science in Sports and Exercise, 26, 649-660.

Jackson, A. & Baker, A. (1986). The relationship of the sit and reach test to criterion measures of hamstring and back flexibility in young females. Research Quarterly for Exercise and Sport, 57, 183-186.

Jackson, A. & Coleman, A. (1976). Validation of distance run tests for elementary school children. Research Quarterly, 47, 86-94.

Jackson, A. & Langford, N. (1989). The criterion-related validity of the sit and reach test: Replication and extension of previous findings. Research Quarterly for Exercise and Sport, 60, 384-387.

Johnson, B. & Nelson, J. (1974). Practical Measurements for Evaluation in Physical Education, 2nd ed. Minneapolis:Burgess.

Jones, N., & Campbell, E. (1982). Clinical exercise testing. Philadelphis: W.B. Saunders.

Jorgensen, K. (1976). Force - velocity relationship in human elbow flexors and extensors. In : Biomechanics V - A, P.V. Komi, ed. Baltimore : University Park Press.

Karlsson, J. et al. (1971). Muscle Metabolites During Submaximal and Maximal Exercise in Man. Scandinavian Journal of Clinical Laboratory Investigations. 26:385.

Karlsson, J., Saltin, B. (1970). Lactate, ATP, and CP in Working Muscles During Exhaustive Exercise in Man. Journal of Applied Physiology, 29:598.

Kendall, F. (1965). A criticism of current tests and exercises for physical fitness. Journal of American Physical Therapy Association, 45, 187-197.

Kilbom, A. (1971). Physical Training in Women. Scandinavian Journal of Clinical Laboratory Investigations, 28(Supplemental):119.

Kline, G., Porcari, J., Hintermeister, R., Freedson, P., Ward, A., McCarron, R., Ross, J., & Rippe, J. (1987). Estimation of VO2max from a One-mile Track Walk, Gender, Age, and Body Weight. Medicine and Science in Sports and Exercise, 19, 253-259.

Kohrt, W.M. et al. (1989). Longitudinal Assessment of Responses of Triathletes to Swimming, Cycling, and Running. Medicine and Science in Sports and Exercise. 21:569.

Komi, P.V. (1986). Training of muscle strength and power: Interactions of neuromotoric, hypertrophic, and mechanical factors. International Journal of Sports Medicine. 7:10 - 15.

Mahar, M., Jackson, A., & Ross, R. (1985). Predictive accuracy of single and double stage sub max treadmill work for estimating aerobic capacity. Medicine and Science in Sports and Exercise, 17, 206-207.

McArdle, W. D., Katch, F. I., Katch, V. L. Exercise Physiology. Williams & Wilkins, 1996.

Meriam, J. (1978). Engineering Mechanics, Vol. 2:Dynamics. New York: Wiley.

Miller, P. (1985). Assessment of joint motion. In Measurement in Physical Therapy, J. Rothstein, ed. Pp. 103-106. New York: Churchill Livingstone.

Mitchell, J.H. & Blomqvist, G. (1971). Maximal Oxygen Uptake. The New England Journal of Medicine. 284:1018 -1022.

Mitchell, J.H. & Raven, P.B. (1994). Cardiovascular Adaptation to Physical Activity. In Physical Activity, Fitness, and Health. Bouchard, C. et al. (Eds.). Champaign, IL, Human Kinetics.

Moody, D., Kollias, J, and Buskirk, E. (1969). The Effect of a Moderate Exercise Program on Body Weight and Skinfold Thickness in Overweight College Women. Medicine and Science Sports, 1:75-80.

Morrow, J., Jackson, A., Disch, J., & Mood, D. (1995). Measurement and evaluation in human performance. Champaign, IL: Human Kinetics.

Murray, T.D., Walker, J.L., Jackson, A.S., Morrow, J.R., Eldridge, J.A., and Rainey, D.L. (1993). Validation of a 20-minute steady-state jog as an estimate of peak oxygen uptake in adolescents. Research Quarterly for Exercise and Sport, 64, 75-82.

National Strength and Conditioning Association (1994).Essentials of Strength Training and Conditioning. Human Kinetics.

Noakes, T. (1988). Implications of exercise testing for prediction of athletic performance: A contemporary perspective. Medicine and Science in Sports and Exercise, 20, 319-320.

Pate, R., Slentz, C., & Katz, D. (1989). Relationship between skinfold thickness and performance of health-related fitness test items. Research Quarterly for Exercise and Sport, 60, 183-189.

Pechar, G., McArdle, W., Katch, F., Magel, J., and DeLuca, J. (1974). Specificity of Cardiorespiratory Adaptation to Bicycle and Treadmill Training. Journal of Applied Physiology, 36(6):753-756.

Penman, K. (1969). Ultrastructural Changes in Human Striated Muscle Using Three Methods of Training. Research Quarterly. 40:764-772.

Peterson, S.L. (1983). The Woman's Stretching Book. Champaign, IL:Leisure Press.

Pollock, M. et al. (1987). Effect of age and training on aerobic capacity and body composition of master athletes. Journal of Applied Physiology, 62, 725-731.

Plowman, S., Drinkwater, B., & Horvath, S. (1979). Age and aerobic power in women: A longitudinal study. Journal of Gerontology, 34, 512-520.

Roetert, E. P., Ellenbecker, T. S., Chu, D. A., Bugg, B. S. (1997). Tennis Specific Shoulder and Trunk Strength Training. National Strength and Conditioning Association Journal, 19(6), 31-39.

Rogers, M. et al. (1990). Decline in VO2max in master athletes and sedentary men. Journal of Applied Physiology, 68, 2195-2199.

Ross, R., & Jackson, A. (1990). Exercise concepts, calculations, and computer applications. Carmel, IN: Benchmark Press.

Saltin, B. (1973). Metabolic Fundamentals in Exercise. Medicine and Science in Sports, 5 : 137.

Sloan, A. (1959). A modified Harvard step test for women. Journal of Applied Physiology, 14, 235-241.

Spassov, A. (1989). Strength Preparation of the Tennis Player. National Strength and Conditioning Association Journal, 11(3), 72-73.

Spina, R.J. et al. (1992). Exercise Training Improves Left Ventricular Contractile Response to B-adrenergic Anagonist. Journal of Applied Physiology. 72:307.

Staron, R. et al. (1994). Skeletal muscle adaptations during early phase of heavy-resistance training in men and women. Journal of Applied Physiology. 76:1247.

Tanaka, K. et al. (1993). Assessment of Exercise-induced Alterations in Body Composition of Patients with Coronary Heart Disease. European Journal of Applied Physiology. 66:323.

Tipton, C.M., Matthes, R.D., Maynard, J.A., Carey, R.A. (1975). The Influence of Physical Activity on Ligaments and Tendons. Medicine and Science in Sports. 7(3):165-175.

Treiber, F. A., Lott, J., Duncan, J., Slavens, G., Davis, H. (1998). Effects of Theraband and Lightweight Dumbell Training on Shoulder Rotation Torque and Serve Performance in College Tennis Players. The American Journal of Sports Medicine, 26(4), 510-515.

United States Tennis Association (1998). Complete Conditioning for Tennis. Human Kinetics.

United States Tennis Association Player Development Program (Producer). (1990). Fitness Testing for Tennis[Videotape]. Champaign, IL: Human Kinetics Publishers.

Vodak, P. & Wilmore, J. (1975). Validity of the 6-minute jog-walk and 600-yard run-walk in estimating endurance capacity in boys, 9-12 years of age. Research Quarterly, 46, 230-234.

Zorbas, W.S., Karpovich, P. (1951). The effect of weight lifting upon the speed of muscular contractions. Research Quarterly, 22:145 - 148.