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The accuracy and velocity of serving in female tennis players following strength training

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THE ACCURACY AND VELOCITY OF SERVING IN FEMALE TENNIS PLAYERS FOLLOWING STRENGTH TRAINING

by

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An Abstract

of a thesis submitted in partial fulfillment

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Thesis Advisor: Dr. G. A. Sforzo

ABSTRACT

Strength training programs are commonly held to be beneficial to athletic performance and are often prescribed for this purpose. Athletes competing in power events (e.g., sprinting) are confident their performance will be enhanced with improved strength, however, those involved in more complex motor skills (e.g., tennis) sometimes question the value of such training. The purpose of this investigation was to determine the effects of a 6-week isotonic strength training program on the accuracy and velocity of the serve in a group of varsity caliber, college-aged female tennis players. Eighteen subjects were randomly assigned to either a resistance trained (RT, n=10) or control (C, n=8) group. The RT training program involved five sport specific, isotonic, upper body exercises using free weights. Each exercise was performed for three sets at about 70% of 1 Repetition Maximum (RM), three times per week and intensity was adjusted progressively during the training period. Appropriate flexibility exercises were also incorporated into the training sessions. Pretraining testing consisted of an accuracy test and placement test (American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD)) that examined ability to serve a tennis ball into a designated hitting area. Serve velocity measurements were taken using a radar

gun.

Flexibility, strength, and a 30 s power test were used to assess the effectiveness of the training protocol. Posttraining testing was identical to pretraining. Multivariate mixed model analyses demonstrated a significant ($p<.05$) interaction and time main effect for strength and flexibility measures indicating a successful training program. A significant difference was noted for placement ($p=.008$) and accuracy ($p=.002$), displaying improvements in the RT. These findings also demonstrated that velocity of the tennis serve was unaffected by successful strength and flexibility training, however, the test used may have been an invalid measurement of serve velocity. Serve accuracy, a measure that simultaneously considers both power and placement, may well be the parameter most responsible for successful performance, and as this study demonstrated, enhancement of this important variable may be acquired through a successful resistance training program. Considering the low subject size (n=18) and the measurement validity of serve velocity in the present investigation, it is recommended that future attention be given to the study of these variables.

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A Thesis presented to the Faculty of
the Division of Health, Physical
Education, and Recreation at
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In Partial Fulfillment of the
Requirements for the Degree
Master of Science

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by
Stephen J. Wazenski
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Ithaca College

Division of Health, Physical Education, and Recreation

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CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Master of Science Thesis of

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submitted in partial fulfillment of the requirements for the degree of Master of Science in the Division of Health, Physical Education, and Recreation at Ithaca College has been Approved.

Thesis Advisor:

Committee Member:

Candidate:

Chairperson, Graduate Programs in Physical Education:

Dean of Graduate Studies:

Date: 1-7-93

DEDICATION

This thesis is dedicated to my parents, Carol Wazenski and the memory of Frank Wazenski, for their inspiration to pursue my educational goals.

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Chapter 1

INTRODUCTION

Strength is a requirement for most athletic performances. The amount of strength necessary for an athlete is dependent on the particular sport. Strength is important for improving speed and power, and strength training programs are available for most sports. However, the role of strength training in improving athletic skill and performance is not certain. Very little research has been done on the effects of weight training on motor skills, such as serving a tennis ball, kicking a soccer ball, or throwing a football. The proper type and amount of weight training for improving these skills has yet to be determined.

Over the course of history, the practice of strength training has been controversial (Pearl, 1986). Many coaches and athletes believed weight lifting could cause injury or extra muscle bulk that would diminish performance. However, research has changed attitudes towards athletic conditioning. An important study in 1950 found that a weight training program increases athletic power more than a regular fitness program

(Chui, 1950). It was demonstrated in another study from the same era that strength trained individuals were faster than athletes who did not weight train (Zorbas & Karpovich, 1951). These studies, along with others, had a profound effect on the attitudes of coaches and athletes toward strength training.

Strength has been recognized for years to be important to athletes. Much of the research in this area deals with power skills (e.g., running, jumping, sprinting), however, very few studies attempt to investigate whether weight training programs will improve motor performance skills (e.g., pitching, kicking, serving). Sale (1988) indicated that performance not only requires the function of the involved muscles, but also the nervous system to activate the proper muscles. Strength training may cause adaptive changes within the nervous system that allow an athlete to more fully activate prime movers in specific movements and to better coordinate the activation of all relevant muscles. This would permit a greater net force in the intended direction along with more control over those specific muscles.

Women have traditionally had less access than men to strength training programs. Women respond to strength training programs in a manner very similar to men, in terms of strength and power (Holloway & Baechle, 1990). In general, however, women have less absolute muscle mass, smaller muscle fibers, and demonstrate about two-thirds the absolute strength of men. But despite their physical inequalities, female muscle tissue is similar to male muscle in terms of relative force output. Women experience similar increases in strength relative to pretraining status, and some evidence indicates that hypertrophy is very similar in both sexes as a result of strength training (Holloway & Baechle, 1990). More women are active in sports today and strength training may be an important ingredient in achieving top performance.

The success of many athletes is often attributed to their involvement in a strength development program, but the role of strength in skill performance is not empirically certain. Strength training programs require further study to determine their effects on performance of athletic skills.

Scope of the Problem

This investigation was undertaken to determine if resistance training would affect the performance of the tennis serve in women. The subjects were 18 female Ithaca College students who were recruited on a volunteer basis to be in a 6-week training study (n=10) or to participate in a control group (n=8). The tennis serve (accuracy, placement, velocity) and specific muscular performances (strength, power, flexibility) were measured before and after training. Serve accuracy was a measure that simultaneously considered both the power and placement of the serve. Serve placement only considered the placement of a serve in a designated area of the court.

Statement of the Problem

The specific purpose of this study was to investigate the effects of resistance training in women on the performance of the tennis serve.

The Null Hypotheses

1. There will be no significant difference between the strength training group and the control group in accuracy (i.e., placement and power) of the tennis serve following six weeks of resistance training.

2. There will be no significant difference

between the strength training group and the control group in placement of the tennis serve following six weeks of resistance training.

3. There will be no significant difference between the strength training group and the control group in velocity of the tennis serve following six weeks of resistance training.

Assumptions of the Study

The following assumptions were made in this study:

1. The correct muscle fibers were trained to affect tennis serve performance.

2. All subjects were equally motivated and performed a maximal effort during all testing periods.

3. All subjects understood and responded truthfully to the directions in the testing situations.

Definition of Terms

The following are defined for the purpose of this study:

1. Resistance Training: Exercises that involve the raising and lowering of a weighted object in a controlled (rhythmic) repetitive bout of exercise.

2. Power Test: The amount of work accomplished per unit of time. In this study the number of

repetitions done with a specific weight in 30 s.

3. Accuracy of the Tennis Serve: Accuracy was measured by incorporating the placement and power components of the tennis serve into a composite score.

4. Velocity of the Tennis Serve: The speed at which the tennis ball travels after it leaves the racket of a server.

5. Placement of the Tennis Serve: Placement was measured by the appropriateness of positioning a tennis serve in a designated area of the service box.

6. Untrained: Females who have not been strength training, particularly their upper body, for the previous 6 months.

7. Experienced Tennis Server: Good use of shoulder turn (loop), consistent ball toss with adequate height, ability to place serve powerfully in designated areas. Also a player of at least 5 years of previous varsity experience at either high school or college level.

Delimitations of the Study

The delimitations of the study were as follows:

1. The subjects were 18 untrained undergraduate female students from Ithaca College.

2. Only experienced tennis servers that have played tennis for a minimum of 5 years on an organized tennis team, participated in this study.

3. The only exercises performed were three sets of five sport specific exercises, three times a week for 6-weeks, with no additional exercises performed outside the study.

4. The 1 RM and 30 s power test were the only variables used to measure strength.

5. The American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD) tennis service tests were the only variables used to measure accuracy and placement.

6. A JUGS radar gun was used to measure ball speed.

Limitations of the Study

The limitations of the study were as follows:

1. The small sample size may not have represented the total population of college-aged female undergraduates.

2. The skill level of subjects may not have represented the total population of tennis players.

3. The training sessions may not have been

adequate for changes to be seen in performance.

4. The results are only generalizable to the strength exercises used during training.

5. The tennis tests used may not adequately represent all the qualities of the serve (i.e., accuracy, placement, velocity).

Chapter 2

REVIEW OF LITERATURE

In tennis, the serve has the ability to be the single most powerful offensive shot. The serve is the only stroke that is under the complete control of a given player. A properly placed and powerful service can result in a point without any return from the opponent.

Recently, tennis players have been performing various strengthening programs with intentions of improving their games. The importance of strength training in tennis is attributed to improved coordination, injury prevention, muscular endurance, and speed (Groppel & Nishihara, 1988). However, tennis is a sport that requires a great deal of skill, and players are always trying to improve their motor performance (e.g., serve, volley, groundstrokes). There are a few credible studies that deal with athletic motor performance and strength training. In this chapter the literature related to resistance training, motor performance, and power sports will be reviewed. The following topics will be addressed: (a) methods of strength training, (b) strength and power performance, and (c) strength and motor skills.

Methods of Strength Training

Many research studies have shown that human strength can be improved by progressive resistance exercise. The three basic types of exercise used today to increase strength are isotonic, isokinetic, and isometric. Isometric weight training has been demonstrated by many studies to have little effect or changes in strength gains (Dwyer, 1983). Isokinetic training is used infrequently because of limited equipment available, however, it is widely used in research. Isotonic exercises are the most widely used form of resistance training and recognized to produce significant strength gains.

Isotonic exercise is performed with a constant load or resistance (Laird & Rozier, 1979). Work is performed because a force is moving a load through a distance. The load for isotonic exercises consists usually of free weights or weight stacks, such as Nautilus. Many studies have been performed to determine the proper amount of weight, repetitions, and sets required to gain strength (Berger, 1962a, 1962b, 1962c). These studies concluded that three sets with three to nine repetitions were required for optimal strength improvement. This review will concentrate mainly on isotonic exercises and how they compare to other modalities.

A variety of studies compared the effectiveness among exercise training modalities for developing strength. One such study compared the effects of isotonic and isokinetic training on changes in strength, body composition, anthropometric measurements, and motor performance tasks (Pipes & Wilmore, 1975). Thirty-six male subjects were randomly placed in one of four groups: isotonic, isokinetic low speed contraction, isokinetic high speed contraction, and control. Training was performed 3 days a week, 40 min per day, for a total of 8-weeks. Pre and posttraining strength was assessed with a one repetition maximum test (1 RM) to measure isotonic strength and a Cybex isokinetic testing device to measure isokinetic strength. Motor performance was assessed with the standing long jump, 40 yard dash, softball throw for distance, vertical jump, and two-handed sitting shot-put. The results indicated that the isokinetic and isotonic groups increased on all measures. However, only the isokinetic group improved significantly on all the variables measured while none of the strength changes in the control group were significant.

In an attempt to compare the gains in strength between isotonic and isokinetic training, twelve male subjects between the ages of 16 and 18 were divided into four groups: isotonic resistance, low-speed isokinetic, high-speed isokinetic, and control (Smith & Melton, 1981). They participated in training for 6-weeks. The subjects were pre and posttested on strength gains and motor performance. The motor performance tasks were the vertical jump, standing broad jump, and 40-yard dash. It was revealed that the isotonic group had the most significant gains in strength, but the isokinetic group demonstrated the most improvement in the motor performance skills. Similarly, Pipes and Wilmore (1975) found increases in motor performance and strength using a similar protocol. The small group size and the athletic ability of the subjects may have had an impact on the results of this study.

An investigation that compared the effects of isotonic and isokinetic exercise on quadriceps strength showed no significant difference between the two groups (DeLateur et al., 1972). The subjects included 45 college-aged women that were divided into four groups. Two groups trained isotonically and two groups trained isokinetically by performing a leg extension exercise. One of the isotonic groups shifted to the isokinetic exercises and one of the isokinetic groups shifted to the isotonic exercises half way through training. All subjects performed one set of leg extensions for 26 sessions (days) and were told to exercise to fatigue. Data indicated that neither the isotonic, isokinetic training or a combination of both was better than the other for developing strength. The methods of this study, in which only one set and no number of repetitions were assigned, is unusual and may account for these findings.

Muscle action potential produced by isotonic, isokinetic, and isometric contractions was measured using electromyograph analysis by Hinson & Rosentswieg (1973). Fifty-two college women performed maximal knee extension and elbow flexion under the three conditions. The results indicated that there was no significant difference in muscle action potential between contraction types. However, the authors found that there was a degree of specificity regarding the type of contraction and the subject. One subject may employ more motor units during a isotonic exercise than another subject performing the same contraction. It could be speculated, if more motor units were recruited then more muscle fibers would be strengthened, and in turn, an athlete's performance may improve. Based on these findings it was concluded that subjects should possibly be classified according to muscle unit involvement before being placed in a strength or rehabilitation program.

This brief review demonstrates that different types of training programs can produce a variety of results. Isotonic training, which is most widely used, however, does not always generate the best results for all training studies. Based on these studies it appears that three sets of three to nine repetitions, 3 days a week, for a minimum of 6-weeks is recommended when isotonically training to improve muscle strength.

Strength and Power Performance

Muscular power is the ability of a muscle group to contract forcefully with speed. More specifically, power is the amount of work done per unit of time. Therefore, a strong fast muscle contraction is more powerful than a slow contraction applied by the same muscle. In tennis, powerful movements are an important component of the game. The serve requires a powerful stroke to generate speed because their is no previous energy transferred from the ball to the racket as there is in volleys and groundstrokes. Some previous studies have examined the effect of training on measures of power.

The effects of strength training on performance in the 40 yd dash and baseball throwing velocity was studied (Adams, Bangerter, & Roundy, 1988). Sixty-two students, were divided into three groups consisting of two experimental groups and one control group. The subjects aged from 18 to 25 years. The experimental groups participated in a 12-week strength training program that incorporated all major muscle groups. One experimental group (group A), however, incorporated an exercise for the toe flexors and the other experimental group (group B) incorporated an exercise for the wrist/finger flexors. Both experimental groups showed significant increases in the 40 yd dash and baseball throwing velocities with group A showing the most significant increase in the 40 yd dash. The control group showed no improvement in performance from pretest to the posttest scores. It was concluded that specific strength training of toe flexors can enhance performance (i.e., 40 yd dash) more than general strength training. Group B, however, showed no improvement in throwing velocity.

The effects on muscular strength and athletic performance were also studied using different training modalities (Nelson, Chambers, McGown, & Penrose, 1986). The subjects were 30 college women who were assigned to one of three groups (weight training (WT), proprioceptive neuromuscular facilitation (PNF), and control). Subjects were tested before and after training for knee and elbow strength, throwing distance, and standing vertical jump. The two experimental groups trained 3 days a week for 8-weeks. The results indicated that the experimental groups (WT, PNF) had a significant (19 to 29%) increase in elbow and knee strength with the PNF group being significantly greater than the WT group. The WT group had increases in the vertical jump and throwing distance of 12.8% and 9.9% respectively, while the PNF group increased 22.1% and 29.1% on the same tasks. It was concluded that weight training and PNF have a significant effect on performance outcomes, with PNF proving to be a potentially more effective method of training.

Strength and Motor Skills

Athletes are always trying to improve their motor skills, and greater skill levels often require greater speed of performance. For example, a professional pitcher or a quarterback is required to throw a ball faster than an amateur. Similarly, a tennis player must be able to serve powerfully to achieve a high skill level. Although resistance exercises are known to improve the strength of athletes, few studies reveal the effects of weight training for improving motor skills.

The effects of a 9-week supplemental weight training program was measured on seven college female ballet dancers (Stalder, 1990). The investigators studied lower body strength, muscular endurance, flexibility, and ballet performance techniques of dancers. The weight training group trained their lower body 3 days a week for 9-weeks, while seven other dancers served as a control group. All subjects participated in their normal ballet class 4 days per week for 90 min. The results indicated that weight training significantly improved overall performance (skillful movements) in ballet techniques with no change in limb circumference.

Accuracy is an important quality in the achievement of success in many sports. Velocity usually serves little purpose unless an adequate amount of control accompanies it. The effects of strength training on accuracy has not been well documented and the few studies conducted have produced a variety of results.

Bagonzi (1979) studied the effects of overload training in the changes of a thrown baseball. The subjects were 48 high school baseball players, ranging from 15 to 19 years old. They were assigned to one of four experimental groups or a control group. The experimental group performed a specific training program two times per week for 18-weeks. The training programs were composed of graded weighted baseballs, isotonic training, isometric training, and a combination of all three. The results indicated that the use of strength training had a significant effect on the velocity and accuracy of a thrown baseball. The effect of all the various training methods were more pronounced on the velocity variable, accuracy improved but to a lesser degree.

Straub (1968) also investigated the effects of overload training on the velocity and accuracy of the overarm throw. The subjects of this study were 108 males, randomly drawn from a high school population. The experiment had a short and long range time period. The short range portion included 60 subjects that were divided into two groups ranked on their throwing speed and then further assigned to one of three groups that consisted of a 10-oz, 15-oz, and regulation balls (5-oz) to be used in warm-up. This phase of the experiment lasted for 2 weeks. The long range portion included the remaining 48 subjects and lasted for 6 weeks. These subjects were ranked on their throwing speeds and divided into two groups that were further subdivided into a control group and three experimental groups. The control group threw regulation baseballs for the 6 week period while the experimental groups threw progressively heavier baseballs. The performance of both short and long-range periods showed no significant changes in velocity and accuracy. The researcher concluded that a significant change in velocity and accuracy was not observed because the skill level of the subjects was so varied.

A study of 48 college students from three beginning tennis classes examined the effect on strength training on the serve (Dwyer, 1983). The subjects were randomly assigned to a control group or two experimental groups. The experimental groups performed either isotonic of isokinetic exercises three times a week, 15 min per day, for 8-weeks. The subjects were tested pre and posttraining on the accuracy and velocity of the tennis serve. The results demonstrated that the isotonic and isokinetic training groups had significant improvements in accuracy and velocity with no difference between training groups. The control group showed no significant changes. However, the skill level of the subjects (participants in a beginner tennis class during the study), and the short training periods, could be important factors to consider when interpreting the outcome of this study.

Ellenbecker, Davies, & Rowinski (1988) compared the effects of concentric and eccentric isokinetic strengthening on the rotator cuff and its effects on ball velocity of the tennis serve. Twenty-two male and female college tennis players volunteered for 6-weeks of isokinetic training, two times per week. The subjects were divided into two groups that performed either eccentric internal and external shoulder rotation, or concentric internal and external shoulder rotation. Subjects were tested pre and posttraining for strength gains and improvement in ball velocity of the tennis serve. The results indicated that significant gains in strength were made for both training groups. The concentric training group showed significant increases in tennis serving speed while the eccentric training group had no significant changes in the motor skill speed. The authors attributed the improvement to the predominantly concentric movement of the tennis serve and further suggested that strength training be sport specific for improving motor performance. The use of a control group and also a longer duration of training may have furthered the results of this study.

Another investigation examined the effects of strength training on velocity of the slap and wrist shots used in ice hockey (Alexander, Drake, Reidienback & Haddow, 1964). Cinematographic analysis was used to identify eight major muscles used in these shots. Strength tests of these muscles and puck velocity of the two shots were tested before and after training for an 18 member college ice hockey team. The subjects were divided into two groups that either performed eight strength training exercises, seven times a week for 5-weeks or served as a control and only participated in team practices. The results were that the speed of the slap and wrist shots were increased significantly for the experimental group. Also, for the experimental group there was an increase in the eight strength tests measured. The control group showed no significant change in speed for the two shots and had an increase in strength for only one of the eight muscles tests. The investigators concluded that strength training had a significant effect on increasing the velocity of slap and wrist shots.

Summary

A wide variety of studies demonstrate that strength can be acquired through different types of programs and by using either isotonic of isokinetic training. Some investigations have documented that isotonic training is the best modality for increasing strength and power, while others claim isokinetic training is the better of the two. The diversity of methodology used in these training studies may explain the discrepancies in the results presented.

The effects of strength training on sports skills is still questionable. Of the non-specific, power studies, some with weak designs, the results sometimes demonstrate an increase in performance, while sometimes show no improvements in performance. A majority of well-controlled studies for power events (i.e., 40 yd dash, standing vertical jump) have demonstrated significant gains from resistance training. The literature for motor skill enhancement, however, shows less agreement. With respect to motor skills and their accuracy and velocity, conflicting results are reported in the few research studies that have been done. The studies that were well controlled did show significant gains in performance with strength increases. For example, sport skills such as throwing accuracy and the velocity of the hockey slap and wrist shots proved to demonstrate notable results.

When most tennis players begin a weight training program they are more concerned with its effects on their level of play rather than building strength. Little of the work done has used traditional strength training programs and a control to examine the effects of strength training on the tennis serve, but preliminary results are encouraging. More complete and well designed studies are needed in the area of this important sport skill.

Chapter 3

METHODS AND PROCEDURES

Accuracy and velocity are two important characteristics of a good tennis serve. The purpose of this study was to determine whether isotonic strength training would produce any change in the accuracy, placement, or velocity of the tennis serve. This chapter is divided into the following sub-topics: (a) subject selection, (b) testing procedures, and (c) treatment of data.

Subject Selection

This investigation was conducted during the months of January to May of 1992. The subjects were 18 college-aged, female tennis players. Each subject played on an organized tennis team for a minimum of 5 years, including high school tennis. The ages of the subjects ranged from 19 to 21 years. All subjects read and signed an informed consent form (Appendix A) describing the study and the risks that were involved.

Testing Procedures

The subjects were randomly assigned to either an isotonic strength training group or a control group. The experimental group performed various strength training tasks, while the control group did not weight train and, in fact, refrained from any exercise conditioning during the study. The subjects also abstained from any tennis skills practice. The experimental group trained for 30 min, three times per week, for a period of 6-weeks. The experimental group performed strengthening exercises for the muscles incorporated in the service motion, specifically, the shoulder, biceps, triceps, and forearm muscles (Behm, 1988).

Exercise Sessions

A pretraining orientation session was held prior to the experiment to familiarize the subjects with their assigned exercise group and equipment use. Each of the exercises were demonstrated for proper techniques and safety precautions. The five exercises (muscle) performed with free weights were: the seated bicep curl (bicep), tricep curl (tricep), frontal raise (deltoid), over-head press (deltoid), and wrist curl (forearm).

The seated bicep curl was performed with the subject seated on the edge of the chair with a dumbbell in her hand. Starting with the right arm the elbow was placed against the inner right thigh. The dumbbell was curled in a semicircular motion to shoulder height.

The tricep curl began with the subject seated in a chair with the lower back supported. A dumbbell was held in the right hand and raised overhead to arm's length. The dumbbell was slowly lowered in a semicircular motion behind the head until the forearm touched the bicep. The dumbbell was then returned to the starting position.

The frontal raise was performed in a stationary chair with the subject's lower back supported. A dumbbell was held to the side of the subject with the palm facing down. With the arm straight and the elbow locked the subject raised the dumbbell in a semicircular motion overhead. Using the same path, the subject returned to the starting position.

The overhead press was performed by the subject seated in a chair with two dumbbells raised to shoulder height. With thumbs facing up the dumbbells were pressed overhead to arms length. The weight was then lowered back to the staring position.

The wrist curl began with the subject seated in a chair and holding a dumbbell in the right hand. The right forearm was placed on the upper right thigh with the palm down. With the wrist placed over the knee the right dumbbell was lowered as far as possible. The dumbbell was then curled as high as possible.

The experimental group initially warmed-up and stretched for 5 to 8 min prior to each exercise session. Five static stretches were performed incorporating the same muscle groups that were tested. Each stretch was performed three times consecutively and held for 30 s. After the warm-up, the subjects performed three sets of 8 to 12 repetitions of the five upper body exercises. The initial training load used for each exercise was 70% of the subjects' 1 RM. If a subject was able to perform more than 12 repetitions with a given resistance than the weight was increased for the next session providing a progressive overload through the 6-week program. A circuit type course was set up so each subject performed an exercise and then continued on to the next one. Approximately a 2 min rest period was given between each exercise. The exercises were sequentially ordered so different muscle groups would be utilized following each station. Each subject's daily weight load and progress were recorded on a group chart.

The training group was encouraged to set attainable goals for themselves. Subjects were motivated by posted test scores and progress charts. The subjects were also motivated to improve the quality of their team.

Muscle Function Measures

All muscle function measures (i.e., strength and flexibility) were made on each subject before and after the training program. Strength was measured as the greatest amount of weight the subject could lift once (i.e., 1 RM) for each exercise. Power is the rate at which physical work is performed over a period of time. Power was determined by multiplying the amount of repetitions the subjects performed in 30 s by the amount of weight used during the exercise. The amount of weight for the power test was determined by taking 70% of the 1 RM for each subject.

Flexibility was measured using a shoulder flexibility test (Johnson & Nelson, 1969). The shoulder elevation test measures flexibility of the shoulders. In a prone position with the arms shoulders-width apart, the subject raised a stick upward as high as possible while keeping the elbows and wrists straight with the chin on the floor. The distance from the bottom of the stick to the floor was measured in inches. The distance was multiplied by 100 and the product was divided by the arms length in inches. The arm length was equal to the distance from the acromion process to the upper surface of the stick, held by the subject with the arms hanging downward.

Skill Measurements

The AAHPERD tennis service test was used to measure accuracy and placement of the service (Hensley, 1989). The test consisted of a target area that measured both the accuracy and placement of a tennis service. Accuracy was a measure that incorporated placement and power simultaneously. Placement was measured by one's ability to land a serve in a designated area of the service box. A line was marked down the center of each service court, dividing it into left and right halves to measure accuracy and placement. Another line was behind the baseline exactly 9 feet to measure power (Figure 1).

All subjects were permitted a warm-up of 5 min before testing began. After the warm-up, each subject

SERVE TEST

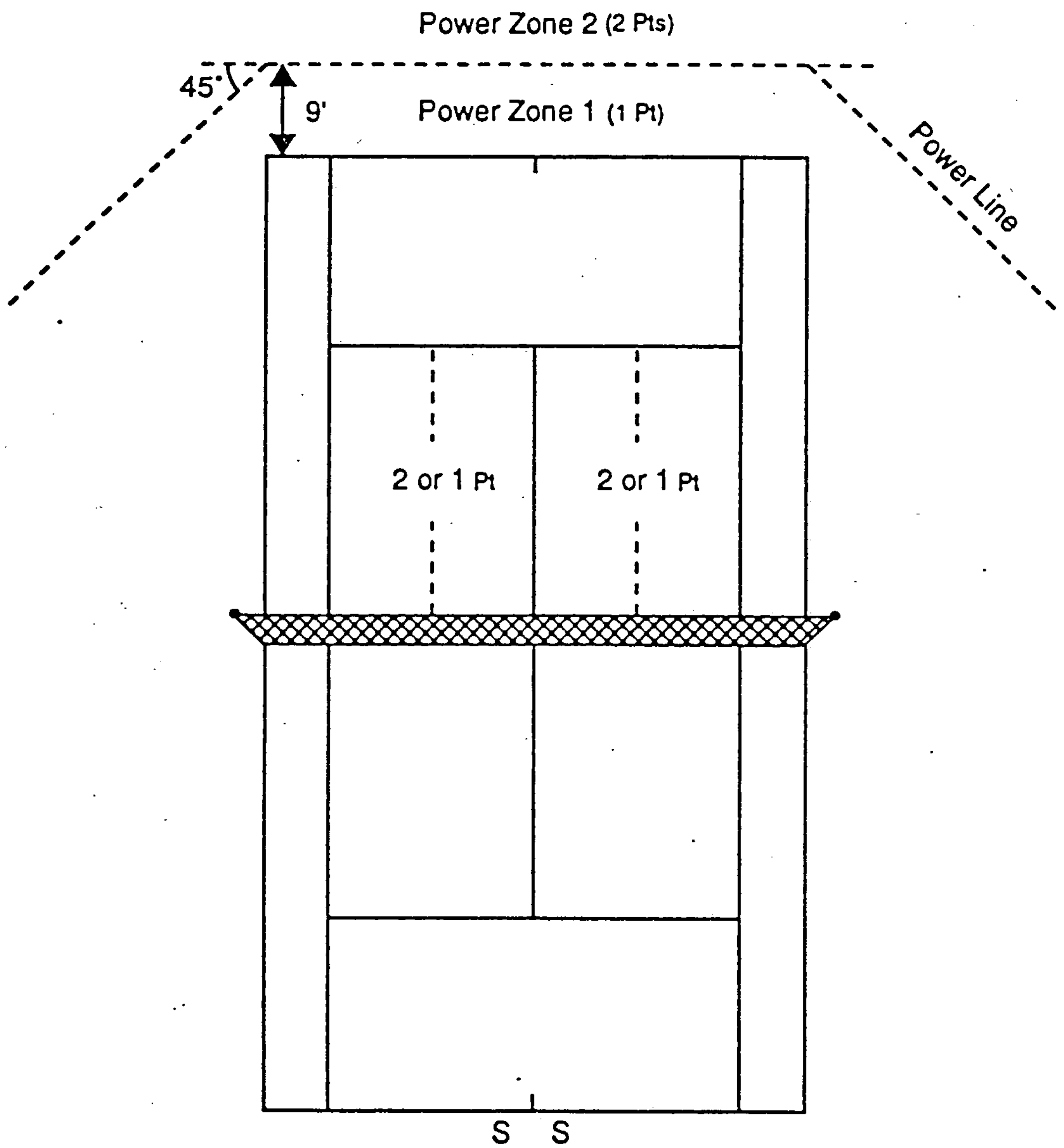

Figure 1. The court markings and scoring structure for measuring the accuracy, placement, and power of the tennis serve. Note. From "Tennis Skills Test Manual" by L. Hensley, 1989, Reston: AAHPERD Press.

was asked to serve eight balls to a designated area in the deuce court and eight balls to a designated area in the ad court. The first four serves were to be directed toward the outside half of the service court, and the second four serves toward the inside of the service court. Each service attempt had a second serve if the first one was a fault. A fault occurred when a ball was served into the net or missed the designated target area.

Each of the service attempts was scored for placement and accuracy. The placement area was designated by a certain target area (Figure 1). Serves landing in the target area received a score of two points. Serves landing elsewhere in the service court received a score of 1 point. Serves landing outside the designated court receive a scored of 0. For each serve that landed in the service court, a score for power was determined based on the second bounce (Figure 1). For balls that landed outside the service court or hit the net a score of 0 was given for power. The accuracy score was the sum of the placement and power scores for each of the 16 trials.

A high speed radar gun (JUGS, JUGS MFG) was utilized to measure ball velocity. The radar gun was placed directly behind the intended service box. The speed of each serve during the AAHPERD test was logged after the ball passed the net.

Each test described above (i.e., accuracy, placement, and velocity) was completed by subjects in both groups, before and after the 6-week strength training program.

Treatment of Data

Independent and dependent _t_-tests were used for statistical analysis of the tennis variables in this study. Three _t_-tests were used to detect statistically significant differences between the groups for accuracy, velocity, and placement of the tennis serve. The SPSS _t_-test procedure was used.

A 2 x 2 mixed model ANOVA was utilized to determine statistical significance between the groups for flexibility. Simple effects analyses were used to follow up significant interactions found in the mixed model ANOVA. The SPSS MANOVA procedure was used.

A multivariate mixed model (Shultz & Gessaroli, 1987) was performed on the five 1 RM strength test scores taken before and after training. The dependent variables included the bicep curl, tricep curl, frontal raise, over-head press and wrist curl. The between-subject variable was group (experimental, control) and the within-subject variable was time (pretraining, posttraining). A significant interaction was followed up with univariate analyses of variance for each of the dependent variables. If the univariate ANOVAs were significant, three pairwise contrasts were performed using the Bonferroni procedure. The contrasts of interest were: (a) experimental posttraining vs. control posttraining, (b) experimental pretraining vs. experimental posttraining, and (c) control pretraining vs. control posttraining. The SPSS MANOVA procedure was used.

Potential significant differences between the groups were also examined for the 30 s power test using a multivariate mixed model. The dependent variables were the bicep curl, tricep curl, frontal raise, over-head press, and wrist curl.

Chapter 4

ANALYSIS OF DATA

The purpose of this investigation was to determine the effects of a 6-week resistance training program on the accuracy, placement, and velocity of the tennis serve. Additionally, flexibility and muscular strength measurements were made prior to and following strength training. The results of this investigation are presented in the following chapter.

Description of Subjects

The subjects used in this study were 18 college-aged female tennis players who were not currently participating in a resistance training program. The experimental group comprised of ten subjects and the control group had eight subjects. The experimental group participated in a 6-week strength training program while the control group did not perform any strength training. The ages of the subjects ranged from 19 to 21 years. Some subjects (n=8) were members of a Division III college varsity tennis team but were out of season during the time of this investigation. The tennis team's season is in early fall and late spring, and there was no preseason practice during the time of this study.

Analysis for Serving Accuracy

An independent t-test was used to determine if differences existed between the groups for serving accuracy. The dependent variable, was posttraining serve accuracy, and was measured with the serving test in the AAHPERD Tennis Skills Test battery (Hensley, 1989). The research hypothesis was that the experimental group would perform significantly more accurately than the control group after strength training as detected by the independent t-test. Two dependent t-tests were used to compare the pretraining to posttraining scores for the control and experimental groups. It was hypothesized that the experimental group but not the control group would significantly improve serving accuracy as detected by the dependent t-tests. The mean scores and standard deviations for the serving accuracy test are illustrated in Table 1. Two subjects were deleted (1 experimental subject and 1 control subject) from this analysis because their scores were more than 3 standard deviations from the mean. The independent t-test was not significant ($t(14)=.06$, $p>.05$) indicating that posttraining

Table 1

Descriptive Statistics for the Tennis Skill and Flexibility Tests

Variable	Group	Time	n	Mean	SD	Range
Accuracy	Experimental	PRE	10	31.40[a]	9.38	29
		POST	10	40.20[d]	11.17	39
	Control	PRE	8	41.13	10.79	33
		POST	8	42.38	6.63	18
Placement	Experimental	PRE	10	15.20[a]	4.32	13
		POST	10	19.80[d]	5.96	21
	Control	PRE	8	20.13	5.96	17
		POST	8	21.00	3.85	12
Velocity	Experimental	PRE	9	56.44[b]	8.38	23
		POST	10	58.80	10.92	35
	Control	PRE	8	56.63	7.98	24
		POST	8	59.25	9.77	27
Flexibility	Experimental	PRE	10	48.70[c]	12.41	46
		POST	9	64.11[d]	16.43	56
	Control	PRE	8	50.38	15.47	44
		POST	8	52.88	16.41	48

[a]points designated by the AAHPERD Tennis Skills Test

[b]miles per hour

[c]inches

[d]significantly different than pretraining ($p<.05$)

accuracy was not different between the groups (Table 2). The dependent t-test for the experimental group was significant ($t(8)=4.63$, $p<.025$). The experimental group's mean posttraining accuracy score ($M=40.2$) was significantly higher than their mean pretraining score ($M=31.4$). The dependent t-test for the control group was not significant ($t(6)=1.30$, $p>.025$) indicating no change in performance occurred with time.

Analysis for Serving Placement

In Table 3, the results from an independent t-test for serving placement is illustrated. The control and experimental group were compared. The dependent variable was posttraining serving placement which was measured with the serving test in the AAHPERD Tennis Skills Test battery (Hensley, 1989). The research hypothesis was that the experimental group's serve would be significantly more accurate in terms of placement in a designated area in the service box than the control group after strength training. The pretraining to the posttraining scores for the control and experimental groups were compared with two dependent t-tests. It was also hypothesized that the experimental group but not the control group would

Table 2

Independent and Dependent t-tests for Serving Accuracy

Test	DF	t	p
Independent			
Expeimental vs. Control	14	.06	.956
Dependent			
Experimental			
Pre vs. Post	8	4.63	.002
Control			
Pre vs. Post	6	1.30	.241

Table 3

Independent and Dependent t-tests for Serving Placement

Test	DF	t	p
Independent			
Experimental vs. Control	14	.08	.937
Dependent			
Experimental			
Pre vs. Post	8	3.54	.008
Control			
Pre vs. Post	6	1.11	.309

significantly improve their serving placement. The mean scores and standard deviations for serving placement are illustrated in Table 1. The independent $\underline{t}$-test between the groups' mean posttraining scores was not significant ($\underline{t}(14)=.08$, $\underline{p}>.05$)(Table 3). The dependent t-test for the experimental group was significant ($\underline{t}(8)=3.54$, $\underline{p}<.025$) indicating that the mean posttraining placement score ($\underline{M}=19.8$) was significantly better than mean pretraining score ($\underline{M}=15.20$). The dependent $\underline{t}$-test for the control group was not significant ($\underline{t}(6)=1.11$, $\underline{p}>.025$) indicating no change occurred in the group's mean placement scores during the training period (20.13 vs. 21.0).

Analysis for Serving Velocity

The results from an independent t-test design for serving velocity are illustrated in Table 4. The control and experimental groups were compared. The dependent variable was posttraining serving velocity which was measured in miles per hour using a radar gun. The research hypothesis was that the experimental group would perform significantly better on the serving velocity posttraining than the control group. Two dependent $\underline{t}$-tests were used to compare the pretraining

Table 4

Independent and Dependent t-tests for Serving Velocity

Test	DF	t	p
Independent			
Experimental vs. Control	16	.09	.929
Dependent			
Experimental			
Pre vs. Post	8	.22	.832
Control			
Pre vs. Post	7	.84	.429

to the posttraining scores for the control and experimental groups. It was also hypothesized that the experimental but not the control group would significantly improve serving velocity. The mean scores and standard deviations for the serving velocity test are illustrated in Table 1. The pretraining mean scores for the experimental group and control group were similar, with both groups showing small increases in means and standard deviations for the posttraining scores. The independent *t*-test was not significant ($t(16)=.09$, $p>.05$)(Table 4). The dependent *t*-tests between the pretraining and posttraining for both the experimental ($t(8)=.22$, $p>.025$) and control ($t(7)=.84$, $p>.025$) groups were not significant. These results indicate no between group difference or improvement in velocity for the groups after the training period.

Analysis for Flexibility

The statistical analysis using a 2 x 2 mixed model ANOVA for flexibility is presented in Table 5. The between-subject variable was group (experimental, control) and the within-subject variable was time (pretraining, posttraining). The dependent variable was shoulder flexibility measured in inches with a

Table 5

Mixed Model ANOVA Table for Shoulder Flexibility

Source	DF	MS	F	p
Between Subject Analysis				
Group	1	183.37	.41	.532
Error	15	448.59		
Within Subject Analysis				
Time	1	698.88	28.26	.000
Time x Group	1	367.12	14.84	.002
Error	15	24.73		

shoulder flexibility test. The research hypothesis was that the experimental group would be significantly more flexible at the end of the study than the control group. The mean scores and standard deviations for the flexibility test are illustrated in Table 1. The pretraining mean scores for the experimental and control group were similar with the experimental group showing a large increase in flexibility while the control group had a minimal increase. The interaction (time x group) was found to be significant ($F(1,15)=14.84$, $p<.05$)(Table 5). Simple effects analyses were performed to compare the pretraining and posttraining means for the experimental group and for the control group. The simple effect analysis for the experimental groups was significant ($F=48.51$, $p<.001$) indicating that the trained group's mean posttraining flexibility score ($M=64.11$ in) was significantly higher than the mean pretraining score ($M=48.70$ in). The simple effect analysis for the control group was not significant ($F=1.02$ $p>.05$). The group main effect was not significant ($F(1,15)=.41$, $p>.05$). The time main effect was significant ($F(1,15)=28.26$, $p<.05$), indicating that the mean posttraining flexibility score

($\underline{M}$=58.50 in) was significantly better than the mean pretraining score ($\underline{M}$=49.54 in).

Analyses of 1-RM Strength Tests

A multivariate mixed model MANOVA was performed on the 1 RM strength test scores. The between-subject variable was group (experimental, control) and the within-subject variable was time (pretraining, posttraining). The dependent variables included the 1 RM scores for the bicep curl, tricep curl, frontal raise, over-head press and wrist curl. The research hypothesis was that the experimental group's strength would be significantly greater than that for the control group after training. The mean scores and standard deviations for the 1 RM strength tests are presented in Table 6. The pretraining means for the experimental and control group were similar. A significant multivariate interaction was found ($\underline{F}(5,12)=18.68$, $\underline{p}<.05$) (Table 7). The group main effect was not significant ($\underline{F}(5,12)=.47$, $\underline{p}>.05$). A significant time main effect was found ($\underline{F}(5,12)=43.93$, $\underline{p}<.05$), indicating that posttraining 1 RM strength scores were significantly higher than the pretraining strength scores.

Table 6

Descriptive Statistics for the 1 Repetition Max. Strength Tests

Variable	Group	Time	n	Mean*	SD	Range
Bicep	Experimental	PRE	10	19.50	4.38	10
		POST	10	29.00	3.16	10
	Control	PRE	8	19.38	4.96	10
		POST	8	23.13	6.51	15
Tricep	Experimental	PRE	10	10.30	1.77	7
		POST	10	14.40	2.68	10
	Control	PRE	8	11.13	2.10	7
		POST	8	12.00	2.07	5
Shoulder[a]	Experimental	PRE	10	10.60	1.35	4
		POST	10	14.50	1.58	5
	Control	PRE	8	13.63	3.34	5
		POST	8	14.13	2.80	8
Shoulder[b]	Experimental	PRE	10	19.00	3.16	10
		POST	10	28.00	3.50	10
	Control	PRE	8	19.00	6.05	15
		POST	8	20.25	4.83	13
Forearm	Experimental	PRE	10	12.20	12.82	7
		POST	10	18.40	5.30	13
	Control	PRE	8	11.88	2.80	7
		POST	8	13.25	3.33	10

*pounds; [a]frontal raise; [b]overhead press

Table 7

Multivariate Mixed Model Analysis of 1 Repetition Max. Strength Test

Source	DF	Wilk's Lambda	F	p
Between Subject Analysis				
Group	5	.84	.47	.793
Error	12			
Within Subject Analysis				
Time	5	.05	43.93	.000
Time x Group	5	.11	18.68	.000
Error	12			

The significant multivariate interaction was followed up with univariate interaction ANOVAs for each of the dependent variables (α=.05/5). All of the univariate interactions on the dependent variables were significant except for the tricep (Table 8). Three pairwise contrasts for each dependent variable (except tricep) were performed using the Bonferroni procedure. The three contrasts of interests were: (a) experimental posttraining vs. control posttraining, (b) experimental pretraining vs. experimental posttraining, and (c) control pretraining vs. control posttraining. A significant difference was found between the two group's mean posttraining scores for the bicep strength variable ($\underline{t}$=6.46, $\underline{p}$<.05)(Table 9). The experimental posttraining scores ($\underline{M}$=29.0 lbs) were significantly greater than the control posttraining scores ($\underline{M}$=23.1 lbs). For the shoulder frontal raise, a significant difference was found between the experimental pre ($\underline{M}$=10.6 lbs) and posttraining ($\underline{M}$=14.5 lbs) scores ($\underline{t}$=7.8, $\underline{p}$<.05), but not between the control pre ($\underline{M}$=13.6 lbs) and posttraining ($\underline{M}$=14.3 lbs) scores ($\underline{t}$=.37, $\underline{p}$>.05). For the shoulder over-head press a significant difference was found between the experimental ($\underline{M}$=28.0

Table 8

Univariate Interaction Tests for the 1 Repetition Maximal Dependent Variables

Dependent Variable	Time x Group F(Probability)
Bicep	9.04(.008)
Tricep	7.41(.015)
Frontal Raise	9.56(.007)
Overhead	65.21(.000)
Forearm	11.79(.003)

Table 9

Bonferroni Pairwise Contrast for each Dependent Strength Test

Source	*M**	*t*
Bicep		
Experimental Post	29.00	2.24
Control Post	23.13	
Experimental Pre	19.50	6.46**
Experimental Post	29.00	
Control Pre	19.38	2.40
Control Post	23.13	
Frontal Raise (Shoulder)		
Experimental Post	14.50	.33
Control Post	14.13	
Experimental Pre	10.60	7.8**
Experimental Post	14.50	
Control Pre	12.38	2.9**
Control Post	14.13	

*lbs
**$p < .05$.

lbs) and control posttraining scores ($\underline{M}$=20.5 lbs)($\underline{t}$=3.18, p<.05) and between the experimental pre ($\underline{M}$=19.0 lbs) and posttraining scores ($\underline{M}$=28.0 lbs)($\underline{t}$=12.16, $\underline{p}$<.05)(Table 10). For forearm strength a significant difference was found between the experimental pre ($\underline{M}$=12.2 lbs) and posttraining scores ($\underline{M}$=18.4 lbs)($\underline{t}$=5.49, $\underline{p}$<.05). In general, the experimental group increased in strength for all variables measured, except for the tricep curl, while the control group showed no significant improvement in the tests of strength.

Analyses of Power Tests

A multivariate mixed model MANOVA was used to determine if there was a significance between the groups for the 30 s power strength tests. The between-subject variable was group (experimental, control) and the within-subject variable was time (pretraining, posttraining). The dependent variables (repetitions in 30 s x weight lifted) included power tests for the bicep curl, tricep curl, frontal raise, over-head press, and wrist curl. The research hypothesis was that the experimental group would perform significantly better than the control group. The mean scores and

Table 10

Bonferroni Pairwise Contrast for each Dependent Strength Test

Source	*M**	*t*
Over-head Press (Shoulder)		
Experimental Post	28.00	3.18**
Control Post	20.25	
Experimental Pre	19.00	12.16**
Experimental Post	28.00	
Control Pre	19.00	1.51
Control Post	20.25	
Forearm		
Experimental Post	18.40	2.48
Control Post	13.25	
Experimental Pre	12.20	5.49**
Experimental Post	18.40	
Control Pre	11.88	1.09
Control Post	13.25	

*lbs
**$p < .05$.

standard deviations for the 30 s power strength tests are presented in Table 11. The pretraining means were fairly similar for the experimental and control group across all exercises with the experimental group showing some improvement for each dependent variable from pre to posttraining. The control group had minimal increases in their pre to posttraining power scores. There was not a significant interaction (time x group) ($F(5,12)=1.91$, $p>.05$)(Table 12). The groups main effect was not found to be significant ($F(5,12)=.88$, $p>.05$). The time main effect was also not significant ($F(5,12)=2.11$, $p>.05$).

In summary, the experimental group improved in accuracy (the sum of placement and power) and placement from pre to posttraining with no improvement shown in the control group. Serving velocity showed no improvements from pre to posttraining for either group. Significant flexibility and strength gains were seen after 6-weeks of training for the experimental group with the control group showing an increase in only one of the strength measures. There was no change in power seen for either group.

Table 11

Descriptive Statistics for the 30 s Power Strength Tests

Variable	Group	Time	n	Mean*	SD	Range
Bicep	Experimental	PRE	10	157.60	55.35	219
		POST	10	203.50	97.27	270
	Control	PRE	8	192.38	69.57	183
		POST	8	152.63	43.83	117
Tricep	Experimental	PRE	10	88.50	31.18	88
		POST	10	104.40	38.33	130
	Control	PRE	8	103.00	43.21	110
		POST	8	116.75	48.71	176
Shoulder[a]	Experimental	PRE	10	93.50	25.83	85
		POST	10	112.20	38.37	132
	Control	PRE	8	87.50	37.06	120
		POST	8	109.25	37.08	110
Shoulder[b]	Experimental	PRE	10	186.50	76.99	228
		POST	10	238.50	66.38	220
	Control	PRE	8	180.00	100.75	268
		POST	8	168.86	77.27	230
Forearm	Experimental	PRE	10	118.50	39.56	110
		POST	10	164.30	90.70	248
	Control	PRE	8	125.00	39.35	100
		POST	8	119.88	38.41	108

*reps x weight lifted in 30 s; [a]frontal Raise; [b]overhead press

Table 12

Univariate-Multivariate Analysis of Variance of the 30 s Power Tests

Source	DF	Wilk's Lambda	F	p
Between Subject Analysis				
Group	5	.73	.88	.521
Error	12			
Within Subject Analysis				
Time	5	.53	2.11	.134
Time x Group	5	.56	1.91	.167
Error	12			

Chapter 5

DISCUSSION OF RESULTS

This investigation demonstrated that female tennis players can make significant strength gains in a 6-week resistance training program without a decrease in flexibility. In fact, a supplemental stretching program caused flexibility to increase during training for the experimental group. As a result of strength training, significant improvements in tennis serve accuracy and placement were found, however ball velocity of the tennis serve did not change. The following sections discuss these subtopics: (a) strength response to resistance training, (b) tennis serve accuracy and placement response to resistance training, (c) tennis serve velocity response to resistance training, and (d) summary.

Strength Response to Resistance Training

Adaptive changes in muscular strength have been demonstrated in many training studies. The duration, frequency, and intensity (i.e., weight, reps, sets) of training determine the type of strength gains obtained. The variety of weight training programs that have been studied demonstrate that certain recommendations should be followed to see significant gains in strength (Berger, 1962a, 1962b, 1962c)(McArdle, Katch & Katch, 1991). The present study demonstrated significant improvements in muscular strength via 1 repetition maximal (RM) strength tests after training in college-aged tennis players. The experimental group demonstrated a 30% average increase in performance for each exercise, while the control group increased minimally or not at all. Smith and Melton (1981) found a 10% increase in strength for non-tennis players during their investigation which used a protocol similar to this study's. However, a low number of subjects (3 training isotonically) and the ages (young males) of the subjects could account for the difference in gains found between studies. Nelson et al. (1986) found gains of 20% in strength for their subjects who performed some exercises that were similar to this study's training program.

The subjects in this study had little prior experience in strength training programs. Muscular strength increases for untrained subjects are easily attained during the early weeks of strength training. These training effects are mainly due to neural adaptions that can lead to subsequent hypertrophic adaptations in the muscle (Hakkinen, 1989). Gains in muscular strength for previously strength trained athletes are not as great compared to those who have never done any resistance training before. Therefore, a factor that likely contributed to the large strength gains of the subjects was their initial low starting levels. The subjects, adjusted quickly to the training methods and were possibly motivated to increase their strength and possibly their tennis performance. While the experimental group improved performance in testing across five muscle groups, the control group had a small but significant gain in strength for only one of the tested exercises. This result was not generalized across the other exercises for the control group and the significant difference may have been due to chance.

Flexibility increased using a supplemental stretching program. Women in general tend to be more flexible than men. The subjects initial flexibility for this study was average or above and increased after the program. It was important that the range of motion in the tennis serve was not inhibited by the resistance training program and therefore this stretching program was administered to prevent any decreases in the subject's movement.

There were no significant improvements in muscular power from pre to posttraining for both groups. Unfortunately, the test used may not have been a true test of power. All trained subjects increased their strength and the weight that was used in the posttraining power test (i.e., 70% 1 RM). However, subjects consistently did substantially less repetitions with the new weight. The methods used for training the experimental group (8 to 12 reps at an individual pace for about 1 to 2 min) may have used a slightly different energy system (glycolysis) than the one used in the 30 s "all out" power test (predominantly ATP and CP). This may also have accounted for no change in the posttraining power test for the experimental group. A more effective test of muscular power for this study probably would have involved using the same test weight pre and posttraining, and performing a maximal number of repetitions for 90 s rather than 30 s. A test of this sort would have been more specific to the training protocol and more likely to assess changes that may occur in muscle power.

Tennis Serve Accuracy and Placement Response to Resistance Training

Accuracy is the most important part of the tennis serve. Without an accurate serve, velocity is unimportant. The role of resistance training and strength gains on improving the accuracy component of a motor skill is virtually unknown.

Present findings document a significant improvement in accuracy for those subjects that performed a resistance training program. Dwyer (1983) found improvements for tennis serve accuracy after isotonic and isokinetic training was performed over an 8-week period. Moreover, Stalder (1990) demonstrated that a 9-week supplemental weight training program improves overall performance in ballet techniques. These studies used similar protocols that were used in this investigation, in which a supplemental isotonic strength training program was performed three days a week for 6 or more weeks. Seemingly contrary to this however, an overarm throwing study documented no improvements in throwing accuracy after a 6-week resistance training program that incorporated weighted balls during the throwing motion (Straub, 1968). The strength training program for Straub's study was different to that used in Dwyer and Stalder studies and, may account for the difference in the performance outcomes. In the former study, more emphasis was placed on training with weighted balls rather than lifting near maximal overload resistance. A program which emphasized greater increases in strength through weight lifting, such as in this study, may in turn make a difference in the results.

In this present study no significant differences were found between the groups for accuracy, however, a significant improvement was seen in the resistance training group over time. The large range of pretraining scores and the low statistical power (due to a small subject size) may have detrimentally influenced the outcome of the between group results. The considerable difference in the accuracy pretraining scores might have been avoided if the subjects had been initially matched according to skill level, and then randomly assigned to either the control or experimental group. Unfortunately, this was not done.

A mechanism that may explain the training group's significant improvements in accuracy may be related to changes in neuromuscular factors. Some research studies have documented changes in neuromuscular control consequent to muscular resistance training. Strength training may cause adaptive changes in the nervous system that allow one to better coordinate the activation of relevant muscles in a specific movement (Sale, 1988). Researchers demonstrated that after a 10-week resistance training study, the amplitude of the muscular response as determined by an electromyograph increased almost two-fold (Roy et al. 1984). The changes in muscular response were attributed to greater recruitment of motor units in the trained muscle. Greater number of recruited motor units increase the activation of prime movers in a specific movement. Alterations in strength and appropriate changes in the activation of synergists and antagonists may in turn produce improved skill and coordination of the proposed skill (Sale, 1988). Non-strength trained athletes may not be able to fully activate specific motor units to trigger prime movers, causing them to be unable to thoroughly perform their sport skill. This theory could be a notable factor in the improvement of motor skills (e.g., serving).

The practical significance of this investigation's findings are that resistance training improved strength and flexibility along with improving the performance of the tennis serve. In conjunction with other studies, there seems to be an important association between strength training and motor skills. It seems that sport specific strength training may enhance skill performance. This may be important to all tennis players interested in increasing their strength and possibly their level of play.

Tennis Serve Velocity Response to Resistance Training

Currently, ball velocity is a topic of interest in tennis. In the professional ranks, an increase in ball velocity has been attributed to new technology, in which larger and stronger frames are making tennis rackets a more powerful piece of equipment. In addition, increases in ball velocity have been attributed to athletes being stronger and more fit. However, the present study did not support the latter concept although the training group did increase their muscular strength.

Investigations dealing with weight training and its affects on the speed of a movement (e.g., throwing speed, kicking speed, racket speed) have demonstrated positive results for performance. Adams et al. (1988) found increases (about 4%) in throwing speed using a strength training program similar to this study, that incorporated all the major muscles in throwing. Alexander et al. (1964) found similar results in their study, which showed improvements in hockey wrist and slap shot velocity after a 5-week training program. Ellenbecker et al. (1988) and Bagonzi (1979) also demonstrated that sport specific strength training (resistance training similar to the sport movement itself) produced increases in performance speeds (i.e., serving and pitching) by about 10%.

Present findings document no significant improvements in velocity for the tennis serve after a 6-week training program. A 4% increase was seen for both the experimental and control group posttraining. A variety of reasons could account for the same margin of improvement between the two groups. A learning effect could be a factor allowing subjects to become more accustomed to the tests and consequently perform better. A motivational effect could have also caused the subjects to perform better. For example, the subjects could have been trying to improve their pretraining scores or trying to perform better than another subject.

The most likely explanation for the lack of a significant improvement in serve velocity for the training group in this study is related to the test used to measure velocity. The serving test was specifically designed for accuracy and power. Power was measured by a line that was placed nine feet from the base line. It was not difficult to pass this line with a serve of moderate speed. Even though velocity was stressed as an important part of performance, most players slowed their swing down during the testing to get the ball placed in the designated service court for a successful serve. The subjects may have been more concerned with placing the serve in the service court than with having the ball pass the power line to receive the highest score. The relevance of measuring the velocity with a radar gun during serves that are not projected with an all out effort will not give a true indication of the effects of strength training. This likely caused the test of velocity in the present study to become invalid. This could have been overcome by performing a test for velocity that was separate from the accuracy and placement tests.

Some contradicting studies have demonstrated that training certain sport specific muscles by weight lifting does not necessarily mean that the performance of that muscle group will improve (Coyle, Feiring, Rotkis, Cowte & Rowby, 1981). For example, strengthening the legs by the performance of squats may not always show any improvement in another leg movement such as jumping. These studies demonstrated there is little transfer of newly acquired strength to other types of sport movements, even though the same muscles are being trained. Therefore, strengthening muscles for a specific sport may require more than identifying and overloading the muscles for that movement (Duchateau & Hainaut, 1984). Training may have to be sport specific, in which the muscles are trained with a movement as close as possible to the desired sport skill.

Summary

It is clear that a 6-week training program will produce significant gains in strength and flexibility for female tennis players following this study's protocol. Accuracy of the serve which simultaneously considered both power and placement, and placement alone did demonstrate significant improvements after training. The velocity of the tennis serve was statistically unaffected by a successful strength and flexibility training program, however, the relevance of this study's measure of velocity may have been invalid.

There may be potential benefits of using a weight training program for improving motor skill performance, such as throwing, kicking, and serving a tennis ball. A variety of resistance training programs are used by athletes in many sports today. Studies have showed that improvements can be made in athletic performance with increases in muscle strength through strength training, with this investigation reinforcing those results. It can be concluded from this study that after a 6-week resistance training period, college-aged females increased in strength and flexibility, and in turn, improved their tennis serve performance.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This study was designed to determine the effects of a 6-week resistance training program on the velocity, accuracy, and placement of the tennis serve. Additionally, pre and posttraining muscular strength, power, and flexibility were measured.

Before 6-weeks of resistance training, all college-aged female subjects were measured for strength and power of five exercises, specifically: the bicep curl (bicep), tricep curl (tricep), frontal raise (deltoid), over-head press (deltoid), and wrist curl (forearm). Flexibility was measured using a shoulder elevation test. Accuracy and placement tests (AAHPERD) were used to examine the ability to serve a tennis ball in a designated hitting area. Serve velocity was measured using a radar gun. All measurements were taken pre and posttraining to assess the effectiveness of the training protocol. The resistance training group (n=10) exercised three times a week for 6-weeks, performing three sets of five sport specific exercises. The control group (n=8) remained sedentary (no strength training) for the entire training period. Furthermore, flexibility exercises were performed at the beginning of each training session for the experiment group. A significant group x time interaction for strength and flexibility indicated a successful training program for the experimental group. The testing of accuracy and placement for the trained group revealed a significant change for the better. However, serve velocity for both groups did not display any improvement. These results are in agreement with other findings that demonstrate an improvement in a motor skill is possible after resistance training in skilled subjects.

Conclusions

The results of this investigation led to the following conclusions with respect to resistance training effects on the accuracy, velocity, and placement of the tennis serve:

1. The accuracy and placement scores for the experimental group following a 6-week resistance training program displayed a significant improvement while this improvement was not seen in the control group.

2. The velocity scores for the experimental group in response to a 6-week training program demonstrated no

statistical difference compared to the control group, however, test validity on this parameter must be questioned.

3. The measurement of strength and flexibility in response to a 6-week training program demonstrated a significant increase.

4. The measurement of power in response to a 6-week training program demonstrated no significant increase compared to the control group, however, test validity on this parameter was also questionable.

Recommendations

The following recommendations for further study were made after the completion of this investigation:

1. A similar study should investigate the same variables with twice as many subjects matched for initial skill level. More subjects would increase statistical power and should provide more clear cut information on the effects of resistance training while skill matching would allow experimentally induced differences between groups to be more easily noticed.

2. A study should be designed to investigate the effects of a total body weight training program on the same variables measured, in which lower body exercises

are incorporated into the training program.

3. A similar study could be done using the same protocol in which a speed serve condition was tested with diminished emphasis on accuracy.

4. A study could be performed in which a longer training period is used to promote larger strength gains.

Appendix A

INFORMED CONSENT

1. Purpose of the study:

The purpose of this study is to investigate the effects of strength training on the performance of the tennis serve.

2. Benefits:

The subjects may improve their performance of the tennis serve along with increased strength. These findings may lead investigators in other sports to research this area in improving athletes skill.

3. Method:

In this study you will be randomly assigned to one of two groups, consisting of one experimental group and a control group. The experimental group will perform various upper body exercises three days per week, 30 minutes per day for six weeks. The control group will not perform any training. All subjects will be pre and post-tested on their accuracy and velocity of their tennis serve. The testing will take approximately one hour on two separate days.

4. Are there any risks involved?:

You may experience muscle soreness in the initial few days of training. A possible risk of muscle injury is always present when you exercise, however, all possible safety precautions and proper preventive injury techniques will be enforced.

5. Need more information?:

Please contact: Stephen J Wazenski or Dr. G. A. Sforzo
Physical Education Department, Hill Center

Phone: 274-1301 or 274-3359

6. Withdrawal from the study?:

You are free to withdraw from the study at any time. Even though your coach has agreed for your participation in the study you are not required to participate. Your academic status or placement on your team will not be affected by your participation or non-participation in this investigation.

7. Will the data be maintained in confidence?:

Yes. All data will be kept in complete confidence. Your data will be kept anonymous in that your name or any other type of identification will not ever be published in association with this study. Furthermore, your coach will not be given this information unless you so request.

8. I have read the above and I understand its contents and I agree to participate in the study. I acknowledge that I am 18 years of age or older.

______________________________ ______________________

Signature Date

Appendix B

SCORE SHEET

Name:____________________________ Subject Code:__________

Age:______ Phone:______________ Address:________________

STRENGTH TESTS

Pretraining Data:

a. 1 Repetition Max

exercise	weight(lbs)	repetitions
bicep curl	____________	____________
tricep curl	____________	____________
frontal raise	____________	____________
over-head press	____________	____________
wrist curl	____________	____________

b. 30 s Power Test

exercise	weight(lbs)	repetitions
bicep curl	____________	____________
tricep curl	____________	____________
frontal raise	____________	____________
over-head press	____________	____________
wrist curl	____________	____________

c. Flexibility Test

measurement(in)___ * 100 / arm length___ = ___

Posttraining Data:

a. 1 Repetition Max

exercise	weight(lbs)	repetitions
bicep curl	____________	____________
tricep curl	____________	____________
frontal raise	____________	____________
over-head press	____________	____________
wrist curl	____________	____________

b. 30 s Power Test

exercise	weight(lbs)	repetitions
bicep curl	____________	____________
tricep curl	____________	____________
frontal raise	____________	____________
over-head press	____________	____________
wrist curl	____________	____________

c. Flexibility Test

measurement(in)___ * 100 / arm length___ = ___

Appendix C

RAW DATA

Pretraining Descriptive Variables for the Tennis Serve

Control Subjects:

ID#	Accuracy	Placement	Velocity(ave mph)
1	24	10	66
2	30	14	49
3	43	21	61
4	52	25	54
5	39	19	63
6	39	19	57
7	45	26	42
8	57	27	61

Experimental Subjects:

ID#	Accuracy	Placement	Velocity(ave mph)
9	23	11	46
10	28	14	69
11	36	18	-
12	23	11	67
13	34	16	50
14	40	19	58
15	42	20	64
16	40	17	63
17	35	19	50
18	13	7	46

Posttraining Descriptive Variables for the Tennis Serve

Control Subjects:

ID#	Accuracy	Placement	Velocity(ave mph)
1	47	23	65
2	30	14	70
3	47	23	68
4	48	21	57
5	39	19	64
6	47	24	47
7	45	26	43
8	36	18	60

Experimental Subjects:

ID#	Accuracy	Placement	Velocity(ave mph)
9	36	18	63
10	43	21	69
11	40	20	75
12	44	22	64
13	11	4	40
14	45	21	62
15	44	20	60
16	50	22	58
17	50	25	55
18	39	25	42

Pretraining Scores for the 1 Repetition Max. and 30 s Power Test

Control Subjects:

ID#	Exercise	1 Repetition Max lbs	30 s Power Test lbs/reps
1	Bicep curl	25	20/12
	Tricep curl	12	10/17
	Frontal raise	12	10/10
	Over-head press	25	20/17
	Wrist curl	15	12/12
2	Bicep curl	20	15/21
	Tricep Curl	12	10/17
	Frontal raise	15	12/14
	Over-head press	25	20/16
	Wrist curl	15	12/15
3	Bicep curl	25	20/13
	Tricep curl	10	8/13
	Frontal raise	15	12/8
	Over-head press	20	15/12
	Wrist curl	15	12/15
4	Bicep curl	15	12/12
	Tricep curl	8	5/12
	Frontal raise	10	8/6
	Over-head press	10	8/9
	Wrist curl	8	5/16

Pretraining Scores for the 1 Repetition Max and 30 s Power Test

Control Subjects:

ID#	Exercise	1 Repetition Max lbs	30 s Power Test lbs/reps
5	Bicep curl	25	20/8
	Tricep curl	15	12/6
	Frontal raise	15	12/6
	Over-head press	25	20/9
	Wrist curl	12	10/12
6	Bicep curl	15	12/11
	Tricep curl	12	10/8
	Frontal raise	12	10/8
	Over-head press	20	15/10
	Wrist curl	10	8/11
7	Bicep curl	15	12/11
	Tricep curl	12	10/8
	Frontal raise	20	15/10
	Over-head press	12	10/9
	Wrist curl	10	8/12
8	Bicep curl	15	12/13
	Tricep curl	10	8/11
	Frontal raise	10	8/10
	Over-head press	15	12/9
	Wrist curl	10	8/14

Pretraining Scores for the 1 Repetition Max and 30 s Power Test

Experimental Subjects:

ID#	Exercise	1 Repetition Max lbs	30 s Power Test lbs/reps
9	Bicep curl	15	12/15
	Tricep curl	10	8/17
	Frontal raise	10	8/12
	Over-head press	20	15/16
	Wrist curl	15	12/14
10	Bicep curl	25	20/8
	Tricep curl	10	8/9
	Frontal raise	12	10/14
	Over-head press	20	15/20
	Wrist curl	15	12/11
11	Bicep curl	15	12/15
	Tricep curl	8	5/21
	Frontal raise	10	8/14
	Over-head press	20	15/17
	Wrist curl	12	10/17
12	Bicep curl	20	15/17
	Tricep curl	10	8/16
	Frontal raise	10	8/14
	Over-head press	20	15/12
	Wrist curl	12	10/8

Pretraining Scores for the 1 Repetition Max and 30 s Power Test

Experimental Subjects:

ID#	Exercise	1 Repetition Max lbs	30 s Power Test lbs/reps
13	Bicep curl	15	12/15
	Tricep curl	10	8/15
	Frontal raise	10	8/13
	Over-head press	20	15/18
	Wrist curl	15	12/12
14	Bicep curl	25	20/8
	Tricep curl	10	8/10
	Frontal raise	12	10/8
	Over-head press	25	20/7
	Wrist curl	15	12/10
15	Bicep curl	20	15/11
	Tricep curl	10	8/6
	Frontal raise	12	10/10
	Over-head press	15	12/10
	Wrist curl	10	8/17
16	Bicep curl	25	20/7
	Tricep curl	15	12/5
	Frontal raise	12	8/9
	Over-head press	20	15/12
	Wrist curl	12	10/11

Pretraining Scores for the 1 Repetition Max and 30 s Power Test

Experimental Subjects:

ID#	Exercise	1 Repetition Max lbs	30 s Power Test lbs/reps
17	Bicep curl	15	12/13
	Tricep curl	10	8/8
	Frontal raise	8	5/11
	Over-head press	15	12/9
	Wrist curl	8	5/12
18	Bicep curl	20	15/8
	Tricep curl	10	8/9
	Frontal raise	10	8/8
	Over-head press	15	12/6
	Wrist curl	8	5/13

Posttraining Scores for the 1 Repetition Max and 30 s Power Test

Control Subjects:

ID#	Exercise	1 Repetition Max lbs	30 s Power Test lbs/reps
1	Bicep curl	30	25/9
	Tricep curl	15	12/18
	Frontal raise	15	12/12
	Over-head press	25	20/15
	Wrist curl	15	12/6
2	Bicep curl	30	25/5
	Tricep curl	12	10/13
	Frontal raise	20	15/12
	Over-head press	25	20/12
	Wrist curl	20	15/9
3	Bicep curl	30	25/8
	Tricep curl	12	10/12
	Frontal raise	15	12/7
	Over-head press	20	15/14
	Wrist curl	15	12/15
4	Bicep curl	15	12/9
	Tricep curl	10	8/12
	Frontal raise	12	10/8
	Over-head press	12	10/7
	Wrist curl	10	8/18

Posttraining Scores for the 1 Repetition Max and 30 s Power Test

Control Subjects:

ID#	Exercise	1 Repetition Max lbs	30 s Power Test lbs/reps
5	Bicep curl	25	20/7
	Tricep curl	15	12/9
	Frontal raise	15	12/8
	Over-head press	25	20/6
	Wrist curl	12	10/15
6	Bicep curl	15	12/9
	Tricep curl	12	10/12
	Frontal raise	12	10/10
	Over-head press	20	15/10
	Wrist curl	10	8/11
7	Bicep curl	20	15/9
	Tricep curl	10	8/5
	Frontal raise	12	10/7
	Over-head press	15	12/8
	Wrist curl	12	10/8
8	Bicep curl	20	15/12
	Tricep curl	10	8/13
	Frontal raise	12	10/12
	Over-head press	20	15/11
	Wrist curl	12	10/11

Posttraining Scores for the 1 Repetition Max and 30 s Power Test

Experimental Subjects:

ID#	Exercise	1 Repetition Max lbs	30 s Power Test lbs/reps
9	Bicep curl	30	25/11
	Tricep curl	15	12/7
	Frontal raise	15	12/8
	Over-head press	30	25/10
	Wrist curl	25	20/16
10	Bicep curl	30	25/14
	Tricep curl	15	12/5
	Frontal raise	15	12/9
	Over-head press	30	25/9
	Wrist curl	25	20/13
11	Bicep curl	30	25/8
	Tricep curl	15	12/11
	Frontal raise	15	12/8
	Over-head press	25	20/9
	Wrist curl	25	20/14
12	Bicep curl	30	25/7
	Tricep curl	20	15/12
	Frontal raise	15	12/8
	Over-head press	30	25/9
	Wrist curl	20	15/7

Posttraining Scores for the 1 Repetition Max and 30 s Power Test

Experimental Subjects:

ID#	Exercise	1 Repetition Max lbs	30 s Power Test lbs/reps
13	Bicep curl	30	25/14
	Tricep curl	15	12/9
	Frontal raise	15	12/10
	Over-head press	25	20/11
	Wrist curl	15	12/6
14	Bicep curl	35	30/9
	Tricep curl	15	12/7
	Frontal raise	15	12/8
	Over-head press	35	30/6
	Wrist curl	20	15/12
15	Bicep curl	25	20/8
	Tricep curl	12	10/13
	Frontal raise	15	12/10
	Over-head press	25	20/14
	Wrist curl	15	12/7
16	Bicep curl	30	25/13
	Tricep curl	15	12/10
	Frontal raise	15	12/8
	Over-head press	30	25/11
	Wrist curl	15	12/11

Posttraining Scores for the 1 Repetition Max and 30 s Power Test

Experimental Subjects:

ID#	Exercise	1 Repetition Max lbs	30 s Power Test lbs/reps
17	Bicep curl	25	20/4
	Tricep curl	10	8/12
	Frontal raise	10	10/9
	Over-head press	25	20/10
	Wrist curl	12	10/12
18	Bicep curl	25	20/5
	Tricep curl	12	10/5
	Frontal raise	15	12/7
	Over-head press	25	20/10
	Wrist curl	12	10/9

Pretraining and Posttraining Scores for the Flexibility Test

Control Subjects:

ID#	Preflexibility (in)	Postflexibility (in)
1	77	79
2	46	50
3	48	48
4	35	31
5	69	66
6	33	33
7	43	52
8	52	64

Experimental Subjects:

ID#	Preflexibility (in)	Postflexibility (in)
9	54	72
10	44	65
11	42	65
12	51	
13	68	96
14	45	50
15	45	49
16	58	70
17	22	40
18	58	70

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