THE EFFECT OF GRIP AND WRIST STRENGTHENING EXERCISES ON TENNIS PLAYING ABILITY

by

Mary Ann Vogt

A Thesis Submitted to
the Faculty of
the Consolidated University of North Carolina
in Partial Fulfillment
of the Requirements for the Degree
Master of Science in Physical Education

Greensboro
1961

Approved by

Gail M. Hennis
Adviser

APPROVAL SHEET

This thesis has been approved by the following committee at The Woman's College of the University of North Carolina, Greensboro, North Carolina.

Thesis Adviser Gail M. Dennis

Orals Committee Members Dorothy Davis

Eileen Griffin

Laura G. Anderton

ACKNOWLEDGMENTS

The writer wishes to express her sincere gratitude and appreciation to Dr. Gail Murl Hennis of the Department of Physical Education of The Woman's College of the University of North Carolina, for her interest and valuable guidance throughout the course of this study.

Appreciation is extended to those students of The Woman's College of the University of North Carolina who acted as subjects and gave so willingly of their time.

The writer wishes to thank the following graduate students of the Department of Physical Education for their assistance in the testing of subjects: Pauline Gosselin, Lorraine Khouri, Margaret Kingston, Emily Mercer, Sally Nelson, and Jean Osborne.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF FIGURES

CHAPTER I

INTRODUCTION

There are a number of prerequisites necessary for efficient movement. Broer (3) has separated these prerequisites into three main categories: physical, mental, and emotional. The mental characteristics of movement occur when the individual makes spatial judgments. For example, the tennis player knows that the racket, which acts as the extension of his arm, will hit the ball at exactly the right time. Many sports require quick decisions which draw upon the mental abilities of the player. The emotional characteristics are concerned with the individual's desire to learn the elements of a new skill. In physical education fear enters into many activities so much so that the student's learning capacities are hindered until his emotional state is more stabilized, which is particularly true in swimming. The physical qualities of movement consist of the individual's physical make-up, that is, the ability to make use of muscular force, flexibility, reaction time, and sharpness of the senses. It is how effectively the individual uses these elements that makes movement more purposeful. Morehouse and Cooper (15:117) state that

> Through more effective use of available forces, a small man can out wrestle a larger man, a short-statured golfer can out drive a taller golfer, a person with a short arm can throw farther than another with a long arm, and a weak-muscled person can move a heavier load than a strong-muscled person.

The writer's primary interest in this study was in the area of the physical qualities of efficient movement of which strength is one

of the components. In some athletic activities this quality is not important, but in others it may make the difference between the winning or losing of a match.

In the game of tennis, players and instructors (11, 24, 38, 41) disagree as to which areas of the body are most important for the development of strength. It is possible that the back and leg muscles carry the greatest burden since they are involved in continuous running and rapid changes of direction. The shoulder girdle could also carry a great deal of the strain because of the swinging action of racket games. The grip and wrist, however, seem also to have a considerable amount of strain to bear in order to hold the racket. Driver (7) has mentioned that there is a great deal of difference between the wrist action of the advanced player and the beginning player. The advanced player can use his wrist to place deceptive shots, whereas the beginner lacks the wrist strength to control the racket.

The inability of the player to squeeze the racket at the moment of impact causes the ball to be deflected off the strings of the racket at an angle. The squeezing action is important because it tightens the muscles of the forearm which control the wrist. A stabilized wrist is necessary particularly for the beginner; however, for more advanced players a wrist snap can be employed in order to add more force to the stroke. The advanced player must know how and when this wrist snap should take place. It should occur just before the ball is hit, and then the grip and wrist should be firm in order to withstand the impact of the ball.

The writer feels that research in the field of tennis is lacking. Perhaps if there were more of a scientific basis for teaching, the student could be helped to understand the necessity for better wrist action. It is for this reason that this study has been undertaken. If the teacher of tennis feels that the grip and wrist action are of such importance, then methods should be employed to strengthen them and increase the player's playing potential.

CHAPTER II

STATEMENT OF PROBLEM

The purpose of this experiment was to determine whether a program of exercises to increase grip and wrist strength would have any effect on tennis playing ability. Before the major portion of the study was begun a number of sub-problems had to be dealt with.

1. A sufficient number of subjects had to be selected from those students who had reached intermediate or advanced level of tennis playing ability.

2. A reliable tennis skills test was needed to determine each subject's tennis playing ability.

3. A reliable testing instrument was needed to determine each subject's grip strength, wrist palmar flexion strength, and wrist dorsal flexion strength.

4. A series of exercises was needed and selected for the purpose of increasing strength of grip and wrist.

The final portion of the experiment was the analysis of data to determine if there were any significant difference between groups in increase of grip and wrist strength from the initial tests to the final tests. It was also necessary to determine whether there was a significant increase in tennis playing ability from the initial test to the final test.

CHAPTER III

REVIEW OF LITERATURE

Players and teachers of tennis have divergent opinions about the game of tennis. To some of the experts strategy is the most important factor; to others it is the development of proper skills. The writer was particularly interested in what the professional players and instructors of tennis stressed about the wrist action during the tennis stroke.

In one of the earlier tennis books written in 1888, Osborn (18:40) explains that a player will never develop "the art of handling a racket" unless he has an easy and flexible wrist. Although at this time a "firm and steady wrist" was advocated, Osborn felt that the rebounding of the ball from the racket was enough to carry the ball over the net. No mention was made of any force being exerted by the forearm or shoulder.

During the early part of the twentieth century, National Doubles Champions Reginald Doherty and Hugh Doherty (6) based their tennis game on a firm, not a tight wrist. Many of the players at this time seemed to have conflicting ideas about the firmness and tightness of the grip.

Paret (20:19), winner of the 1899 All-Comers National Tournament, listed Five Cardinal Principles of a good stroke, the first of which reads: "Always hold the racket tight in the hand, as the stroke is made increase the tightness of this grasp." In another book written by Paret (19:12) in 1916 he had dropped the word tight and was using the

term "firmly held racket." He states that the reason for this firm racket is that ". . . a loose grip is one of the worst errors possible. It permits the racket to turn in the hand when the ball is slightly off the center of the racket's string. . . ."

Paret, as well as Austin (1:34), also a championship player, saw the value in a firm wrist but did not feel that the muscles of the arm were important for a good tennis stroke. Rather than strength they felt that the momentum of the racket propelled the ball over the net.

By the late thirties, Godfree (9:24), winner of the 1927 National Women's Doubles, and other players were beginning to realize that the strength of the wrist and forearm played a very important part in the execution of the tennis stroke. Jacobs (11), in 1941, recommended a cocked backswing which is snapped forward as the ball is hit. However, she stressed that in order to have power and accuracy one must have rhythm in the stroke. Robinson (43:7) teaches a cocked and relaxed wrist because he feels"that this action prevents the player from making a stiff arm stroke and gives the stroke more zip and smoothness."

Driver (7:68) lists a number of common faults made by beginners in tennis, but does not mention the inability of the beginner to squeeze the racket. However, she does mention the error of a cramped elbow during the swing, but does not give reasons why the player does this. Broer (3:14) explains this is a compensatory action due to lack of strength. With the support of the arm against the body less strength is required to withstand the impact. To help the student Broer suggests that the racket be squeezed at the moment of impact in order to tighten

the wrist muscles and to aid in resisting the force of the ball.

Viewpoints have varied among the champions and instructors of tennis concerning the proper amount of strength that should be exerted by the wrist in order to keep the racket under control. In the early nineteenth century little stress was placed upon the strength of the forearm or the grip, but during the past sixty years increasing emphasis has been placed on the strength of the forearm and shoulder. In order to aid the player in controlling the racket, tennis players and coaches have felt that it would be beneficial to squeeze the racket at the moment of impact to prevent the racket from turning in the hand. If, however, the player's wrist seems to lack the strength necessary for this action, Broer (3:14) recommends that exercises be performed to help increase strength.

A review of suggested conditioning exercises for tennis has indicated a change from less strenuous activity to that which is more strenuous.

In 1913, Wilding (24:82-85), Wimbledon Men's Singles Champion, recommended a diversified program of exercises that he used to prepare for tennis matches. Among these were skipping and short fast sprints to develop quickness on the court, and ball-punching, in order to loosen the shoulders and aid in accuracy. Vaile (22:189-191) and Bjurstedt (2:155) felt that the main part of exercising should consist of tennis practice. This practice should be done with someone of equal ability and for only short periods throughout the day.

Austin (1:66-75) set up for herself a program of daily exercises

which consisted of muscle stretching for brief periods in the morning; deep breathing to improve stamina and general health; walking 200 yards and then sprinting for fifty yards; and, finally, a properly controlled diet to maintain good physical health.

Jacobs (11:73) also felt that it was necessary for tennis players to be in good physical condition. She suggested "simple foods at regular hours, to have eight or nine hours sleep." However, she stressed the benefits gained from horseback riding and walking, because of their value in strengthening the leg and back muscles. Driver (7:38), however, felt that the beginner should spend more time in the development of strength in the shoulder girdle and arm muscles.

From the point of view of a tennis coach Lefevre (39:54) states:

> For conditioning most coaches recommend running, especially early in the season. Some coaches require four or five miles of roadwork daily. Frequently special calisthenics, working with weights, rope skipping, and other techniques are used to build up strength as well as endurance. It would be wise to avoid those activities which tend to "tie up" or toughen the players.

Frederick (35) and Leighton (12) both recommend some type of warm-up drill before the class instruction. Leighton (12:6) suggests seven such warm-up drills:

1. Knee bending. Leading up to the crouch position for low bouncing balls.
2. Lunging. To correct a great weakness in tennis players - the ability to sustain the weight over the front knee long enough to complete the stroke.
3. Back bending. Vital for the full swing service.
4. Skipping sidewards. For gliding or drifting into position.
5. Running backwards and forwards. For footwork.
6. Squeezing. Squeezing a tennis ball in one hand and relax to develop forearm and wrist.
7. Tossing. Toss ball with left hand catch it to develop control of left side. Toss ball underhand to partner so he can catch it with right hand, then to left so he can catch it with left

hand.

McPherson (41) has also developed a set of drills for the tennis player consisting of a variety of movements: rope jumping to build endurance and strength; floor and ground drills that involve hopping which will aid in quick shifts of direction on the court; the boxer's drill which involves rapid changes in foot position and speed up reaction time; and high jumps to develop the strength needed to lift the body into the air in full extension.

Kline (38:18) suggested that before a coach begins to train a tennis player, the player should participate in a conditioning program. Recommended are such drills as running, coordinated stretching exercises, push-ups, and sit-ups. Kline places a substantial amount of emphasis on the strength of hands and wrists.

> A limited amount of time should be spent on strengthening the forearm and wrist, as well as the grip of the tennis arm. The raising and lowering of weights by wrist movement only is a great developer of the forearm muscles and grip. Stronger muscles will make the racket feel much lighter and produce a firmer and more confident grip.
>
> When starting to condition these muscles, count the number of times you do each exercise -- that is, raising and lowering the wrist with the forearm resting on a flat plane with the hand over the edge: 20 times the first period, adding five each exercise period.

TENNIS SKILL TESTS

In the selection and reviewing of tennis skill tests the writer has used the criteria of a good test as recommended by Scott and French (21).

1. Tests should be as much like the game situation as possible.

Many times tests are constructed so that the subject makes continual violations of the basic rules of the game.

2. Tests should measure the skills which are involved in the particular sport.

3. Tests should be concerned with only one person at a time. If the subject tested must depend on a partner, the scores may not be true due to the inferior or superior skill of the partner. Where possible, it is best to have rallying situations where the subject can be assured of continuous play by his sending and receiving the ball.

4. Tests should have a sufficient number of trials. From one to three trials are recommended.

5. Tests should score accurately and enable the recorder to score the results with ease.

6. The test should be of sufficient difficulty so that there will not be a massing of scores at one point. Also the test if too easy or too hard will have scores that appear at the extremes of the scale.

7. A good test should have reliability coefficients between .75 and .85 and validity coefficient no lower than .60.

The original Dyer Backboard Test of Tennis Ability (32) had a validity and reliability coefficient of .90. "The backboard test has been designed to measure ability in tennis for classification purposes." (32:63) In 1938, a revision (33) of the test was necessary in order to standardize the restraining line, method of ball handling, and the method of scoring. A validity coefficient of .92, using Round Robin Tournament as the criterion, was found for the revision indicating the

changes had had some positive effect.

With respect to the Dyer Backboard Test, Scott and French (21) recommend that the restraining line should not be any closer to the wall than twenty-four feet. However, more advanced players will perform better when the restraining line is farther from the wall, because they have more power in their stroke. They suggested that the line be at least thirty to thirty-six feet away from a very fast wall. The modification of the Dyer Backboard Test, called the Wallboard Test, recommends a line twenty-seven and one-half feet from the wall (21:222-223).

Driver (7) has constructed a tennis test of form and playing ability. The test involves the subject's hitting a thrown ball between the net and a line ten feet above the net. The court opposite the subject is marked off into scoring areas. Driver states that "the test has fair reliability." She does not, however, give any statistical evidence to verify this statement.

Broer and Miller (25) have devised an objective tennis skill test to be used for grading purposes and also to point out the player's weakness and strength in placement of forehand and backhand drives into the back court area. The test requires that the player hit a ball so that it will go into the backcourt area after passing over the net and under a four-foot line. Each player has fourteen trials with the forehand and backhand. A reliability coefficient of .80 was found when the first seven trials were correlated with the second seven trials. Validity was obtained by judges' ratings. The result of correlating the combined scores of the two judges' subjective ratings with the test was

.85. The test has only been administered to small groups and, therefore, the results show only that the test may have potential value as a measuring instrument.

In trying to find a test that would measure consistently the playing ability of tennis players, Fox (34) combined the Dyer and Miller tests. The correlation between the Dyer and Miller tests showed low coefficients thus indicating that the tests do not measure exactly the same thing. Hence this may indicate that a combination of the Dyer and Miller tests may be a truer measure of tennis playing ability.

Leighton (40) has developed a test which involves a number of strokes used in the tennis game. His whole emphasis is on the pace or power to hit the ball. He states that it is necessary to use "normal hitting power." In other words, soft strokes should not be considered as having scored. It is the opinion of the writer that this type of test could not be very reliable since it calls for only one judge in the recording of the scores and requires a very subjective conclusion on the part of the judge in determining the power of the stroke used by the player.

INSTRUMENTS TO MEASURE STRENGTH

The writer has chosen, because of the nature of the study, to limit this part of the review only to those strength testing instruments that have been found useful in measuring grip or wrist strength.

The pneumatic dynamometer constructed by Geckler (36:353) measures grip strength from the feeblest to the strongest. "This instrument combines an air gauge and blood pressure bulb connected with

rubber tubing." The rubber bulb enables even the partially stiff hand to squeeze with ease. This type of apparatus can also be used for daily exercise for an injured hand.

The Wakim-Porter Strain Gauge (30) has a degree of precision that is satisfactory for strength testing. However, it is sensitive to slight tension and to changes in temperature. When strong strength tests are conducted, a distortion of the aluminum ring occurs and is slow in returning to shape.

Rather than applying tension by pulling, the Newman Myometer (30) is based upon resistance to pressure, which is limited to sixty pounds. Fatigue of the testers and bruising of the subjects might occur if greater resistance were applied.

The manuometer or hand dynamometer (13) is used to measure grip strength. The subject places the dynamometer in the hand so that the indicator is toward the palm. The subject then grips the dynamometer as tightly as possible. The grip strength can then be read directly from the dial.

Clarke (4), in connection with the Army Air Force, adapted a device, constructed to measure the tensile strength of airplane cable, for measuring the strength of muscle groups. During the initial study the tensiometer only measured up to 300 pounds, and did not measure accurately below thirty pounds. Therefore, the construction of a second instrument was necessitated to measure from five to one hundred pounds. This newer instrument was then used to measure smaller muscle groups.

Cable tension is determined by measuring the force needed to create offset (on riser) in the cable between two set points (the sectors).

> The cable tension may be converted directly into pounds on a prepared calibrated chart attached to the inside of the cover of the tensiometer case. (31:120)

STRENGTH STUDIES

One of the prerequisites to efficient movement is the physical condition of the body. These physical qualities are endurance, strength, muscular power, acuity of the senses, and reaction time (3). Each one of these is used in varying degrees during different types of activities. It is the effective use that an individual makes of these elements that will make his movement produce the desired results. In physical activities a combination of these components is necessary to produce the level of skill necessary to play a successful game. For example, kinesthetic awareness is an important mechanism for the tennis player. The player should be able to watch his court position and the ball without having to concentrate on his racket position.

Strength as a physical element is not needed in all types of movement. It is predominately associated with the lifting and carrying of heavy loads. However, most sport activities require a certain amount of strength for skilled performance.

Morehouse and Rasch (17:108) define strength "as the ability of the muscle to exert force against a resistance." Some activities do not require the exertion of a great deal of force, hence little strength may be necessary. Those activities that do require strength most often call into play larger muscle groups in order to avoid strain.

All the muscles of the body do not have the same potential force. This is due to a number of factors which determine the strength of the

muscles. Size and quantity of muscular tissue aid in the amount of force exerted. Wells (23:41) states that:

> The magnitude of muscular force is in direct proportion to the number and size of the fibers in the muscle which is contracting. In the living body it is impossible to gauge the magnitude of a single muscle's force because of the fact that muscles contract in groups, not individually.

Besides the size and quantity of muscle fiber, the placement of the muscles over and near the joint will have an effect on the amount of strength potential. Leverage, whether it is internal or external, has an effect on the amount of force potential. The relationship of the muscles to the joint has an effect on their ability to exert force. Morehouse and Rasch (17:109) state that "The strength of a muscular action is affected by the distance from the joint at which the muscle is inserted. The further the insertion from the joint the greater is the muscular power." Besides the internal lever, implements are employed externally to aid muscular force. In sports a bat or racket is used as an artificial extension of the arm. These implements increase the velocity of the swing causing a more powerful hit.

The amount of strength which a muscle can exert will be greatly reduced when there is a large amount of fat tissue in the body. Because fat has no powers of contraction, it will limit the contractions of the muscle fibers (17).

The strength of a muscle will also depend on its ability to recover from strenuous activity. This recuperative ability of the muscle is of importance in athletic activity. Appropriate rest periods throughout lengthy games enable the player to keep performing at a high

level of ability. If the muscle is able to rest between contractions, then fatigue will not occur as rapidly. Yockelson, as cited by Hunsicker and Greey (37), has found that when a muscle is allowed to rest for one minute after a standard exercise there will be a forty per cent recovery; after a two-minute rest, sixty-five per cent recovery; after a four-minute rest, eighty-five per cent recovery; and after eight minutes, a ninety-five per cent recovery. It is also helpful if there is mild movement during the rest period.

Temperature has been found to have an effect on the strength potential of the muscle. To determine if body temperature has any effect on strength of grip, Wright (48) raised the temperature of the subject by immersion in hot water. This immersion was done at a time of day when it was known that the subject's grip was static or decreasing. A body temperature increase of two degrees Fahrenheit was found to increase grip strength.

Perhaps the area which has received the most attention in research has been the relationship of training programs to increased strength. Because of the nature of this study, a review was made of the various methods used to increase strength.

There are many research studies indicating that strength can be significantly increased when the muscle contracts against a resistance and puts forth effort. As the muscle increases in strength the resistance must become progressively greater.

DeLorme's (5) method of strengthening exercises uses this basic principle in progressive resistance exercises. These exercises were

originally developed as a course of treatment for rehabilitation of injured patients. There are two types of exercises, load-resisting and load-assisting. The load-resisting exercises are based on load increase when 10-repetition maximum is obtained. Load-assisting exercises are based on 10-repetition maximum. Progressive resistance exercises are based primarily on empirical judgment. Through experience the weight-lifter has determined for himself that unless the load increases as strength increases there will be no increase in strength. Hence, through empirical judgment DeLorme (5:24) has devised a method for approximating the exercise load for load-resisting and load-assisting exercises:

Load-Resisting Exercises

First set of 10 repetitions	Use $\frac{1}{2}$ of 10-repetition maximum
Second set of 10 repetitions	Use 2/3 of 10-repetition maximum
Third set of 10 repetitions	Use 10-repetition maximum

Load-Assisting Exercises

First set of 10 repetitions	Use twice the 10-repetition minimum
Second set of 10 repetitions	Use $1\frac{1}{2}$ times the 10-repetition minimum
Third set of 10 repetitions	Use 10-repetition minimum

In a study on the effects of systematic weight training, Capen (27) wished to determine what effect a program of weight training would have on power, strength, and endurance. Two groups of students were selected, Group A was a weight training class and Groub B was a conditioning class. Group A's class periods were devoted only to weight training exercises. The weight determined for the various exercises

was the number of curls that could be completed eight times. This weight was used until fifteen executions were completed, then the subject selected another weight that allowed only eight repetitions. Group B's conditioning classes consisted of tumbling, bag relays, lifts, carries, hand combat, and conditioning gymnastics. Muscular strength was determined by right grip, left grip, back lift, chinning, and dipping on the parallel bars. Muscular endurance was measured by chinning, push-ups, sit-ups (two minutes), and squat jumps. Circulo-respiratory endurance was determined by performing a 300-yard shuttle run. Athletic power was determined by the standing broad jump, standing Sargent jump, running Sargent jump, and eight pound shot-put. The results of the study indicated that muscular strength was increased in both groups. Muscular endurance increased in both groups, however, not in the same events. Group A increased in chinning, dipping, and squat jumps; whereas Group B increased more than Group A in push-ups and sit-ups (two minutes). Circulo-respiratory endurance improved similarly in both groups. Both improved in athletic power, Group A being slightly superior.

In an experimental study conducted by Chui (29), weight training exercises were performed two to three times a week for one hour. Another group participated in physical education classes which did not perform any weight training exercises. The results of the study showed an increase of potential power in the group that performed weight training exercises.

In a study of different programs of heavy resistance exercises,

Capen (28) selected four methods to determine which would significantly increase strength:

Group I: Selected the heaviest weight with which a maximum of eight executions could be performed. Then, when the subject could perform fifteen executions, weight was determined and further exercises were undertaken.

Group II: The subjects determined the heaviest weight by performing a maximum of five executions. The weight was increased when the subject was able to perform six executions.

Group III: The subject selected the weight which allowed five executions, then performed three sets of exercises. When a gain in strength allowed successful completion of five executions, three more sets of exercises were performed with a new weight.

Group IV: The subjects chose the weight with which they could perform one execution. The weight was then decreased slightly for each of the second and third sets.

The results of this study showed that Group IV was superior in strength development over Group I and this difference was significant at the 3 per cent level of confidence. It made little difference if Group I performed exercises three days a week or five days a week. The third group appeared to perform more satisfactorily when the exercises were performed three days a week or five days a week.

Wolbers and Sills (47) studied the effect of static contraction exercises upon high school boys. The experimental group participated in an eight-week training period of exercises which met five days a week.

The exercises were performed by holding a static contraction for six seconds a day, the resistance was offered by a partner. The results of the study indicated that there was a significant increase in strength.

Hettinger and Muller, as cited by Hunsicker and Greey, (37) found that strength increases rapidly when training with a load that is about two-thirds of the individual's complete strength.

A six-week program of isometric and isotonic elbow flexion exercises conducted by Rasch and Morehouse (42) indicated various increases in strength. The mean of the isotonic group increased 14.38 pounds in the exercised arm and 11.58 pounds in the unexercised arm. However, there was no significant increase in strength in either arm for the isometric group. It is interesting to note in this study that there is a change in the strength of the unexercised arm when the other arm is exercised.

Statler-Hammel's (46) study of the transfer effects of systematic exercise utilized a program in which simple flexion and extension of the forearm was performed. A special apparatus was constructed to set the rate of flexion and extension. An electrical device was used to count the number of flexions. The subjects were instructed to keep up the flexions and extensions to the limit of their performance. The groups participating in the study were given an initial test, retested at the end of the program, and were again tested on left arm performance two weeks after the exercise program had terminated. The results of the study showed that the experimental group's left arm had significantly gained in strength over the control group. However, it is interesting

to note that two weeks after the termination of the exercises the experimental group's left arm had lost its superiority over the control group.

The previously mentioned studies have shown that there is an increase of strength when the muscle is overloaded during regular training sessions.

The purpose of a study by Smalley and Smalley (45) was to determine if there were any change in endurance or in arm and shoulder girdle strength of college women enrolled in physical education classes. The greatest improvement in endurance was made by those in swimming classes. Generally those students, enrolled in sports of an individual or dual nature, showed greater improvement than those students in team sports, which is "probably due to the fact that in individual and dual sports each individual student gets more activity during a class period than in team sports where only part of the group is active at a time." (45:143) The greatest improvement in arm and shoulder girdle strength was found in volleyball and the least significant in swimming. This was attributed to the fact that the swimmer would already have good strength and therefore would not improve as much as the other groups. The scores for the tennis group in arm and shoulder girdle strength showed a mean of 92.30 on the first test and 99.40 on the retest, a difference of 7.10 which was significant at the 1 per cent level of confidence.

It appears that shoulder girdle strength plays an important role in athletics. In determining what effect increase in strength of the shoulder girdle would have on the softball playing ability, Grande (49)

selected women subjects from the undergraduate physical education major program. The strength testing was done with the grip dynamometer with the push and pull attachment. The softball throw for distance, as described by Scott and French, was used to measure softball playing ability. The exercises performed during the four weeks of experimentation consisted of arm circling, all fours knee dip, half dip, and the full dip. The results of the study showed increases in push and pull strength which were significant at the 1 per cent level of confidence. There was also an increase in distance for the softball throw which was significant at the 1 per cent level of confidence.

A study by Jacobs (50), to determine if increased grip strength affected the distance of the golf drive, was conducted over a period of nine weeks. Two groups of students, enrolled in golf classes, participated in the study. One group squeezed a tennis ball one minute a day and another group was required to swing a weighted handkerchief ten minutes a week. The results of the study showed no significant increase in strength and no significant increase in driving distance as measured by the golf swing test.

The wrist and grip as well as the arms appear to be important in athletic activities, particularly in racket games. The purpose of a study by Reynolds (51) was to determine the effect of wrist strength and a program of wrist strengthening exercises on the ability to play tennis. Subjects used in this study were enrolled in intermediate tennis classes. Resistance exercises were used as means of increasing wrist strength. A ten pound dumbbell provided the resistance. The

subjects performed the following pronation and supination exercises (51:25-26):

> Pronation Exercises: The subject sat on the floor with his legs crossed. The arm with which he played tennis rested on his leg so that the wrist and hand extended beyond the knee. With the hand pronated the subject grasped the dumbell [dumbbell] off center with the little finger nearer to one end than the other. Holding the weight in his [this] manner the subject hyperextended the wrist as far as possible and then returned it to the starting position. The free hand was used to stabilize the exercising arm by holding the upper portion of the forearm against the leg. The exercise was executed at the rate of five seconds per execution.
>
> Supination Exercises: The supination exercise was the same as the pronation exercise with the exception that the hand was supinated. With the hand in this position the subject grasped the dumbbell, flexed the wrist and then returned to the starting position.

In order to determine the proper number of executions for each exercise Reynolds administered the exercises to forty students, requesting that they perform each exercise until they failed to execute the full range of movement. The group mean score was determined for each exercise. The number of executions to be performed was determined by taking two-thirds of the mean. The results of the study showed that the exercises did not significantly increase strength. Neither was there any significant difference in playing ability as measured by the Dyer Backboard Test. The critical ratios may have been low because the exercises were too difficult for some of the subjects, and they were performed only twice a week which may not have been frequent enough.

Exercises can be used to strengthen weak muscles, but it must be understood that this is not a rapid process. With an increase of resistance the muscle will gradually begin to strengthen.

> Exercises will increase the strength of a muscle only if (1) it is intense enough to cause the muscle to work at its maximum

> level of ability; (2) it is repeated persistently over a period of time; and (3) its demands on the muscle are gradually increased by increasing the number of times the movement is performed, the speed with which the movement is executed, or the resistance against which the movement is performed. (14:41)

Since the major portion of this study was concerned with the grip, a number of research studies have been reviewed to better understand the potentialities of the grip.

Rogers (44) explains that if there be a change in the organic functioning of the body there will also be a corresponding change in muscle performance. "When doctors and P.F.I's have disagreed it has often occurred that the former were in error -- P.F.I.'s indicate a condition which routine medical examinations fail to discover." (44:44) Taking one specific segment of the body to measure, Rogers chose the grip strength to see if there would be any indication of the change in the subject's physical condition. During the first period of thirteen days the subject performed heavy manual labor. The subject's grip strength increased from 160 to 180 pounds. During a nine-day interval the subject's grip strength took a sharp decline a few days before he became ill. At this time grip strength dropped to 140 pounds. However, within a week it had risen to 170 pounds. After a day of physical exercise the subject's grip strength was recorded at 172 pounds in the early evening, at 160 pounds at midnight; however, by the following morning it had dropped to 140 pounds.

A group of 311 normal males, ranging from twelve to seventy-nine years, was tested by Burke (26) on a dynamometer to determine if there was any relation between grip strength and grip strength endurance to

age. The subjects were required to apply maximum effort for one minute. The results showed that there was an increase in grip strength and grip strength endurance up to the age of twenty-five. After twenty-five years there was a gradual decrease in grip strength endurance. Grip strength at seventy-nine years of age is about the same as it was between twelve and fifteen.

The purpose of Wright's (48) study was to determine if there were any diurnal pattern in the strength of the grip. The Geckler pneumatic dynamometer was used as the measuring instrument, because of its sensitivity to weak grips. Other instruments included in the study were the Collin elliptical spring steel dynamometer, the Smedley dynamometer, and a modification of the tensiometer. Grip strength was measured at various periods throughout the day. The subject's strength of grip was recorded every fifteen minutes from 6:00 A.M. to 9:00 A.M. and then hourly until 10:00 P.M. There was a marked increase in strength from 6:00 A.M. to 10:00 A.M., then a gradual increase from 10:00 A.M. to 12:00 noon. Strength of grip gradually leveled off during the afternoon and then fell sharply during the late afternoon and early evening.

SUMMARY

The elements of movement are of such a complex nature that it is difficult to say actually which component or prerequisite is most important for any particular sport. In the game of tennis, for example, are the mental capabilities of the individual greater than the emotional desires? Then, again, which of the physical components of movement, endurance, muscular power, strength, acuity of the senses or reaction

time will most aid the tennis player? Until further research is undertaken the coaches and physical educators can only assume that a combination of these qualities is necessary for performance.

A review of tennis literature has shown that many of the early twentieth century tennis champions advocated general body conditioning. Most common were daily exercises of running, walking, horseback riding, and controlled diet. More recently the training programs have begun to include calisthenics and weight lifting.

Strength as a component of the physical qualities of movement can be increased by various methods. Through research it has been found that strength can be increased by overloading the muscle with weights or by holding the muscle in a static contraction for a period of time.

The value of teaching the beginning player to use a cocked wrist to execute a forehand or backhand drive depends on wrist control. This technique requires the player to snap the wrist forward just before hitting the ball and then holding the grip and wrist firm at the moment of impact. The inability of the beginning player to gain complete freedom to swing is due to the fact that the upper arm is held in close to the body to give added support to the long lever. If the wrist were stronger, then this compensatory action would not be necessary. The tennis player who lets the racket turn in the hand at the moment of impact is not gripping the racket firmly enough, therefore causing the ball to be deflected off the strings at an angle.

Instructors of tennis (3, 12, 38) have stressed the importance of helping tennis players increase the strength of their wrist. The

purpose of this study is based on the recommendations of these instructors; that is, to determine whether exercises for the grip and wrist will increase strength and whether this increased strength will have any effect on tennis playing ability as measured by the Wallboard Test.

CHAPTER IV

PROCEDURE

The purpose of this study was to determine whether exercises for strengthening grip and wrist would have any effect on tennis playing ability. The study involved the selection of exercises which would be adequate in increasing strength of grip and wrist. The program of exercises and testing took place over a period of five weeks.

SELECTION OF SUBJECTS

The subjects for this study were selected from the undergraduate students of The Woman's College of the University of North Carolina. Selection was made from those students who were members of the tennis club or who had had tennis instruction and were recommended by their instructors. A letter explaining the purpose of this study was sent to thirty-five students falling into this category. A copy of the letter appears in the Appendix. Eighteen students indicated a willingness to participate in the study.

SELECTION OF TESTS

Wallboard Test

The Wallboard Test, a modification of the Dyer Backboard Test, was selected to measure tennis playing ability, because it is a valid and reliable test. It was also selected because of the ease with which it can be administered. The test was administered to the subjects according to the method recommended by Scott and French (21:222-223). The

restraining line was placed twenty-seven and one-half feet from the wall and a racket press was used to hold the extra balls. The writer and five assistants administered the test to eighteen subjects. The subjects were given three trials and the sum of these trials was the score recorded for each subject. A more detailed explanation may be found in the Appendix.

Grip and Wrist Strength Tests

The selection of a testing instrument was necessary to determine grip and wrist strength. An aircraft tensiometer, model number T5-6007-117-00, manufactured by the Pacific Scientific Company, Inc., Los Angeles, California, was used in this study. This particular instrument measures from three to one-hundred pounds and has been calibrated for an "up pull" on a cable, which passes over a riser and under two sectors. For facility in reading the score a maximum pointer has been inserted in the instrument. The direct reading from the tensiometer can be converted into pounds by means of interpolation from a calibrated chart provided by the manufacturer. The conversion table used by the writer can be found in the Appendix.

In order to use this instrument for measuring strength of grip and wrist two separate pieces of apparatus were needed. A specially constructed frame for use with the tensiometer was used to measure grip strength. The second piece of equipment was a strap to be used for the wrist strength measurements. The regulation strap was constructed by the writer according to the recommendations made by Clarke (4:3). The strap was made of heavy two-inch webbing about two feet long, see

Figure No. 1, page 31. The webbing was folded in half and stitched to a buckle. A keeper was made to fit around the strap. A separate attachment, consisting of a snap, cable and chain, was hooked to the buckle of the strap. The cable was one-sixteenth inch extra flexible cable (7x7). A welded link chain was attached to one end of the cable and at the other end the snap.

A high reliability for the grip strength test was obtained when the test was administered in the following manner. The frame for measuring grip strength, with the tensiometer inserted, was placed on a table in front of the subject, see Figure No. 2, page 32. The apparatus extended over the table slightly so that the subject could grip the handles. Grasping the two parts of the handle, the subject was instructed to grip as hard as possible. The hand not being tested was placed on the table. This procedure was followed for both the right and left hands.

Reliability of wrist strength tests was obtained after three different methods of administering the test were used. For each of the following methods the subjects participated in two testing sessions which occurred on successive days.

Method I. A group of ten graduate students were subjects for the first administration of the wrist strength tests. This method was administered according to recommendations by Clarke (4:12-13). The subject sat at a table which was three feet six inches from the wall, with feet flat on the floor and both arms on the table. The wrist being tested was placed in mid-position of range of motion for dorsal

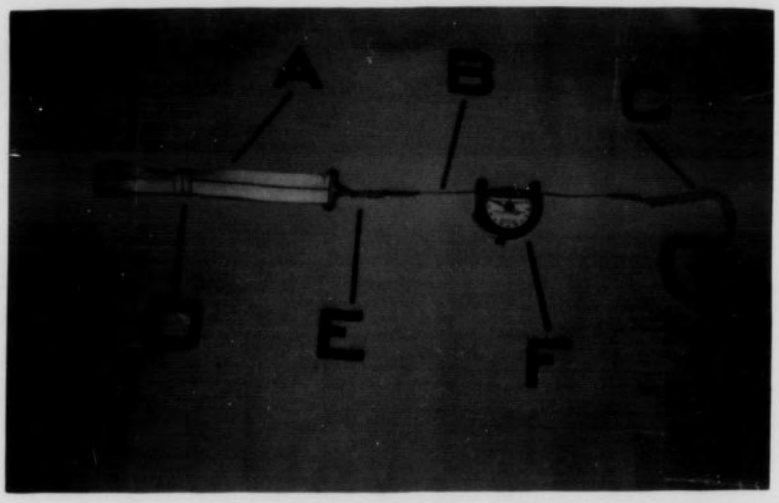


Figure 1.

Tensiometer and Wrist Strength Testing Apparatus

A . . . . . Two-inch webbing

B . . . . . One-sixteenth extra flexible cable

C . . . . . Welded link chain

D . . . . . Keeper

E . . . . . Nickel plate snap

F . . . . . Tensiometer

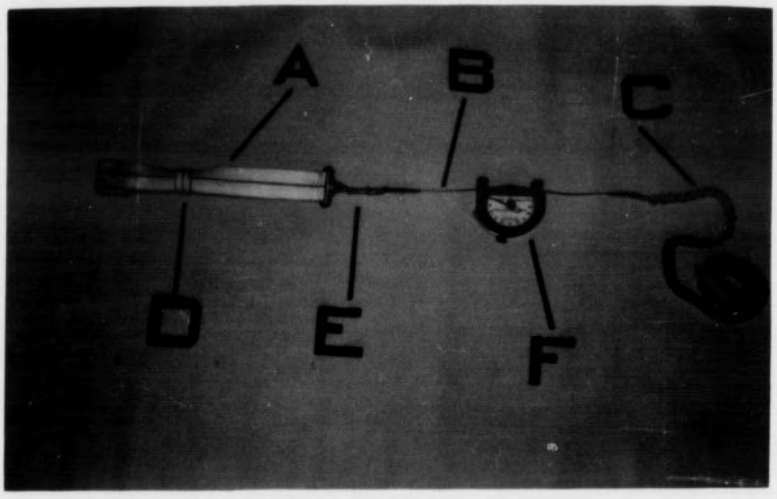


Figure 1.

Tensiometer and Wrist Strength Testing Apparatus

A . . . . . Two-inch webbing

B . . . . . One-sixteenth extra flexible cable

C . . . . . Welded link chain

D . . . . . Keeper

E . . . . . Nickel plate snap

F . . . . . Tensiometer

Figure 2

Grip Strength Test

Figure 2

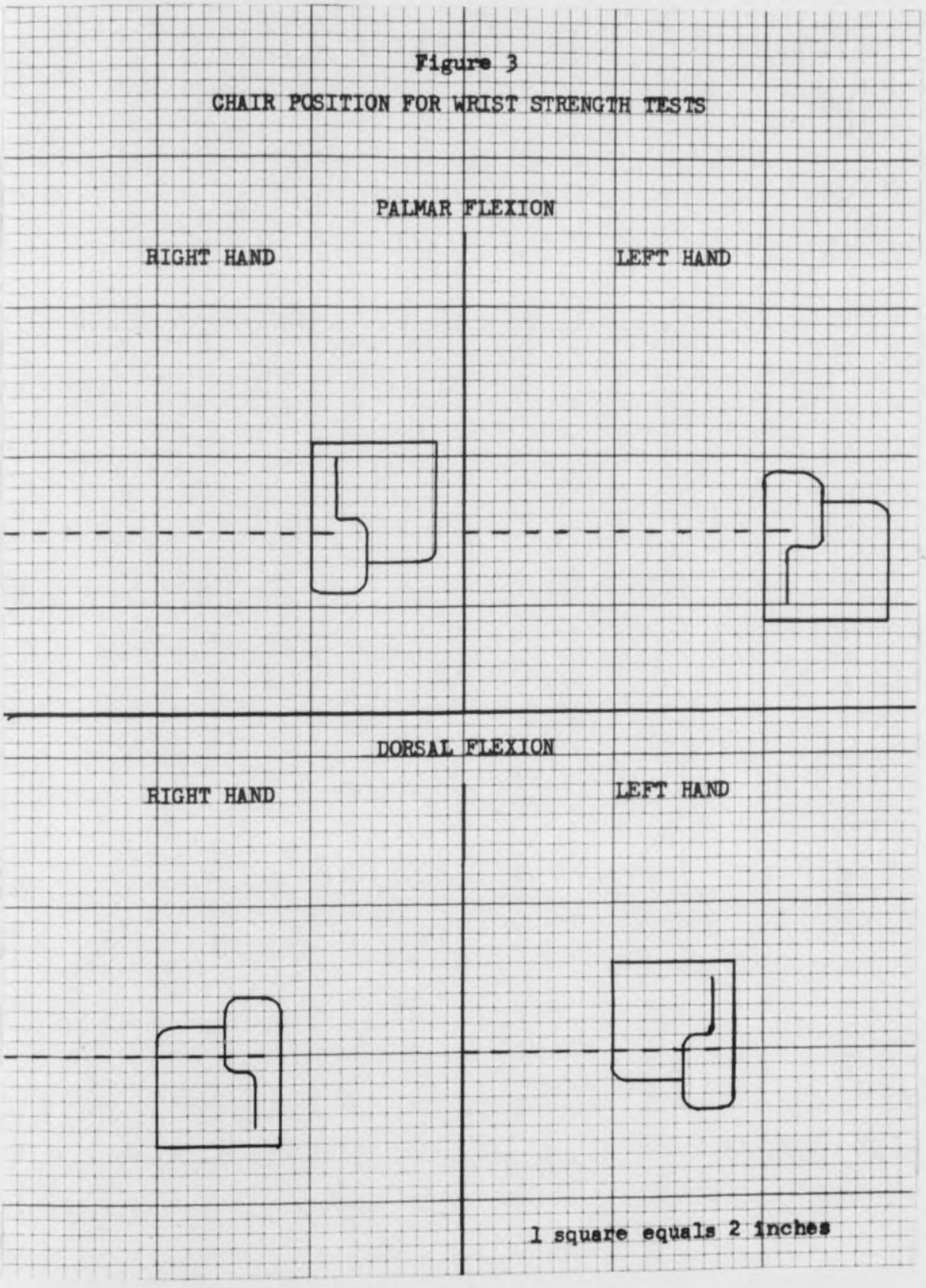
Grip Strength Test

and palmar flexion. The forearm was in mid-prone and supine position. The elbow was at a ninety degree angle as measured by the goniometer. The regulation strap was then placed around the palm of the hand so that the thumb was not covered. The keeper was pushed up against the hand to hold the strap in place. The welded chain was placed over a hook which was two feet five inches from the floor. For palmar flexion, the first link was used and for dorsal flexion the fourteenth link was used. The writer then blocked the subject's forearm and shoulder to prevent extraneous movements. An assistant placed the tensiometer on the cable and lightly supported the instrument. The strength tests were given in the following order: right palmar flexion, left dorsal flexion, left palmar flexion, and right dorsal flexion.

Method II. Ten graduate students were given the same wrist strength tests by a new method. Wrist strength tests were administered to the subjects while sitting in a desk arm chair. Two of these chairs were used, one with a right arm and one with a left arm. The chairs were placed so that the front leg nearest the wall was three feet four inches from the wall for testing wrist palmar flexion and one foot eight inches from the wall for dorsal flexion, see Figure No. 3, page 34. The subjects sat in an upright position with the feet flat on the floor and the wrist to be tested on the arm of the chair. The elbow was placed at a ninety degree angle with the upper arm against the back of the side of the chair. The wrist was placed in mid-position of range of motion for dorsal and palmar flexion. The forearm was in mid-prone and supine position. Both the upper arm and the forearm were strapped to the chair

Figure 3

CHAIR POSITION FOR WRIST STRENGTH TESTS



with heavy belts. The regulation strap, which was hooked to the wall two feet five inches from the floor by the first link of the chain, was placed around the subject's palm. The keeper was pushed up against the hand to hold the strap in place. During all wrist testing the hand not being tested was placed on the forearm to brace the wrist being tested. For wrist palmar flexion strength the strap and tensiometer were in a position facing the dorsal side of the hand, see Figure No. 4, page 36. The measuring instrument was facing the palm for wrist dorsal flexion, see Figure No. 5, page 37. The direction of the pull was away from the tensiometer. When the subject was in position for testing, the tensiometer was placed on the cable and the subject was instructed to pull with maximum force, in either palmar or dorsal flexion. The order of testing was palmar flexion for right and left wrist, then dorsal flexion for right and left wrist. The writer administered all of the tests.

Method III. Ten undergraduate students were given the wrist strength tests, as described in Method II, with a slight variation. The difference was that the subjects had three trials for each measurement. Each trial was separated by approximately one minute of rest. The best of the three trials was the score recorded. A higher reliability was found when the test was administered in this manner. This form of administration was used throughout the study.

TESTING AND ASSIGNMENT OF SUBJECTS TO GROUPS

The eighteen subjects participating in the study were given the Wallboard Test, grip strength test, and wrist strength tests. These

Figure 4

Wrist Palmar Flexion Strength Test

Figure 4

Wrist Palmar Flexion Strength Test

Figure 5

Wrist Dorsal Flexion Strength Test

Figure 5

Wrist Dorsal Flexion Strength Test

tests were administered at the beginning of the study, during the third week, and again at the end of the fifth week. The scores were recorded on Score Card A, a copy of which appears in the Appendix.

The results from the first testing session of the Wallboard Test were used to rank the subjects according to tennis playing ability. This ranking was then used to divide the subjects into two groups of equal tennis playing ability. One group was designated as the control group; the other as the experimental group.

Using the groups assigned according to rank on the Wallboard Test, the t-test of significance was used to determine if there were any difference between the two groups in tennis playing ability, in grip strength, and wrist strength.

As a result of these initial tests it was found that there was no significant difference between the two groups in tennis playing ability, right and left grip strength, and right and left wrist strength.

PROGRAM OF EXERCISES

Since the purpose of the study was to determine if grip and wrist strengthening exercises had any effect on tennis playing ability, a program of exercises for grip and wrist was developed. Not only were the exercises selected for increase of strength but also because of their relationship to the muscular control needed in the tennis stroke. Wells (23:442) explains the muscle action of the wrist during the forehand drive.

> When the mid-position is reached the extensor carpi ulnaris and extensor radialis longus and brevis contract to check further flexion. The hand remains in a position of slight radial flexion

against the downward pull of gravity acting on the racket. The abductor pollicis, extensor carpi radialis longus and brevis and flexor carpi radialis are in static contraction.

The fingers and thumb during the stroke are in strong flexion while gripping the racket.

The writer felt that, since the muscles of the forearm and wrist are held in static contraction during the hitting action, exercises involving contraction might help increase the hitting power. In addition, exercises which would involve finger flexion were selected to increase grip strength.

The following exercises performed by the subjects in the experimental group took place over a five-week period. The subjects met individually with the writer for approximately fifteen minutes per day, five days a week.

Grip and Wrist Exercise

A grip and wrist exerciser, manufactured by Moosehead-Whitely Incorporated, Hackensack, New Jersey, consisting of two wooden handles connected by a steel coil, was used in the study. The apparatus was placed in the palm of the hand and squeezed as tightly as possible. While performing this exercise the subject's forearm was placed in mid-prone and supine position with the hand and exerciser extending over the arm of the chair. The free hand was placed on the forearm to prevent any extraneous movements, see Figure No. 6, page 40. The writer encouraged each subject to work to her maximum capacity and to increase the number of contractions each day. The number of contractions was recorded on Score Card B so that progress could be noted. A sample of

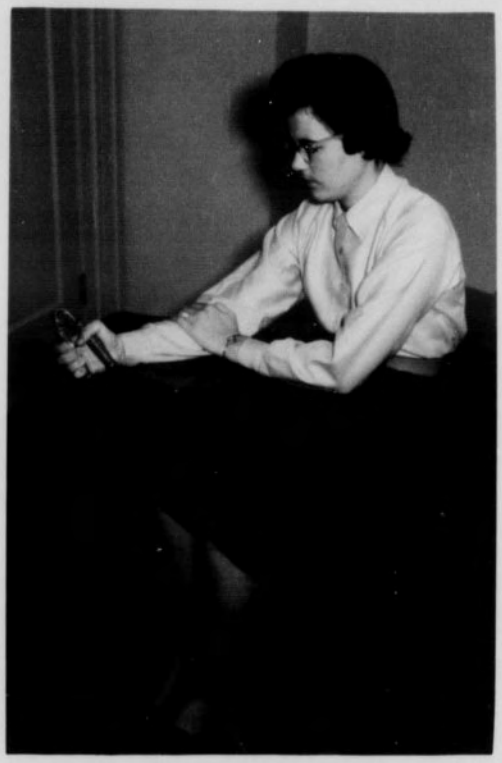


Figure 6

Grip and Wrist Exercise

Figure 6

Grip and Wrist Exercise

this score card appears in the Appendix. This exercise was performed by both the right and left hand. A more detailed description of the exercise may be found in the Appendix.

Wrist Palmar and Dorsal Flexion Exercise

The subject performed this exercise while seated in a desk arm chair, with the forearm and wrist resting on the arm of the chair. The upper arm and forearm were strapped to the chair and then the testing strap was placed around the palm of the hand. The subject was instructed to pull on the strap and when a specific tension was reached on the tensiometer the contraction was held for six seconds. The tension held was two-thirds of the subject's maximum strength. The static contraction was held in two positions by each hand, palmar flexion and dorsal flexion. At the beginning of every week wrist strength was tested and, if there were any increase from the previous testing, the amount of tension to be pulled was increased accordingly. The six seconds holding time remained constant throughout the study. A more detailed description of the exercises appears in the Appendix.

TREATMENT OF DATA

This study required the use of a reliable testing instrument to measure strength of grip and wrist. The writer submitted the tensiometer and apparatus to a series of tests in order to determine their reliability. The grip strength test was administered twice to both hands and the Pearson Product-Moment method of correlation for ungrouped data was used to determine reliability. Two different strength measures were obtained for each wrist, palmar flexion and dorsal flexion

strength. The subjects were administered the wrist strength tests and the highest score of three trials was recorded. The Pearson Product-Moment method of correlation was used to determine reliability, using the test-retest method.

In order to determine whether there would be any change in grip and wrist strength or tennis playing ability due to exercise, it was necessary to equate the two groups at the beginning of the study. This was done by determining the significant difference between the means.

The analysis of the difference between groups for all three testing periods involved the use of the t-test for significant mean difference. A statistical analysis was also made to determine if there was any significant difference within the groups between testing periods.

CHAPTER V

PRESENTATION AND ANALYSIS OF DATA

The purpose of this study was to determine what effect exercise to increase strength of grip and wrist would have on tennis playing ability.

RELIABILITY OF TESTING APPARATUS

Statistical Procedure

Since the purpose of the study was to increase grip and wrist strength to determine the effect on tennis playing ability, the reliability of the testing instrument and apparatus had to be determined. The apparatus was used to test grip strength, wrist palmar flexion strength, and wrist dorsal flexion strength. The Pearson Product-Moment method of correlation was used to determine reliability. The reliability coefficients were then submitted to a table of r's to determine to what degree they could be considered significant.

Grip Strength

To determine the reliability of the grip strength test, ten graduate students, not participating in the actual study, were administered the test. The tensiometer was inserted in the specially designed frame for grip strength measurement. This preliminary test was given at two testing sessions which occurred on consecutive days. Both the right and left hand grip were tested and the score recorded was the interpolated score from the conversion table that appears in the Appendix. The

results, as shown in Table I, proved to be reliable at the 1 per cent level of confidence.

TABLE I

RELIABILITY COEFFICIENTS FOR GRIP STRENGTH TEST

	Reliability Coefficients	Significance of r
Right Hand	.89	.01
Left Hand	.90	.01

Wrist Strength

Method I. The first method used in testing for reliability of the wrist strength tests was done when the subjects were seated at a table. The testing regulation strap was placed around the dorsum of the hand. The writer held the forearm and shoulder while the subject flexed the wrist. An assistant supported the tensiometer. The results of the tests showed low reliabilities, note Table II. The writer felt that it was impossible to restrain each subject in the same manner. It was quite possible that this was due to the fact that many of the subjects were stronger than the writer, and therefore many extraneous movements occurred which caused an unreliable measurement of wrist palmar and dorsal flexion strength. Since this method showed such low reliability coefficients, another method of administering the wrist strength tests was devised.

Method II. The second method of administering the wrist strength

TABLE II

RELIABILITY COEFFICIENTS FOR WRIST STRENGTH TESTS

	Reliability	Significance of r
METHOD I		
Right Wrist		
Palmar Flexion	-.06	
Dorsal Flexion	.68	Better than .05
Left Wrist		
Palmar Flexion	-.01	
Dorsal Flexion	.01	
METHOD II		
Right Wrist		
Palmar Flexion	.69	
Dorsal Flexion	.65	
Left Wrist		
Palmar Flexion	.92	.01
Dorsal Flexion	.59	
METHOD III		
Right Wrist		
Palmar Flexion	.84	.01
Dorsal Flexion	.83	.01
Left Wrist		
Palmar Flexion	.91	.01
Dorsal Flexion	.71	Better than .05

tests was done with the subject sitting in a desk arm chair. The upper arm and the forearm of the wrist to be tested were immobilized by strapping them to the arm of the chair. The feet remained flat on the floor and the hand of the arm not being tested was placed on the forearm of the wrist being tested. The subject was instructed to flex the wrist; therefore, pulling on the regulation strap which was around the dorsum of the hand. The maximum force pulled was indicated on the tensiometer, which was on the cable of the regulation strap. The score recorded was the interpolated score obtained from the conversion table that appears in the Appendix. As noted in Table II, page 45, the reliability coefficients were still too low to be of any significance. However, it was observed that the coefficients were generally higher than those found for Method I. Because reliabilities were still too low, a slight adaptation in administration was made.

Method III. For the third administration of the test the subject remained in the same position as for Method II. The only variation was that the subject received three trials and the score recorded was the best of these three trials. The reliability coefficients, as noted in Table II, page 45, were considerably higher than those administered from the two previous methods. Right wrist palmar flexion and dorsal flexion and left wrist palmar flexion being significant at the 1 per cent level of confidence while the left wrist dorsal flexion was significant at better than the 5 per cent level of confidence.

Since the grip strength test and the wrist strength tests, Method III, are reliable tests of strength, they were used in this study.

EQUATING GROUPS

Statistical Procedure

The nature of this study required that two groups be selected for comparison purposes; one group would be the experimental group and one the control group. Before exercises could be administered to the experimental group, it was necessary to determine whether the groups were equated in tennis playing ability, right and left grip strength, and right and left wrist strength. Individuals were assigned to the two groups on the basis of scores made on the Wallboard Test. Fisher's t test was used to determine if there were any significant difference between the means of the two groups in tennis playing ability, grip strength, and wrist strength.

Wallboard Test

The Wallboard Test was used to determine tennis playing ability. The mean scores of the experimental group and the control group were compared and the results indicated low t-ratios. See Table III. Statistical analysis showed that even though the experimental group had the higher mean score, there was not a statistically significant difference between the two groups in tennis playing ability.

Grip Strength

The right and left grip strength test was administered to both groups and a statistical comparison made between the means of their score. The mean scores for both the right and left hand were found to be higher in the control group. The resultant low t-ratios indicated that there was no statistically significant difference between the two

TABLE III

MEANS, STANDARD DEVIATIONS, AND SIGNIFICANCE OF DIFFERENCE BETWEEN EXPERIMENTAL AND CONTROL GROUPS ON INITIAL TESTS

Tests N - 9	Experimental Mean	Experimental S.D.	Control Mean	Control S.D.	t
Wallboard Test	32.7777	5.0070	32.0000	4.9669	.2419
Grip Strength					
Right Hand	58.3922	7.9238	63.3788	8.6481	1.2087
Left Hand	53.8788	7.6499	61.6544	8.7465	1.8962
Wrist Strength					
Right Wrist	50.0366	7.6808	53.2677	5.9663	.9445
Left Wrist	50.4877	7.3659	49.1011	3.8847	.4726

groups; note Table III, page 48.

Wrist Strength

To determine right and left wrist strength both groups took the wrist palmar flexion test and the wrist dorsal flexion test. An overall wrist strength score was obtained by adding the raw scores for palmar flexion and dorsal flexion for one hand. The sum of these two scores then gave each subject a wrist strength score. The mean score for the right wrist was higher in the control group and for the left wrist higher in the experimental group; note Table III, page 48. When the test of significance of difference between means was applied, the difference between groups was not sufficient to be considered statistically significant.

The results of the initial tests showed that the mean scores for the experimental group were higher in tennis playing ability and left wrist strength; whereas, the mean scores for the control group were higher in the right grip strength and in right wrist strength. The comparison of the two groups indicated that there was no statistically significant difference between the experimental and control groups in tennis playing ability, and right and left wrist strength.

DIFFERENCE WITHIN GROUPS BETWEEN TESTING SESSIONS

Statistical Procedure

The nature of this study concerned itself with the increase of strength of grip and wrist. The writer organized an exercise program for the experimental group which was intended to increase strength. In

order to determine whether this had been accomplished, statistical analysis was employed to determine if there were any significant difference within the experimental and control groups between testing sessions.

The scores for this analysis were those obtained from three testing sessions which took place throughout the five weeks of the study. The testing periods took place the first week of the study, during the third week, and at the end of the fifth week.

Special attention is called to the fact that the number of subjects was nine for all testing sessions with the control group; however, in the experimental group there were only eight subjects in the third testing session.

DIFFERENCE BETWEEN TESTING SESSIONS FOR THE EXPERIMENTAL GROUP

Wallboard Test

The test for significant change within the experimental group was used to determine whether there had been any significant change in tennis playing ability between the various testing sessions. These data appear in Table V, page 52. The mean scores which appear in Table IV showed that there was an increasing difference between Test I and Test II. This mean difference was found to be significant at the 1 per cent level of confidence, as shown in Table V. From Test II to Test III the mean score decreased slightly and, therefore, there was no significant difference between the means. A comparison of the means from Test I to Test III showed that there was an increase in scores at the final testing period; however, since the mean had decreased slightly between Test II

TABLE IV

MEANS AND STANDARD DEVIATIONS FOR THE EXPERIMENTAL GROUP

	TEST I N-9		TEST II N-9		TEST III N-8	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Wallboard Test	32.7777	5.0070	37.7777	3.8807	36.0000	4.8477
Grip Strength						
Right Hand	58.3922	7.9328	62.3611	10.1893	66.4062	10.9055
Left Hand	53.8788	7.6499	54.5366	8.3000	57.4487	9.0504
Wrist Palmar Flexion						
Right Wrist	25.8811	5.3254	32.6411	4.9163	38.0462	4.9810
Left Wrist	27.4311	5.9901	31.9444	4.8052	37.9187	6.8564
Wrist Dorsal Flexion						
Right Wrist	24.1666	3.0074	28.6355	3.3511	31.8250	6.7476
Left Wrist	23.0566	2.6268	26.4833	4.5475	30.4700	6.3325

TABLE V

SIGNIFICANCE OF CHANGE IN TENNIS PLAYING ABILITY, GRIP AND WRIST STRENGTH BETWEEN TESTING SESSIONS FOR THE EXPERIMENTAL GROUP

	t TEST I & TEST II N - 9	t TEST I & TEST III N - 8	t TEST II & TEST III N - 8
Wallboard Test	4.3759*	1.5535	1.1633
Grip Strength			
Right Hand	2.3371***	3.4844**	1.3462
Left Hand	.5739	1.8885	1.8655
Wrist Palmar Flexion			
Right Wrist	3.6877*	5.1204*	4.0507*
Left Wrist	1.9965	3.2967**	3.1151**
Wrist Dorsal Flexion			
Right Wrist	6.8184*	3.6853*	1.7242
Left Wrist	2.4971***	3.3330**	1.8404

* Indicates statistical significance at the 1 per cent level of confidence
** Indicates statistical significance at the 2 per cent level of confidence
*** Indicates statistical significance at the 5 per cent level of confidence

and Test III, there was no significant increase in tennis playing ability.

Grip Strength

As is evidenced by the data in Table IV, page 51, the mean scores for left wrist strength showed a steady increase between all testing periods. This increase was not sufficient to cause any statistically significant difference between testing sessions as is shown in Table V, page 52. The right hand, however, showed some significant changes. Table IV shows means for right grip strength that were increasing steadily. Between Test I and Test II the difference between means was significant at the 5 per cent level of confidence. Increase in strength between Test II and Test III was not sufficient to be statistically significant; however, from Test I to Test III there was an increase which was significant at the 2 per cent level of confidence.

Wrist Palmar Flexion

The greatest consistent change within the experimental group took place in right wrist palmar flexion strength. The difference between all testing periods was statistically significant at the 1 per cent level of confidence. The greatest increase in strength took place from the first to the final testing sessions. The left wrist increased significantly in strength only between two testing periods, even though the mean scores show a steady increase of strength throughout the study. Comparison of the means between Test I and Test II was not statistically significant. However, comparisons between Test II and Test III and Test I and Test III were statistically significant at the 2 per cent level of

confidence.

Wrist Dorsal Flexion Strength

The mean scores, note Table IV, page 51, for the right and left wrist dorsal flexion show an increase over the five weeks of this study. Right wrist dorsal flexion showed a statistically significant change at the 1 per cent level of confidence from Test I to Test II and from Test I to Test III. Comparisons between Test II and Test III were not statistically significant. Left wrist dorsal flexion strength from Test I to Test II showed a change which was statistically significant at the 5 per cent level of confidence. The difference between Test I and Test III was significant at the 2 per cent level of confidence. From Test II to Test III there was no statistically significant difference.

Summary

It is interesting to note that the greatest change in strength took place in right wrist palmar flexion. This change was statistically significant at the 1 per cent level of confidence between all the testing sessions. Most of the higher significant t-ratios occurred between the first and last testing session, with two exceptions. In the Wallboard Test and right wrist dorsal flexion strength the higher t-ratios occurred when comparisons were made between the means of Test I and Test II.

DIFFERENCE BETWEEN TESTING SESSIONS FOR THE CONTROL GROUP

Wallboard Test

The mean scores for the control group, found in Table VI, show an increase of tennis playing ability from Test I to Test II, and a decrease

TABLE VI

MEANS AND STANDARD DEVIATIONS FOR THE CONTROL GROUP

	TEST I N-9		TEST II N-9		TEST III N-9	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Wallboard Test	32.0000	4.9669	35.1111	5.9338	33.8888	8.0753
Grip Strength						
Right Hand	63.3788	8.6481	65.0233	8.6371	68.6355	11.8979
Left Hand	61.6544	8.7465	58.5422	8.6371	62.9166	6.4281
Wrist Palmar Flexion						
Right Wrist	25.9522	4.5321	30.4866	7.9354	30.5100	4.0915
Left Wrist	24.8633	2.5957	28.4733	7.1141	30.0011	6.4815
Wrist Dorsal Flexion						
Right Wrist	27.3166	3.1055	28.1266	4.1316	28.4511	5.0507
Left Wrist	24.2377	2.8671	26.9244	3.2864	26.8766	3.6905

from Test II to Test III. This decrease in the mean score for Test III remained above the mean score for the first test. Even though there was a mean change in tennis playing ability it was not sufficient to be statistically significant between any of the testing sessions. The resulting data from the t-tests are presented in Table VII.

Grip Strength

Right hand grip strength means scores indicated that there was an increase in strength between all testing sessions. However, statistical analysis of the means proved that there was only statistical significance from Test I to Test III, which was at the 5 per cent level of confidence. Left grip strength fluctuated between the three testing sessions as can be seen in Table VI. Mean scores showed a decrease from Test I to Test II and then an increase from Test II to Test III. An analysis of means showed no statistically significant difference between any of the testing sessions.

Wrist Palmar Flexion Strength

The strength of the right wrist in the control group increased throughout the length of the study. The mean scores, which appear in Table VI, page 55, show an increase in strength; however, it does not appear to be a rapid increase. A comparison of the mean scores showed that there was a statistically significant increase at the 2 per cent level of confidence from Test I to Test II and from Test I to Test III. Left wrist strength increased slowly throughout the study and increased significantly between Test I and Test III at the 2 per cent level of confidence.

TABLE VII

SIGNIFICANCE OF CHANGE IN TENNIS PLAYING ABILITY, GRIP AND WRIST STRENGTH BETWEEN TESTING SESSIONS FOR THE CONTROL GROUP

	t TEST I & TEST II N - 9	t TEST I & TEST III N - 9	t TEST II & TEST III N - 9
Wallboard Test	1.9522	1.1143	1.9841
Grip Strength			
Right Hand	.5392	2.7261***	1.1889
Left Hand	2.1813	.5786	1.9034
Wrist Palmar Flexion			
Right Wrist	2.6955**	3.2842**	.0100
Left Wrist	1.7179	3.2133**	1.0692
Wrist Dorsal Flexion			
Right Wrist	.6833	.5956	.1960
Left Wrist	3.2819**	4.3019*	.0794

* Indicates statistical significance at the 1 per cent level of confidence
** Indicates statistical significance at the 2 per cent level of confidence
*** Indicates statistical significance at the 5 per cent level of confidence

Wrist Dorsal Flexion

Right wrist dorsal flexion strength increased slightly, as the mean scores indicate in Table VI, page 55. This increase, however, was not statistically significant between any of the testing sessions. The left wrist increased in strength considerably more than the right wrist in dorsal flexion strength. This increase was significant at the 2 per cent level of confidence from Test I to Test II and at the 1 per cent level of confidence from Test I to Test III.

Summary

At no time throughout the duration of the study did the control group make any significant change in tennis playing ability, as measured by the Wallboard Test. Change in the various strength measures did occur, however. The most significant changes occurred for the control group from Test I to Test III. Right grip strength increase was significant at the 5 per cent level of confidence and wrist palmar flexion for both hands was significant at the 2 per cent level of confidence. Left wrist dorsal flexion strength change was significant at the 1 per cent level of confidence. The writer made no attempt at any time throughout the length of the study to control the physical activity of the control group. The high t-ratio found in the left wrist dorsal flexion might be attributed to the fact that there was one member of this group whose left hand was the dominant hand.

Comparison of the Two Groups

The most predominant difference between the two groups was in right wrist palmar flexion strength. The experimental group's scores

all showed statistical significance at the 1 per cent level of confidence. Whereas, the control group's scores between Test I and Test II and between Test I and Test III were significant at the 2 per cent level of confidence. The significance of the increase in tennis playing ability within the experimental group and an increase in right wrist palmar flexion strength may indicate a trend toward an increase in wrist strength having an effect on tennis playing ability.

DIFFERENCE BETWEEN GROUPS

Statistical Procedure

At the beginning of the study a comparison based upon all initial test scores, note Table III, page 48, showed that there was no statistically significant difference between the experimental group and the control group. Therefore, the two groups began the study at a comparable level of tennis playing ability, grip strength, and wrist strength. To determine whether grip and wrist strength exercises had increased strength and therefore had changed the tennis playing of the experimental group further analyses were made. The test of significant difference between uncorrelated means was applied between the experimental and control group, see Table VIII.

Wallboard Test

The mean difference between the experimental and control groups in tennis playing ability was not statistically significant at either the first, second or third testing periods. At the second testing the difference between the two groups was changing, however, not sufficiently to be statistically significant. By the third testing there was

TABLE VIII

SIGNIFICANT MEAN DIFFERENCE BETWEEN THE EXPERIMENTAL AND CONTROL GROUPS IN TENNIS PLAYING ABILITY, GRIP AND WRIST STRENGTH

	t TEST I N - 18	t TEST II N - 18	t TEST III N - 17
Wallboard Test	.3208	1.0665	.6042
Grip Strength			
Right Hand	1.7726	.4607	.3767
Left Hand	1.8962	.2337	1.3604
Wrist Palmar Flexion			
Right Wrist	.0283	.6544	2.9144**
Left Wrist	1.1375	1.1433	2.2918***
Wrist Dorsal Flexion			
Right Wrist	2.0611	.2711	1.1055
Left Wrist	.6251	.2217	1.3589

** Indicates statistical significance at the 2 per cent level of confidence
*** Indicates statistical significance at the 5 per cent level of confidence

a decrease in the difference between the two groups. Therefore there was not any indication of an upward trend in the difference between the two groups.

Grip Strength

The right and left grip strength measurements did not show a statistically significant difference between the two groups at any of the testing sessions. The mean scores for the control group were consistently higher throughout the length of the study for both the right and left hand, see Table IV and Table VI, pages 51 and 55. Therefore even though the difference between the two groups seems to be decreasing it only indicates that the mean scores for the experimental group were increasing.

Wrist Palmar Flexion

There was no statistically significant difference between the two groups from Test I to Test II in right or left wrist palmar flexion. By the third testing session there was a significant increase of strength between the two groups which was statistically significant at the 2 per cent level of confidence for the right wrist and at the 5 per cent level of confidence for the left wrist. The mean scores for the two groups, see Table IV and Table VI, pages 51 and 55, show that the mean score for the experimental group was higher than that of the control group. This therefore indicates that the exercises used in this study proved to be significant in increasing strength of wrist palmar flexion in the experimental group.

Wrist Dorsal Flexion

The mean scores for the experimental group were lower than those of the control group at the beginning of the study. However, after five weeks of grip and wrist strengthening exercises the means for the final testing showed that the experimental group's scores were higher than the control group. Even though it appeared that the experimental group was increasing strength of wrist dorsal flexion there was no statistically significant difference between the means of the experimental and control groups at any of the three testing sessions in wrist dorsal flexion strength.

Summary

Tennis playing ability did not change significantly between the two groups at any time throughout the study. However, the experimental group's mean scores, which appear in Table IV, page 51, do indicate that tennis playing ability within the experimental group was increasing.

At no time throughout the course of the study did grip strength of either hand increase enough to indicate a significant difference between the two groups. The mean scores for the control group in grip strength were consistently higher than those of the experimental group.

Wrist palmar flexion strength scores indicated an increasing difference between the two groups. At the beginning of the study the control group's mean score for right wrist palmar flexion was slightly higher than that of the experimental group. However, by the end of the study the experimental group's mean was high enough so that there was a statistically significant difference between the means of the groups to

be significant at the 2 per cent level of confidence. In left wrist strength the experimental group was higher in mean score values than the control group throughout the duration of the study. Even though the experimental group had higher mean scores for left wrist palmar flexion, there was no significant difference between the two groups until the final test period. At this final testing period the difference between the two groups was statistically significant at the 5 per cent level of confidence. The exercises appeared to have more effect on wrist dorsal flexion than on any other measurement, so perhaps if the study had been conducted for a greater length of time strength could have been increased more significantly.

No significant difference occurred between the groups in right or left wrist dorsal flexion between any of the testing sessions. An analysis of the means from Table IV and Table VI, pages 51 and 55, shows that the experimental means were lower for both the right and left wrist at the beginning of the study. At the third testing session the experimental group means were higher than the control group's scores. However, the exercises failed to increase strength sufficiently since there was no significant difference between the two groups at any of the testing sessions.

INTERPRETATION

Physiological studies have shown that the physical condition of the body can be determined through a study of an individual's grip strength (44). Just as pulse rate, temperature, and metabolism of the

body have a diurnal cycle, the grip has also been found to follow such a pattern. Through Wright's (48) study it was found that grip strength is on the increase from early morning until noon, then levels off and becomes static during the early afternoon. Since the writer's study involved the testing of grip strength, it would have seemed advisable to test at the time of day when the grip had reached a plateau. However, because the subjects in this study were engaged in such a wide variety of activities, it was impossible to schedule the strength testing at the same time of day. It is possible, therefore, that this fact had some influence on the results of this study.

The writer chose to have exercises performed by the non-dominant hand because of research (46) indicating that exercises performed on one side of the body will increase strength on the contralateral side. It is presumed, that since the subjects in the writer's study increased in wrist palmar flexion strength, the contralateral exercises aided in increasing strength.

Increase of strength through sports activities has been cited by Smalley and Smalley (45). The results of this study showed that shoulder girdle strength increased significantly in players after an eight-week period of tennis lessons. If this is true of the shoulder girdle then perhaps the wrist and grip would also increase in strength after a program of tennis lessons. Since the writer succeeded in increasing wrist palmar flexion strength, then perhaps a combined program of tennis lessons and wrist strengthening exercises would have more of an appreciable effect on tennis playing ability. However, in a study by Jacobs

(50), after nine weeks of golf lessons and grip exercises there was no significant gain in strength or increase in hitting distance. This may indicate that the exercises did not overload the muscles sufficiently to increase strength or that golf practice over a nine-week period is not a long enough time to increase strength. Even though tennis and golf are individual sports, the amount of strength exerted in each is of a somewhat different nature, therefore this may indicate that the type of exercises used for increasing strength should be appropriate to the activity. This is the reason the writer chose exercises that had a similar muscular action as that that takes place during the hitting of a tennis ball.

In a study similar to the writer's, Reynolds (51) wanted to determine what effect wrist strength had on tennis playing ability. The results of the study indicated that the exercises performed by an experimental group did not increase wrist strength significantly when compared with the control group. However, Reynolds did not state whether there was any change within either group in wrist strength or tennis playing ability. It could be possible that there was an equal change within the two groups in wrist strength and tennis playing ability from initial to final tests, which did not make any appreciable difference between the two groups at the end of nine weeks. This might indicate that wrist strength would increase equally as well in a program of tennis lessons as in a program of tennis lessons and wrist strengthening exercises. Reynolds felt that lack of increased strength was due to the fact that the number of repetitions of an exercise should be handled

individually, because some of the subjects could not perform the average number that was required for the entire group. The writer incorporated many of the suggestions made by Reynolds in hopes of increasing strength of grip and wrist. Exercises were prescribed on a basis of an individual's strength potential rather than the group's strength potential. Each individual will vary as to the amount of his strength potential and it is the writer's opinion that subjects should be prescribed exercises which they are capable of performing. It is equally important that they do not perform exercises which are too easy. It is for this reason that the writer encouraged the subjects to increase the number of contractions made with the grip and wrist exerciser at their individual rates. The amount of tension held was also increased in accordance with an increase in wrist strength. The amount of time spent performing the exercises per week was increased considerably. The subjects in Reynold's study performed exercises for ten minutes a week; whereas, in the writer's study exercise time was approximately one hour and fifteen minutes per week. It was also recommended by Reynolds that a rest period between exercises be taken in order to increase the amount of work performed by the muscles controlling the wrist. This was taken into account in the writer's study and a three-minute rest period took place between the palmar-dorsal flexion exercise and the grip and wrist exercise. The writer felt that with these factors taken into consideration wrist palmar flexion strength was increased in the experimental group, even though grip strength was not increased. This may indicate that a still longer period of time must be spent performing exercises or that the

exercises are not appropriate for increasing grip strength. However, it should be noted that even though wrist palmar flexion strength was increased there was still no change in tennis playing ability.

Further research is necessary in the field of physical education to determine if strengthening exercises should be incorporated in a program of sports activities.

CHAPTER VI

SUMMARY AND CONCLUSIONS

This study was conducted for the purpose of determining whether exercises to increase strength of grip and wrist would have any effect on tennis playing ability.

The subjects for this experiment were selected from undergraduates of The Woman's College of the University of North Carolina. These students were either members of the tennis club or were recommended by their tennis instructors. The eighteen subjects participating in the study were divided into experimental and control groups by ranking them according to tennis playing ability.

Exercises were performed by the experimental group approximately fifteen minutes a day, five days a week, for five weeks. One exercise consisted of palmar flexing and dorsi flexing the wrist and holding a static contraction which was two-thirds the subject's strength for six seconds. The second exercise consisted of squeezing a grip and wrist exerciser. The subjects were instructed to squeeze the exerciser as many times as possible each session.

The aircraft tensiometer and regulation strap were submitted to three different testing procedures in order to determine test reliability. The third method, using the best of three trials, proved to be the most reliable for wrist palmar flexion and wrist dorsal flexion strength. The aircraft tensiometer and specially designed frame for grip strength measurement was also found to be a reliable testing de-

vice. All reliabilities were found to be significant at better than the 5 per cent level of confidence.

In order to determine if there were any statistically significant difference between the two groups at various periods throughout the study, it was necessary to equate them at the beginning of the experiment. The t-test of significant difference between means was used to equate the groups at the beginning of the study as well as to compare the groups at the second and third testing sessions. Statistical comparisons were made within groups to determine if there were any significant difference between each testing session.

FINDINGS

Wallboard Tennis Test

1. The experimental group changed significantly in tennis playing ability between Test I and Test II.

2. There was no change within the control group in tennis playing ability between any of the testing sessions.

3. The mean difference between the two groups at all of the testing sessions did not show any statistically significant differences.

Grip Strength

1. Right grip strength was increased in the experimental group from Test I to Test II and from Test I to Test III; however, in the control group right grip strength also changed significantly from Test I to Test III.

2. Due to the somewhat similar increase in both groups in right grip strength the mean difference between the two groups was not

significant.

3. Left grip strength in both groups did not make any significant change.

4. The mean difference between the two groups in left grip strength was not significant.

Wrist Palmar Flexion Strength

1. Right wrist palmar flexion strength was increased in the experimental group between all testing periods. In each case the amount of increase was significant at the 1 per cent level of confidence.

2. The difference within the control group between Test I and Test II and between Test I and Test III was significant at the 2 per cent level of confidence.

3. The mean difference between the two groups in right wrist palmar flexion at the third testing session was statistically significant at the 2 per cent level of confidence with the difference being in favor of the experimental group.

4. The experimental group increased strength in the left wrist between Test I and Test III and between Test II and Test III at the 2 per cent level of confidence.

5. The control group's significant change in strength occurred between Test I and Test III.

6. As a result of the greater increase in strength in the experimental group there was a significant mean difference at the 5 per cent level of confidence between groups at the third testing sessions.

Wrist Dorsal Flexion

1. Right wrist dorsal flexion strength within the experimental group was significant at the 1 per cent level of confidence between Test I and Test II and between Test I and Test III.

2. In the control group there was no significant change in right wrist dorsal flexion strength.

3. Even though the experimental group showed a statistically significant increase in strength it was not sufficient to cause a statistically significant difference between the final mean scores of the experimental and control groups.

4. Left wrist dorsal flexion within the experimental group made a significant increase at the 5 per cent level of confidence between Test I and Test II. Between Test I and Test III the change was significant at the 2 per cent level of confidence.

5. The control group made greater changes in strength of left wrist dorsal flexion than any other of the strength measurements. Test I and Test II showed a change significant at the 2 per cent level of confidence. The change between Test I and Test III was significant at the 1 per cent level of confidence.

6. The statistically significant change in strength in the control group in left wrist dorsal flexion did not result in a significant mean difference between the two groups.

CONCLUSIONS

Strength as a prerequisite to movement may prove itself invaluable to many physical activities. The method used to increase strength and

the manner in which strength is used are equally important. The purpose of this experiment was to determine whether exercises to increase strength of grip and wrist would have any effect on tennis playing ability.

The results of this study, which took place over a five-week period, have shown the following:

1. That the exercises used in this study were of value in increasing strength of right and left wrist palmar flexion. This strength was increased significantly in the experimental group when compared with the control group at the end of the study.

2. Right grip strength was increased slightly in the experimental group; however, there was also a corresponding change in the control group. Therefore at the final analysis the experimental group had not increased in right grip strength sufficiently for the difference to be statistically significant. The exercises used in this study did not prove to be significant in increasing grip strength.

3. Wrist dorsal flexion strength increased significantly in the experimental group. Strength increased for the right wrist was even more significant. A significant change in left wrist dorsal flexion occurred in both groups. At the final analysis any change in strength in either wrist did not prove to make any statistical significant difference between the two groups.

4. The only change in tennis playing ability occurred in the experimental group over a very short period of time. A comparison between the two groups did not result in a significant increase of

tennis playing ability by the group performing the exercises.

5. The purpose of this study was to increase the strength of grip and wrist and then to determine whether this increase had any effect on tennis playing ability. Since grip strength was not significantly increased then it could not be determined whether an increase of grip strength had any effect on tennis playing ability.

6. The results of this study show that wrist palmar flexion strength was increased significantly. Since tennis playing ability was not increased, it appears that an increase of wrist palmar flexion strength had no effect on tennis playing ability.

7. Since only one strength measurement was increased it would indicate two things: (1) that the exercises were not conducted for a long enough period or (2) that the exercises did not overload the muscles of the grip and wrist sufficiently to increase strength.

It is the recommendation of the writer that different areas of this study be explored in greater detail:

1. That grip and wrist strengthening exercises be conducted over a longer period of time and with groups of different abilities. By doing this it might be determined which level of ability would profit more from specific grip and wrist strengthening exercises.

2. That the exercises be conducted at the same time that the subjects were taking tennis lessons, to determine if the combination would obtain more significant results.

3. That the final testing session consist of a tennis tournament to determine whether the experimental group was superior in a more real-

istic playing situation.

4. Compare a program of grip and wrist strengthening exercises to a program of general fitness exercises as to their value in tennis playing ability.

A review of literature has shown that strength can be increased in a number of ways. The most predominant appeared to be weight lifting in a phasic type of action and in holding a static contraction. The phasic and static contraction exercises performed in this study proved to be of value in increasing strength significantly in right wrist dorsal flexion. Literature has also shown that strength will increase when exercises are performed for a sufficient length of time. Some research indicated a six-week period and another a program of exercises for eight weeks. The five-week period during which this study took place may not have been long enough to cause a more significant increase of strength. However, the writer feels that the fifteen minutes for five days a week did indicate a beginning of a change in strength in the experimental group. Since there is research to substantiate the value of rest between exercises, the writer requested that the subjects rest for three minutes between the static contraction exercise and the phasic exercises. This rest period may have aided the increase of strength in wrist palmar flexion in the experimental group.

Tennis players should understand that the game of tennis is not entirely a contest of strength, but rather a combination of learned skills and body movements. Unless the movements of the body are efficient the skills learned will be of little value. It was for this

reason that the writer hoped to increase strength of grip and wrist since the action of the wrist in the game of tennis is of such vital importance.

BIBLIOGRAPHY

BIBLIOGRAPHY

A. BOOKS

1. Austin, 'Bunny', Lawn Tennis Made Easy. New York: The MacMillan Company, 1935. 109 pp.

2. Bjurstedt, Molla, and Samuel Crowther, Tennis for Women. New York: Doubleday, Page and Company, 1916. 175 pp.

3. Broer, Marion, Efficiency of Human Movement. Philadelphia: W. B. Saunders Company, 1960. 351 pp.

4. Clarke, Harrison, Cable-Tension Strength Tests. Chicopee: Brown-Murphy Company, 1953. 31 pp.

5. DeLorme, Thomas, and Arthur Watkins, Progressive Resistance Exercise. New York: Appleton-Century-Crofts, Incorporated, 1951. 245 pp.

6. Doherty, Reginald, and Hugh Doherty, Lawn Tennis. New York: The Baker and Taylor Company, 1903. 233 pp.

7. Driver, Helen, Tennis for Teachers. Philadelphia: W. B. Saunders Company, 1941. 219 pp.

8. Edwards, Allen, Experimental Design in Psychological Research. New York: Rinehart and Company, Incorporated, 1950. 446 pp.

9. Godfree, L. A., and H. B. Wakeham, Lawn Tennis. Philadelphia: David McKay Company, 1937. 233 pp.

10. Guilford, J. P., Fundamental Statistics in Psychology and Education. New York: McGraw-Hill Book Company, Incorporated, 1956. 565 pp.

11. Jacobs, Helen, Tennis. New York: A. S. Barnes and Company, 1941. 77 pp.

12. Leighton, Harry, Tennis-Instructor's Guide, Chicago: The Athletic Institute, 1955. 62 pp.

13. McCloy, Charles, and Norma Young, Tests and Measurements in Health and Physical Education. New York: Appleton-Century-Crofts, Incorporated, 1954. 497 pp.

14. Metheny, Eleanor, Body Dynamics. New York: McGraw-Hill Book Company, Incorporated, 1952. 225 pp.

15. Morehouse, Laurence, and John Cooper, Kinesiology. St. Louis: C. V. Mosby Company, 1950. 435 pp.

16. _____, and Augustus Miller, Physiology of Exercise. St. Louis: C. V. Mosby Company, 1959. 349 pp.

17. _____, and Philip Rasch, Scientific Basis of Athletic Training. Philadelphia: W. B. Saunders, 1958. 238 pp.

18. Osborn, R. D., Lawn-Tennis Player. London: "Pastime" Offices, 1888. 68 pp.

19. Paret, J. Parmly, Lawn Tennis. New York: The MacMillan Company, 1916. 135 pp.

20. _____, Methods and Players of Modern Lawn Tennis. New York: American Lawn Tennis, 1915. 295 pp.

21. Scott, M. Gladys, and Esther French, Measurement and Evaluation in Physical Education. Dubuque: W. C. Brown Company, 1959. 493 pp.

22. Vaile, P. A., Modern Tennis. New York: Funk and Wagnalls Company, 1915. 301 pp.

23. Wells, Katherine F., Kinesiology. Philadelphia: W. B. Saunders Company, 1950. 478 pp.

24. Wilding, Anthony F., On the Court and Off. New York: Doubleday, Page and Company, 1913. 273 pp.

B. PERIODICALS

25. Broer, Marion, and Donna Miller, "Achievement Tests for Beginning and Intermediate Tennis," The Research Quarterly, 21:303-313, October, 1950.

26. Burke, W. E., et. al., "The Relationship of Grip Strength and Grip Strength Endurance to Age," Journal of Applied Physiology, 5:628-630, April, 1953.

27. Capen, Edward, "The Effects of Systematic Weight Training on Power, Strength, and Endurance," The Research Quarterly, 21:83-93, May, 1950.

28. _____, "Study of Four Programs of Heavy Resistance Exercises for Development of Muscular Strength," The Research Quarterly, 27:132-142, May, 1956.

29. Chui, Edward, "The Effect of Systematic Weight Training on Athletic Power," The Research Quarterly, 21:188-194, October, 1950.

30. Clarke, Harrison, "Comparison of Instruments for Recording Muscle Strength," The Research Quarterly, 25:398-411, December, 1954.

31. _____, "Objective Strength Tests of Affected Muscle Groups Involved in Orthopedic Disabilities," The Research Quarterly, 19:118-147, May, 1948.

32. Dyer, Joanna Thayer, "The Backboard Test of Tennis Ability," The Research Quarterly, 6:62-74, March, 1935.

33. _____, "Revision of the Backboard Test of Tennis Ability," The Research Quarterly, 9:25-31, March, 1938.

34. Fox, Katherine, "A Study of the Validity of the Dyer Backboard Test and the Miller-Forehand-Backhand Test for Beginning Tennis Players," The Research Quarterly, 24:1-7, March, 1953.

35. Frederick, Mary, "Drill and Skill Before the Kill," Journal of Health, Physical Education and Recreation, 30:30-31, January, 1959.

36. Geckler, Edwin, "A Pneumatic Dynamometer," The American Journal of Surgery, 45:353, August, 1939.

37. Hunsicker, Paul, and George Greey, "Studies in Human Strength," The Research Quarterly, 28:109-122, May, 1957.

38. Kline, George, "Conditioning for Tournament Tennis," Scholastic Coach, 27:16-18, April, 1958.

39. Lefevre, John R., "Organize Your Tennis Practice," Journal of Health, Physical Education and Recreation, 29:54, March, 1958.

40. Leighton, Harry, "Problems in Testing Tennis," Official Tennis-Badminton Guide, June, 1952-June, 1954, pp. 83-88.

41. McPherson, Frances, "The Forgotten Step in Tennis," Selected Tennis and Badminton Articles, 1936-1958, pp. 22-27.

42. Rasch, Philip, and Laurence Morehouse, "Effects of Static and Dynamic Exercises on Muscular Strength and Hypertrophy," Journal of Applied Physiology, 11:29-34, July, 1957.

43. Robinson, Al, "Teaching the Forehand Stroke," Athletic Journal, 39:7-8, April, 1959.

44. Rogers, Frederick, "The Significance of Strength Tests in Revealing

Physical Condition," The Research Quarterly, 5:43-46, October, 1934.

45. Smalley, Jeannette, and Marian Smalley, "Changes in Endurance and in Arm and Shoulder Girdle Strength of College Women in Certain Physical Education Classes," The Research Quarterly, 16:139-147, May, 1945.

46. Statler-Hammel, Arthur, "Bilateral Effects of Muscular Activity," The Research Quarterly, 21:203-209, October, 1950.

47. Wolbers, Charles, and Frank Sills, "Development of Strength in High School Boys by Static Muscular Contraction," The Research Quarterly, 27:446-450, December, 1956.

48. Wright, Verna, "Factors Influencing Diurnal Variations of Strength of Grip," The Research Quarterly, 30:110-116, March, 1959.

C. UNPUBLISHED MATERIALS

49. Grande, Pauline, "The Effect of an Increase in Strength of the Shoulder Girdle of College Women on the Softball Throw for Distance." Unpublished Master's thesis, The Woman's College of the University of North Carolina, Greensboro, North Carolina, 1956. 37 pp.

50. Jacobs, Helene E., "The Effect of Grip Strength as Related to Distance in the Golf Drive." Unpublished Master's thesis, The Woman's College of the University of North Carolina, Greensboro, North Carolina, 1952. 36 pp.

51. Reynolds, Nancy, "The Effect of Wrist Strength and Wrist Strengthening Exercises on Tennis Playing Ability." Unpublished Master's thesis, University of Michigan, Ann Arbor, Michigan, 1959. 42 pp.

APPENDIX

TABLE IX

CORRECTED SCORES FOR CABLE TENSIOMETER

Instrument Reading	Correction	Corrected Reading	Instrument Reading	Correction	Corrected Reading
0	0	0	10.5	.625	18.13
.5	1.250	1.25	11.0	.625	18.75
1.0	1.250	2.50	11.5	.625	19.38
1.5	1.250	3.75	12.0	.625	20.00
2.0	1.250	5.00	12.5	.625	20.63
2.5	.625	5.63	13.0	.625	21.25
3.0	.625	6.25	13.5	.625	21.88
3.5	.625	6.88	14.0	.625	22.50
4.0	.625	7.50	14.5	.625	23.13
4.5	.625	8.13	15.0	.625	23.75
5.0	.625	8.75	15.5	.625	24.38
5.5	.625	9.38	16.0	.625	25.00
6.0	.625	10.00	16.5	.625	25.63
6.5	1.250	11.25	17.0	.625	26.25
7.0	1.250	12.50	17.5	.625	26.88
7.5	1.250	13.75	18.0	.625	27.50
8.0	1.250	15.00	18.5	.625	28.13
8.5	.625	15.63	19.0	.625	28.75
9.0	.625	16.25	19.5	.625	29.38
9.5	.625	16.88	20.0	.625	30.00
10.0	.625	17.50	20.5	.833	30.83

TABLE IX (continued)

Instrument Reading	Correction	Corrected Reading	Instrument Reading	Correction	Corrected Reading
21.0	.833	31.67	32.0	.833	48.33
21.5	.834	32.50	32.5	.833	49.17
22.0	.833	33.33	33.0	.834	50.00
22.5	.833	34.17	33.5	1.250	51.25
23.0	.834	35.00	34.0	1.250	52.50
23.5	.625	35.63	34.5	1.250	53.75
24.0	.625	36.25	35.0	1.250	55.00
24.5	.625	35.88	35.5	.833	55.83
25.0	.625	37.50	36.0	.833	56.67
25.5	.625	38.13	36.5	.834	57.50
26.0	.625	38.75	37.0	.833	58.33
26.5	.625	39.38	37.5	.833	59.17
27.0	.625	40.00	38.0	.834	60.00
27.5	.833	40.83	38.5	.625	60.63
28.0	.833	41.67	39.0	.625	61.25
28.5	.834	42.50	39.5	.625	61.88
29.0	.833	43.33	40.0	.625	62.50
29.5	.833	44.17	40.5	.625	63.13
30.0	.834	45.00	41.0	.625	63.75
30.5	.833	45.83	41.5	.625	64.38
31.0	.833	46.67	42.0	.625	65.00
31.5	.834	47.50	42.5	1.250	66.25

TABLE IX (continued)

Instrument Reading	Correction	Corrected Reading	Instrument Reading	Correction	Corrected Reading
43.0	1.250	67.50	54.0	1.250	90.00
43.5	1.250	68.75	54.5	.833	90.83
44.0	1.250	70.00	55.0	.833	91.66
44.5	1.250	71.25	55.5	.834	92.50
45.0	1.250	72.50	56.0	.833	93.33
45.5	1.250	73.75	56.5	.833	94.16
46.0	1.250	75.00	57.0	.834	95.00
46.5	1.250	75.83	57.5	1.250	96.25
47.0	.833	76.67	58.0	1.250	97.50
47.5	.834	77.50	58.5	1.250	98.75
48.0	.833	78.33	59.0	1.250	100.00
48.5	.833	78.17			
49.0	.834	80.00			
49.5	.833	80.83			
50.0	.833	81.66			
50.5	.834	82.50			
51.0	.833	83.33			
51.5	.833	84.16			
52.0	.834	85.00			
52.5	1.250	86.25			
53.0	1.250	87.50			
53.5	1.250	88.75			

Woman's College
Woman's Hall
February 1, 1961

I am writing to you concerning a research study that I am undertaking for six weeks this semester, from February 13th through March 24th. The purpose of this study is to determine whether a program of exercises to increase grip and wrist strength will have any effect on tennis playing ability. In order to carry on this study it is necessary for me to have a sufficient number of skilled subjects.

It has been called to my attention that you have indicated an interest and demonstrated skill in tennis. Therefore, you have been selected as a possible participant in this study.

The subjects for this study will be divided into two groups. One group will perform certain exercises for fifteen minutes Monday through Friday throughout the duration of the study. The time for these exercises will be scheduled at the convenience of those participating. The second group will not perform the exercises, but will participate in three testing sessions with the first group.

It is sincerely hoped that since you profess an interest in tennis you will participate in this study. Please respond on the enclosed postcard and return it by Monday, February 6th. If you should wish more information, you may contact me by writing or calling the address that appears below.

Sincerely yours,

Campus Address:
Woman's Hall, Box 617
Phone: 238

RETURN POSTCARD

Please fill out the following information and return this card by February 6, 1961.

Name _____

Campus Address _____ Phone _____

I will / will not be able to participate in this study.

SCORE CARD A

Name _____ Group _____

Campus Address _____ Phone _____

Year In School _____ Age _____

	TEST I	TEST II	TEST III
Wallboard Test			
Grip Strength			
Right Hand			
Left Hand			
Wrist Palmar Flexion			
Right			
Left			
Wrist Dorsal Flexion			
Right			
Left			

SCORE CARD B

MONDAY		TUESDAY		WEDNESDAY		THURSDAY		FRIDAY	
Right	Left	Right	Left	Right	Left	Right	Left	Right	Left

R.P. - Right Wrist Palmar Flexion L.P. - Left Wrist Palmar Flexion

R.P. R.D. L.P. L.D. R.D. - Right Wrist Dorsal Flexion L.D. - Left Wrist Dorsal Flexion

WALLBOARD TEST
Modification of Dyer Test (21:222-223)

Equipment:

1. Backboard or wall, approximately 10 feet in height allowing 15 to 20 feet in width per person taking the test at one time; stop watch; two balls and a racket per player. Balls should be in good condition and racket should be tightly strung. Box for extra balls, about 12 inches long, 9 inches wide, and 3 inches deep, placed on the floor where the restraining line (described below) joins the side (at the left for right-handed players and right for left-handed players). A racket may be substituted for the box; the racket placed on the floor in the same position as that described for the box, and the balls are laid on the face of the racket.

2. Markings: A line 3 inches in width should be drawn on the wall to represent the net, so that the top is 3 feet from the floor. A restraining line, 27.5 feet from the base of the wall should be drawn on the floor, parallel to the wall.

Test:

On the word Go of the signal, Ready, Go! the player drops the ball and lets it hit the floor once and then starts rallying it against the wall. He continues rallying until the signal to stop. The ball may bounce any number of times or it may be volleyed. At the start of the test and whenever a new ball is put in play, it must be allowed to bounce before being hit. Any stroke may be used, but all strokes should be played from behind the restraining line. The player may cross the line to retrieve the ball but hits made from this position are not scored. If the ball gets out of control, the player may take another ball from the box.

Scoring:

Each time a ball strikes the wall on or above the net line, having been hit from behind the restraining line, one point is scored. Three trials are given, and the score is the sum of these trials. The length of each trial is thirty seconds.

GRIP AND WRIST EXERCISE

Equipment

Right and left arm desk chair, grip and wrist exerciser

Body Position

1. General body position
   The subject was seated in a desk arm chair with arm to be exercised on the arm of the chair.
2. Hand and wrist position
   The hand and wrist were extended over the arm of the chair, in mid-position of range of motion for dorsal and palmar flexion.

Position of the grip and wrist exerciser

The exerciser was placed in the palm of the hand so that the wooden handles were grasped by the thumb and fingers. The steel coil that connects the two wooden handles extends upward.

Action of the exercise

The exerciser was squeezed as tightly as possible then partially released and then contracted again.

WRIST PALMAR FLEXION EXERCISE

Equipment

One left and one right desk arm chair, aircraft tensiometer, regulation strap, one-sixteenth inch extra flexible cable (7 x 7), buckle, nickel-plated snap, welded link chain, two heavy straps, two-inch hook, and a stop watch.

Position of chair

The chair was placed so that the front leg nearest the wall was three feet and four inches from the wall.

Body Position

1. General body position: The subject was seated in a desk arm chair with feet flat on the floor and the wrist to be exercised on the arm of the chair.
2. Upper arm and forearm position: The upper arm was placed against the side of the back of the chair so that it was adducted and extended at the shoulder to one hundred and eighty degrees and strapped in place. The forearm, which was on the arm of the chair, was in mid-prone and supine position, and was also strapped into position. The elbow was at a ninety degree angle.
3. Wrist position: The wrist was in mid-position of range of motion for dorsal and palmar flexion.

Position of strap and cable

The regulation strap was placed around the dorsum of the hand above the metacarpophalangeal joint. The cable was attached to the strap by means of a snap. The welded link chain, which was at the opposite end of the cable, was attached to the wall by means of a hook which was two feet and five inches from the floor. The keeper on the strap was pushed up against the back of the hand to hold the strap in place.

Position of the tensiometer

The tensiometer was placed on the cable so that the cable passed under the two sectors and over the riser.

WRIST PALMAR FLEXION EXERCISE (continued)

Action of the Exercise

The subject palmar flexed the wrist until the tester instructed the subject to hold the contraction. The contraction held for six seconds was two-thirds maximum strength. The pulling action was away from the tensiometer therefore the apparatus was facing the back of the hand.

WRIST DORSAL FLEXION EXERCISE

Equipment

One left and one right desk arm chair, aircraft tensiometer, regulation strap, one-sixteenth inch extra flexible cable (7 x 7), buckle, nickel-plated snap, welded link chain, two heavy straps, two-inch hook, and a stop watch.

Position of Chair

The chair was placed so that the front leg nearest the wall was one foot and eight inches from the wall.

Body Position

1. General body position: The subject was seated in a desk arm chair with feet flat on the floor and the wrist to be exercised on the arm of the chair.
2. Upper arm and forearm position: The upper arm was placed against the side of the back of the chair so that it was adducted and extended at the shoulder to one hundred and eighty degrees and strapped in place. The forearm, which was on the arm of the chair, was in mid-prone and supine position, and was strapped in place. The elbow was at a ninety degree angle.
3. Wrist position: The wrist was in mid-position of range of motion for dorsal and palmar flexion.

Position of strap and cable

The regulation strap was placed around the dorsum of the hand above the metacarpophalangeal joint. The cable was attached to the strap by means of a snap. The welded link chain, which was at the opposite end of the cable, was attached to the wall by means of a hook which was two feet and five inches from the floor. The keeper on the strap was pushed up against the palm of the hand to hold the strap in place.

Position of the tensiometer

The tensiometer was placed on the cable so that the cable was passed under the two sectors and over the riser.

WRIST DORSAL FLEXION EXERCISE (continued)

Action of the Exercise

The subject dorsal flexed the wrist until the tester instructed the subject to hold the contraction. The contraction held for six seconds was two-thirds maximum strength. The pulling action was away from the tensiometer therefore the apparatus was facing the palm of the hand.

Figure 7

Arm Position for Wrist Palmar and Dorsal Flexion Test

Figure 7

Arm Position for Wrist Palmar and Dorsal Flexion Test

TABLE X

RAW DATA FOR WALLBOARD TESTS

EXPERIMENTAL GROUP	AGE	YEAR	TEST I	TEST II	TEST III
1.	18	Fr.	41	45	36
2.	18	Fr.	38	39	39
3.	19	Soph.	38	40	47
4.	18	Fr.	34	42	34
5.	19	Soph.	32	34	30
6.	20	Jr.	30	35	35
7.	18	Fr.	29	34	
8.	19	Fr.	27	33	35
9.	18	Fr.	26	38	32

CONTROL GROUP	AGE	YEAR	TEST I	TEST II	TEST III
1.	20	Jr.	39	48	37
2.	19	Soph.	39	38	41
3.	21	Sr.	35	30	45
4.	18	Fr.	34	42	44
5.	20	Sr.	31	31	35
6.	19	Soph.	30	33	29
7.	20	Soph.	29	30	26
8.	20	Soph.	28	33	27
9.	19	Soph.	23	31	21

TABLE XI

RAW DATA FOR GRIP STRENGTH TESTS

EXPERIMENTAL GROUP	RIGHT TEST I	RIGHT TEST II	RIGHT TEST III	LEFT TEST I	LEFT TEST II	LEFT TEST III
1.	52.50	59.17	47.50	50.00	47.50	45.00
2.	70.00	82.50	80.00	61.25	55.83	61.88
3.	61.25	65.00	70.00	50.00	52.50	50.00
4.	62.50	62.50	65.00	53.75	59.17	63.13
5.	67.50	66.25	76.67	62.50	63.75	68.75
6.	45.00	40.83	52.50	42.50	45.00	48.33
7.	52.50	59.17		49.17	47.50	
8.	63.13	67.50	75.83	67.50	71.25	70.00
9.	51.25	58.33	63.75	48.33	48.33	52.50

CONTROL GROUP	RIGHT TEST I	RIGHT TEST II	RIGHT TEST III	LEFT TEST I	LEFT TEST II	LEFT TEST III
1.	84.16	90.83	90.00	78.33	71.25	68.75
2.	65.00	65.00	76.67	57.50	66.25	70.00
3.	62.50	73.75	76.67	62.50	56.67	66.25
4.	66.25	70.00	70.00	66.25	67.50	70.00
5.	65.00	75.83	72.50	62.50	61.88	60.00
6.	53.75	52.50	50.00	66.25	52.50	62.50
7.	61.25	41.67	68.75	60.00	49.17	63.75
8.	60.00	60.63	60.63	58.33	58.33	52.50
9.	52.50	55.00	52.50	43.33	43.33	52.50

TABLE XII

RAW DATA FOR WRIST PALMAR FLEXION STRENGTH TESTS

EXPERIMENTAL GROUP	RIGHT			LEFT		
	TEST I	TEST II	TEST III	TEST I	TEST II	TEST III
1.	20.63	32.50	38.75	23.75	30.83	35.00
2.	30.83	35.00	38.75	34.17	33.33	35.63
3.	23.75	35.63	33.33	27.50	28.75	26.88
4.	34.17	39.38	43.33	35.00	41.67	46.67
5.	34.17	31.67	37.50	33.33	26.25	40.00
6.	20.63	20.63	28.75	21.88	25.63	30.00
7.	25.00	32.50		28.75	30.83	
8.	22.50	35.63	45.83	25.00	36.88	42.50
9.	21.25	30.83	38.13	17.50	33.33	46.67

CONTROL GROUP	RIGHT			LEFT		
	TEST I	TEST II	TEST III	TEST I	TEST II	TEST III
1.	29.38	31.67	32.50	30.00	34.17	43.33
2.	23.13	23.75	35.00	20.63	24.38	25.00
3.	34.17	42.50	34.17	25.00	27.50	29.38
4.	28.75	45.00	36.25	27.50	30.00	31.67
5.	20.63	22.50	25.00	24.38	22.50	22.50
6.	28.75	33.33	27.50	26.25	45.83	38.75
7.	18.75	23.13	27.50	23.13	22.50	26.25
8.	25.00	27.50	25.00	23.13	23.75	27.50
9.	25.00	25.00	31.67	23.75	25.63	25.63

TABLE XIII

RAW DATA FOR WRIST DORSAL FLEXION STRENGTH TESTS

EXPERIMENTAL GROUP	RIGHT TEST I	RIGHT TEST II	RIGHT TEST III	LEFT TEST I	LEFT TEST II	LEFT TEST III
1.	25.00	30.83	35.00	25.00	25.63	32.50
2.	25.00	29.38	25.63	22.50	26.88	28.75
3.	22.50	26.88	23.13	23.13	25.63	20.00
4.	28.75	31.67	45.00	23.75	35.00	40.00
5.	26.25	30.00	35.63	26.25	21.25	36.25
6.	18.75	20.00	24.38	17.50	18.75	23.13
7.	25.00	30.83		23.75	25.63	
8.	26.25	30.00	30.83	25.63	28.75	28.13
9.	20.00	28.13	35.00	20.00	30.83	35.00

CONTROL GROUP	RIGHT TEST I	RIGHT TEST II	RIGHT TEST III	LEFT TEST I	LEFT TEST II	LEFT TEST III
1.	33.33	30.00	38.75	26.25	28.13	32.50
2.	29.38	31.67	34.17	28.75	31.67	32.50
3.	23.75	31.67	25.63	26.25	30.00	28.75
4.	29.38	32.50	30.00	21.88	29.38	23.75
5.	26.25	24.38	26.88	21.88	21.88	24.38
6.	26.25	26.25	22.50	27.50	28.75	28.75
7.	23.13	20.00	25.00	23.75	23.13	23.75
8.	29.38	31.67	30.00	21.88	26.25	25.63
9.	25.00	25.00	23.13	20.00	23.13	21.88

Typed by Kathleen Mitchell