WALL VOLLEY TEST PERFORMANCE AS A FUNCTION OF

GRIP AND WRIST STRENGTH

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WALL VOLLEY TEST PERFORMANCE AS A FUNCTION OF GRIP AND WRIST STRENGTH

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CHAPTER I

INTRODUCTION

Strength has long been recognized as a basic requisite for many gross motor activities. Almost every sport requires substantial strength in some body part. This is evidenced by the conditioning phase of training schedules and the multitude of test batteries, including assessments of strength, which are used to predict motor ability, skill, or achievement. Whether or not a specific degree of strength is indicated, all motor performance tests, like movement, require a certain amount of strength. Effects of strength and other components of motor performance have to be considered when constructing tests. Knowledge of effects of strength will affect, not only testing results, but teaching and training methods also.

Successful performance on many motor performance assessment batteries may be as dependent upon strength as upon skill or motor ability. For example, the original Brace Motor Ability Test (3), which was the first published attempt to quantify motor ability, contained several stunts that required a relatively high degree of strength. McCloy felt that the test was too weighted with a strength component and attempted to improve the test by adding the criterion that the items have a low correlation with strength (17).

It is interesting to note that further investigation (4) found the Brace test to be more predictive than the revised version. From these early efforts, a panorama of tests has evolved.

Rogers, an early pioneer, took a slightly different approach when he developed the Strength Index (20) as a measure of general athletic ability based on the hypothesis that a high Strength Index would enhance an individual's performance in various activities after a period of training. Various independent findings have substantiated this hypothesis. Some investigations have been centered around correlations between strength and athletic ability (1, 2, 11), strength as a basis for equating teams (5, 9, 19, 20), and still others have related strength to general achievement (21, 22).

Hinton and Rarick (13) were among the first to use strength measures to predict achievement in a specific activity such as basketball. Similar investigations have been initiated involving other activities (14, 16), but they are not adequate to meet the innumberable questions related to strength and performance.

A glance at the many different texts discussing tennis, badminton, and volleyball reveals the recognition that grip and wrist strength are factors pertinent to these activities. One of the reasons given for preference of the eastern grip in tennis is that it compensates for weak grip and wrist strength by putting the hand behind the racket. Other sources related to badminton are concerned with a powerful snap of the wrist when executing high clears. Grip and wrist strength are also recognized as contributors in the execution of the set-up in volleyball.

Since there are so many variables involved in the assessment of playing ability in tennis, badminton, and volleyball, one particular type of test was chosen to determine playing ability. Wall volley tests were chosen because they have been developed and validated to be used as measures of playing ability in the above named activities.

Statement of Problem

This study tested the hypothesis that grip and wrist strength affect performance on wall volley tests that were designed to test ability in tennis, badminton, and volleyball. If this hypothesis were true, training designed to increase grip and wrist strength would be desirable in these activities. This study provided an opportunity to determine whether women produce a strength testing pattern that is similar to that of men (15) in test-retest situations. Answers to these questions were determined by comparing results on selected wall volley tests with cable tensiometer strength measures, by subjecting some of the subjects to strength training, and by comparing strength measures of test-retest sessions.

Purposes of Study

The purposes of the study were: a) to determine the relationship between grip strength and scores on selected wall volley tests, b) to determine the relationship between wrist strength and scores on selected wall volley tests, c) to determine the effect of strength training on wall volley scores, d) and to determine whether women produce a strength testing pattern that is similar to men in test-retest situations (15).

The following null hypotheses were tested:

1. No signficant difference exists among the initial, criterion, and final means of the strength measures.

2. No significant difference exists between the initial and final means of the wall volley scores.

3. No significant difference exists between the means of the experimental and control groups' a) initial measures of strength, b) criterion measures of strength, c) final measures of strength, d) initial wall volley scores, and final wall volley scores.

4. The true correlation among all strength measures and wall volley scores is not significantly different from zero.

Definition of Terms

The following definitions are pertinent to this study:

1. Strength.--Maximum force of tension applied in a single contraction (6, p. 203).

2. Wrist flexion strength.--Maximum tension applied to cable while flexing the wrist. The tension was measured according to Clarke's procedures (7, p. 12).

3. Wrist extension strength.--Maximum tension applied to cable while extending the wrist. The tension was measured according to Clarke's procedures (7, p. 12).

4. Tensiometer.--A small compact unit that was originally designed to test the tension of aircraft cables. Cable tension is determined by measuring the force applied to a riser, causing an offset in a cable stretched taut between two sectors (8, p. 8).

5. Wall volley test.--A specific type of motor performance test that is used in sports. The test usually involves projecting an object rapidly against a wall. The score is derived by counting the number of times the projectile legally strikes the wall within a specified period of time (10, 12, 18).

Limitations of Study

Any study of gross motor performance is subject to many limitations. Since only wall volley tests were used in this study to assess specific skills in tennis, badminton, and volleyball, interpretations of the results were formulated without drawing conclusions regarding the subject's performance in the total activity. A rejected null hypothesis in the initial and final means of the group trained in strength was not interpreted to imply that strength training improved the individual's total ability to play tennis. Conclusions are drawn in terms of the skills utilized only in the wall volley tests.

Tennis, badminton, and volleyball are taught to both sexes on the junior high, high school, and college level. As forty college women were employed in this study, interpretations regarding the data were applied to college women only.

The study was limited in that all subjects were experienced in each of the respective activities. Application of the results has implication only for experienced players. Increased grip and wrist strength might improve performance on wall volley test for experienced players yet be ineffectual for beginners.

This study was further limited in that experience was defined as average or better on the questionnaire (Appendix B). Again, application of findings are pertinent to average or better players only.

Sources of Data

The data necessary for the thesis were collected and studied from both documentary and human sources. The documentary sources consisted of books, periodicals, theses, research studies, and other available materials pertinent to all aspects of the study. The human sources were selected students enrolled at North Texas State University.

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CHAPTER II

SURVEY OF LITERATURE

Introduction

Since this study was concerned with grip and wrist strength relationships to tennis, badminton, and volleyball skills as measured by wall volley tests, the literature reporting the relationship of strength to motor performance; the relationship of grip and wrist strength to tennis, badminton, and volleyball skills; the use of different instruments in the measurement of strength; and the use of wall volley tests in the measurement of sports skills was surveyed.

Relationship of Strength to Motor Performance

Statistical Relationships

Human strength has been an attribute of admiration and interest for centuries. The Biblical characters, Samson and Goliath, were noted for their superior strength. Ancient and modern man have participated in contests requiring feats of strength. As interest in the subject of human strength motivated more objective measurement, physical educators became interested in determining, not only the degree of strength present, but potential relationships of strength to motor ability and motor performance.

Sargent (7) was the first American pioneer in strength testing because he developed the first battery of strength tests, but Fedrick Rand Rogers is credited with standardizing testing procedures and developing norms (46). Rogers' Physical Capacity Test consisted of a lung capacity test and strength tests; lung capacity was assessed by means of a wet spirometer, and strength measures were obtained with a dynamometer or manuometer. In addition, an arm strength score was derived by a formula using sums of push-ups and pull-ups. The Strength Index was the sum of the scores on each of the test items. Rogers hypothesized that an individual with a high Strength Index would have greater potential for good athletic performance after a period of skill training, than an individual with a low Strength Index (46). He tested his hypothesis by determining the correlation between the 100-yard dash, the running broad jump, the running high jump, and the bar vault. The resulting correlation was .76. An r of .81 was obtained when basketball, baseball, and football throwing skills were combined with the track and field events. When athletes and nonathletes were compared on the Strength Index, the athletes proved to have a higher Strength Index. Clarke and Peterson (13) verified Rogers' findings when working with elementary and junior high boys. Strength proved to be a differentiator of athletic ability. The SI was high among athletes and was consistently low among nonparticipants and substitutes.

The Albany staff (15, 16, 17, 18) conducted a series of experiments using the data from the Strength Index to improve and redirect the intramural program in the junior high schools. The Strength Index was used as a basis for equating teams. Track and field events were equated on the basis of the Strength Index for three years, and the results showed performance to consistently improve as the Strength Index level increased (15, 16). The Albany staff used the same procedure for equating teams in aquatic activities, and the results indicated that strength was an important component of success in swimming events (18). The Strength Index also proved to be a highly valid and convenient basis for equating competition in skating events (17).

Wiley (55) further validated the use of the Strength Index as a basis for equating teams on the elementary level. Leonard Clark (6) in his Melrose High School Experiments equated teams on the basis of the Strength Index and had very satisfactory results. Clarke and Bonesteel (12) obtained the same results when equating teams in touch football, speedball, field hockey, and indoor soccer for high school boys. Oesterich (41) equated teams on the basis of the Strength Index for competition in basketball. The results of his tournament were tie ball games or games in which there was only one point difference in the final score.

Hinton and Rarick (26) attempted to determine the correlation between Rogers' test and the Cubberly and Cozens' Test of

Basketball Achievement through the use of multiple correlations. A correlation of .550 between arm strength and basketball achievement proved to be the highest relationship between any two variables.

McCloy (36) initiated changes in Rogers' test. The lung capacity test was deleted on the basis that it was not a strength measure, and a new formula was devised for computing arm strength because McCloy hypothesized that Rogers' method penalized small individuals. Arm strength was assessed from Rogers' formula: arm strength = (pull-ups + push-ups) $(\frac{W}{10}\ H - 60)$ in which W = weight and H = height. McCloy's revision for boys was chinning or dipping strength = 1.77 (weight) + 3.42 (chins or dips) - .46 and chinning and dipping strength = 3.54 (weight) 3.42 (chins + dips) - 92. The formula for girls was chinning strength = 67 (weight) 1.2 (chins) + 52 and dipping strength = .78 (weight) + 1.1 (dips) + .74. McCloy correlated the revision with track and field events and obtained a correlation of .77 which was lower than that obtained by Rogers.

Anderson (2) attempted to construct a battery of strength tests to predict athletic ability in girls using Rogers' test and the revisions recommended by McCloy. She also added a thigh flexor element. Scores on track and field events such as the forty-yard dash, the standing broad jump, the running high jump, and the basketball throw, served as the criteria of athletic ability. The conclusion was that strength is not a sole factor in predicting athletic ability, since a low correlation of .55 was obtained. In a subsequent study Anderson (1) reported the Sargent Jump test to be a better predictor of athletic ability in girls, yielding an _r_ of .646. It must be noted that the criterion of athletic ability in this second study was the subjective rating by a panel of judges. It seemed that the revisions in Rogers' original test battery only weakened its use as a predictor of athletic ability. While Anderson reported low correlations, thus disputing the valid use of the Strength Index as an indicator of athletic ability in girls, it must be remembered that the original test was altered. The Albany studies included favorable reports from the use of the Strength Index in connection with skating competition involving girls, and Hinton and Rarick (26) reported a high _r_ of .809 between the Strength Index and basketball ability in girls. Larson (30) attributed the usefulness of the Strength Index as a differentiator of athletic ability to the dynamic element contributed by the arm strength test.

Various other studies have utilized slightly different factors in relating strength to athletic ability or skill in specific activities. Hooks (27) compared nineteen structural and strength measures to success in baseball and reported the strength measures to have a consistently high correlation with criteria of baseball ability. Wessel and Nelson (54) related grip strength of girls to achievement in college physical education classes reflected by grades, and found a significant relationship. These findings substantiated the results of an earlier study by Tinkle and Montoye (52), who used college men as subjects.

Theoretical Relationship

Of all the factors involved in athletic performance, strength may be considered as one of the most important (5, 44). Motor performance tasks require the development of kinetic energy. Kinetic energy is expressed in the formula $Fd = 1/2\ mv^2$ in which F = force, d = distance, m = mass, and v = velocity. Ordinarily the mass is held constant in sports skills, and it is conceivable to hold the distance constant. In this event, force would be equal to velocity squared or $v = \sqrt{F}$. Muscular strength is responsible for force in most activities. In view of this rationale, it is impossible to negate the importance of muscular strength.

In applying the kinetic energy formula to tennis, the racket would represent the mass, and the space through which the racket travels on the foreswing would represent the distance through which the muscular force was applied. The velocity would be the average speed of the racket as it moved through the given distance. However, the formula must be corrected for the application of angular force, which is the case in all projectile sports. The corrected formula is: $Fd = 1/2\ mv^2 + mgd\ (\sin\theta)$, in which the $\sin\theta$ is a trigometric function of the angle of applied force.

Power is the crucial concern in many motor activities. However, the relationship between work and time can be computed from the formula P = fd/t, in which P = power, F = force, d = distance, and t = time. As stated earlier, force varies directly with the square of velocity. Through further mathematical computation (5) it was possible to show that power varies directly with the cube of velocity. From these relationships, it is apparent that there is a diminishing return for increases in force. In the human body, if applied force is to be increased efficiently, greater maximum force must exist (5).

Strength Training

There is strong evidence to support the value of strength training (5, 33, 39, 44). A relationship exists between the optimum level at which an athlete can perform effectively and the level of available strength. When muscular strength is increased, the athlete can perform at a much higher level of efficiency. Muscles operate at the optimum level of efficiency at a point mid-way between maximum muscular force and maximum velocity (44). When an all-out effort is required in speed or applied force to accomplish a given task, fatigue and inefficiency will result.

Strength training is a part of many athletic activities. An excess in strength above the required level to accomplish a given task is required to meet emergencies and to improve performance (41, 44). Many training schedules are demanding and require more strength than that which is required in actual competition (44). In track and field events, athletes run in weighted shoes and practice with heavier shots than are used in competition. Gymnasts practice progressive resistance exercises.

Experiments (5, p. 36) with the Sargent Jump test gave evidence to the value of strength training. With increased strength, a deeper crouch could be employed thus increasing the height attained. Lindeburg, et al (31), however, reported static exercises to be inefficient in improving standing broad jumpting ability. One group of boys was subjected to isometric exercises and the other group was scheduled to practice broad jumping. Neither group improved. In this particular study, no attention was given to the take-off angle. Had instruction based on kinesiological principles been given to both groups, the strength training group might have improved more than the other group. Although it seems that an improvement should have resulted on the basis that since greater applied force would have been possible greater distance should have been attained. This reverts back to the relationship between force and velocity. As force increases, velocity increases. The distance an object will travel is dependent in part upon the velocity (5).

Voyt (53) studied the effect of isometric grip and wrist strengtening exercises on tennis playing ability as measured by the Dyer Wall Volley Test. Two groups were employed, a control group which was not subject to strength training and an experimental group which was. The experimental group trained for five weeks, five days per week through static exercises that were analogous to testing procedures, i.e., using the cable assembly, grip apparatus, and tensiometer. Both groups were given the Dyer test before and after strength training. The experimental group gained in tennis playing ability and the control group did not, although there were no significant differences between the two groups at any testing session. In view of this, the small improvement evidenced by the experimental group on wall volley test performance could not be attributed to strength training. Furthermore, both groups experienced strength gains in right grip and right wrist flexion. The experimental group improved in left wrist flexion strength, and the control group did not. The same was evidenced in right extension strength. Since both groups experienced certain strength increases and yet no significant differences existed between the two, no conclusions concerning the effect of grip and wrist strength training could be ventured.

Isometric Strength Training

Several studies have shown isometric exercises to be efficient in strength building (3, 19, 20). A five per cent weekly increase over original levels of strength resulted from a training program based on a maximum contraction held for six seconds performed five days per week (40, 43, 51). These findings were substantiated by similar results of other studies (3, 19, 20, 33). Static exercise performed at one joint angle has been reported to increase the strength throughout the range of motion (19). Although conflicting results have been reported (34, 35, 45) concerning the amount of increase obtained weekly, there is a concensus of opinion concerning the effectiveness of isometric contractions in the development of strength.

Grip and Wrist Strength Related to Tennis, Badminton, and Volleyball

Empirical observation attests to the importance of grip and wrist strength in projectile sports. Students have often complained of the grip or wrist giving at impact. A weak grip and wrist account for loss of power and control due to recoil (5). Many authorities recommend the eastern grip (5,21,25,42) in tennis because it compensates for weakness by putting the bulk of the hand behind the racket to help prevent recoil. An individual with weak grip and wrist cannot execute the snap that is so imperative to deep high clears in badminton (5), and loses force and control at the moment of impact in volleyball skills. In volleyball the fingers must be rigid at impact or force will be lost and perhaps no return at all will be made. Lamp (29) investigated the relationship of physiological and growth factors to volleyball playing ability. Test items included the serve, set-up, net pass, and volley skills. Subjective ratings of judges and tournament success were also included in the assessment of ability. Age, weight, height, grip strength and puberty status were statistically correlated with playing ability. The grip strength factor had a low but consistent correlation with all of the items employed to assess playing ability.

In projectile sports, a difficulty in attaining depth of placement, such as from base line to base line, may often be due to lack of strength. The horizontal distance a projectile may be thrust is directly related to the velocity of the projectile, since the velocity of the projectile is dependent upon the speed of both objects before impact (5). The speed of the arm and hand in volleyball and the speed of the racket head in tennis and badminton contribute to the distance of the projectile's flight. Thus, muscular strength contributes to the range of the projectile by increasing potential force.

Instruments to Measure Human Strength

The dynamometer was the first scientific instrument used to measure strength (28). One of the earliest instruments consisted of a large frame and crossbars attached to a steelyard. Known weights were hung on the steelyard. Various adaptations and refinements have evolved. Sargent (28, p. 410) is associated with improvements made in the United States. He employed two types of spring steel dynamometers, the manuometer for grip strength and another form for back and leg strength. The chief fault found in the spring steel instrument has resulted from excessive stretching of the spring, thus altering the initial testing position (28).

Kellogg developed a mercurial dynamometer operating on the hydraulic principle. Kellogg's (28, pp. 412-413) development enabled him to test several muscle groups. The mercurial dynamometer has not been widely used because of its cumbersome nature and high cost.

Hamilton, who was engaged in rehabilitative work, was not satisfied with the steel spring dynamometer because of its lack of sensitivity, so he devised a pneumatic dynamometer which was capable of measuring very weak grip strength (28, p. 414). Only grip strength can be measured with this instrument.

The strain gauge is one of the most recent developments in the dynamometer. The kinematic muscle machine employing the strain gauge can test forces in three planes (28, p. 417). Although this instrument is expensive, it is ideally suited for fatigue studies. The strain gauge is highly sensitive and subject to room temperature changes (28).

Clark, one of the foremost authorities in strength testing, adapted the aircraft tensiometer to test human strength (9). His early battery consisted of twenty-eight tests to measure strength in the hip, shoulder, knee, ankle, and wrist. In a subsequent study, he added ten new tests and altered some of the existing ones (10). In developing the tests, body position, joint angle, gravity, and the attachment of the pulling assembly were under consideration to determine the procedures which would allow for the greatest application of force (9, 10, 11). The muscular force applied to a cable causes an offset on the riser in the tensiometer. The amount of offset is recorded on the calibrated face of the tensiometer. This score can then be converted to pounds of force by means of a chart. Testing procedures for grip and wrist strength appear in Appendix F.

The tensiometer is the most versatile and convenient of all the instruments (8) used to measure strength. Clarke (9, 11) reported the tensiometer to have the greater precision for strength testing, to be the most stable and generally useful, and to be free of the faults found in the other instruments.

Wall Volley Tests

The wall volley test is a specific type of motor performance test that is used in sports. The test usually involves projecting an object rapidly against a wall. The score is derived by counting the number of times the projectile legally strikes the wall within a specified period of time (14, 23, 37). Wall volley tests have been used to assess playing ability in tennis, badminton, volleyball and soccer.

Tennis Wall Volley Tests

Dyer (22) was the first to validate a wall volley test to be used in tennis. The first version employed a three-foot high wall marking, but no restraining line. The subject was instructed to drop the ball and let it hit the floor and then project it against the wall on or above the line as many times as possible in thirty seconds. The score was derived from the sum of three thirty-second trials, with a penalty being levied for missing the ball. In the revised version (23), Dyer added a five-foot restraining line and deleted the penalty for losing control of the ball. A box of reserve balls was placed on the non-dominate side of the subject to improve uniformity in supplying extra balls. The latter version had a validity coefficient of .92 when compared to round-robin tournament results. The reliability coefficient of .70 was established. Since six weeks of instruction and practice occurred between test-retest administration, it had little use to indicate the true realiability; however, it does substantiate the validity. The rationale was that since practice and instruction had occurred, the coefficient should be relatively low due to the intersubject variations in increase in skill (4).

Shay (49) reported that one coach successfully used the Dyer test to select varsity team players. Dovela, who was acting as coach, had a limited time to select team members, so he administered the Dyer test with the one modification being that the restraining line was extended to seven feet. The six boys with the highest test scores were the first men on the team and were never replaced. The team was undefeated and the number one man with the highest score was the National Junior Champion.

Ronning (47) experimented with restraining lines of 5, 15, 25 and 35 feet and trial periods of thirty and sixty seconds, when adapting the Dyer test for college men. A combination of the thirty-five-foot restraining line and a sixty second trial yielded the best results. Round-robin tournament play served as the criterion of validity, which yielded .97. Koski (7) revised the Dyer test by using a twenty-eight-foot restraining line when developing a tennis wall volley test for college men. Correlation with tournament play yielded a low .68.

Hewitt's (24) revision of the Dyer test employed a twenty-foot restraining line, and was initiated with a serve. Hewitt revised the Dyer test when he found it to be a poor differentiator of tennis playing ability at the beginner level.

Badminton Wall Volley Test

Lockhart and McPherson (32) developed a wall volley type test for use in testing badminton playing ability. The test employed a five-foot-high wall marking line and a restraining line of five feet. Subjective ratings and a round-robin tournament were used as the criteria of validity. A validity coefficient of .71 was obtained. Test-retest reliability was established as .90. After extensive study, Miller (37) developed a wall volley test that would measure the high clear, the stroke most commonly used. The wall line was raised to seven and one-half feet and the restraining line was set at ten feet. The test-retest reliability was established to be .94, and validity based on round-robin rank was .83.

Volley ball Wall Tests

Russell and Lang (48) devised a wall volley test of volleyball playing ability for junior high girls. Before developing the test, they surveyed the literature to determine those test items that appeared to be best suited for the junior high level. The final battery consisted of a serving test and a repeated volleys test. The test of repeated volleys called for a seven and one-half foot wall line and a restraining line of three feet.

Three thirty-second trials were given. Test-retest reliability yielded an r of .915, and validity was determined to be .80 on the basis of subjective ratings. This test was adapted from French and Cooper's original battery devised for high school girls. The original repeated volleys test consisted of five fifteen-second trial periods. It is otherwise identical to the Russell-Lange test.

Brady (4) developed a similar test for college men, but the trial period was one minute long. The wall markings were extended to eleven and one-half feet high, and no restraining line was employed. Test retest reliability was established to be .925, and validity based on subjective ratings was established to be .86.

Haverstick and Mohr (38) developed a wall volley test for college women. They experimented with restraining lines of three, five, and seven feet. Results suggested the best test to consist of a seven-foot restraining line and a wall line of seven- and one-half feet. Three thirty-second trials were held constant throughout the testing period. Reliability and validity ranged in the .90's.

Clifton (14) established a single hit volley test which was more consistent with current rules for college women. Markings were the same as those recommended by Mohr and Haverstick; however, only two thirty-second trials were used rather than three. Subjective ratings were used as the criterion to determine validity. Pearson product moment correlation coefficient of .74

between ratings and a wall volley test was obtained. Test retest reliability was found to be .84.

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CHAPTER III

PROCEDURES

Preview

Procedures necessary to meet the objectives of the study were a review of related literature, selection of subjects, administration of initial and final wall volley tests designed to assess playing ability in tennis, badminton, and volleyball, designation of a control and experimental group, conducting a strength training program analogous to the cable-tension tests, analysis of data, which included computation of Pearson product-moment coefficients of correlation, t ratios, and F ratios.

Subjects

Since skilled players are more consistent in the execution of strokes, and in order to enhance the reliability of the measures obtained from the wall volley tests, only students experienced in volleyball, tennis, and badminton were utilized as subjects in the study. An Experience Questionnaire (Appendix B) was constructed to serve as a basis for subject selection. Sixty-five questionnaires were distributed to women students enrolled in physical education classes at North Texas State University during the spring semester, 1968. Questionnaires were provided only to those students who professed to have a playing skill in tennis, badminton, and volleyball, and who were not currently enrolled in a formal class of instruction in any of the three activities. The subjects indicated the amount of instruction in each sport to which they had been exposed, and their evaluation of their skill ability in each of the three activities. After the questionnaires were completed, they were examined by the investigator to determine those students who were average or better in the three activities. There were forty-two students who qualified to be subjects and who, therefore, received a request by letter to participate in the study. Thirty-nine volunteered but due to conflicts in scheduling, injury, and other complications, only thirty subjects completed all the requisites necessary to include their scores in the analysis.

The academic classification of the participants ranged from freshman to senior. The subjects wore street clothes during the strength testing sessions and shorts, shirt, and tennis shoes during the wall volley testing phase.

Tests and Instrumentation

Strength Tests

Cable-Tension Tests developed by Clarke (3) were selected to measure grip strength, wrist flexion, and wrist extension strength. These tests were chosen because they are both valid and reliable, and because specific methods have been described by Clarke (4). Clarke sought the opinion of experts in anatomy and physiology in developing the battery of tests, and in a later study (4) reviewed each test experimentally to determine the angle of maximum potential for the joint tested and to determine the position of attachment of the pulling assembly that would yield optimum results.

The cable-tension tests employ the cable tensiometer. After scholarly investigations of many types of instruments designed to measure strength, Clarke (2, 5) concluded that the tensiometer was the most reliable and objective. Refer to Appendix F for a description of the tests.

Wrist flexion and extension.--A four by bour board six inches in length was mounted on both ends of a table to provide for the attachment of the pulling assembly, which consisted of a handle, cable, and adjustable turnbuckle. The assembly was mounted so that the applied tension would be at a right angle to the point of attachment on the tested limb. A tensiometer was mounted on the table to provide right angle intersection with the cable. Two foam rubber padded adjustable braces were centered in the table to provide stability of the forearm and to isolate wrist action. The attachment was such that the braces fitted the contour of the forearm. Two wide padded leather straps attached to the table between the braces provided further stability.

During the test administration, the subject was seated at a table in a chair with the feet resting on the floor and the free arm resting in the lap. The upper arm on the tested side was adducted and extended at the shoulder to one hundred and eighty degrees. The forearm was resting on the table with the elbow in ninety degrees flexion. In testing wrist flexion and extension strength, the forearm was placed between the braces and strapped to the table so that the forearm was held in mid-prone and supine position. The wrist was held in mid-position of range of motion of palmar and dorsal flexion. Once the arm was stabilized, both flexion and extension were measured. The handle of the pulling assembly was adjusted so that the subject could grasp it while in the required position.

Grip strength.--An adjustable hand grip apparatus employing the tensiometer (Appendix A) was mounted on a foam rubber and which was next to the braces. The grip apparatus was an assembly conversion system which made it possible to use a tensiometer to measure grip strength. The upper part of the grip was attached at right angles to the cable. The tensiometer was mounted on the apparatus to provide right angle intersection with the cable. This assembly was employed only when recording grip strength.

In testing grip strength, the position of the shoulder and the elbow were identical to that employed in testing wrist flexion and extension, but the forearm rested on the table against the outside of the braces and was held in pronation. The wrist was held in mid-position of range of motion of abduction and adduction. Before the subject assumed the testing position, the hand grip apparatus was adjusted so that the mid-phalanx of the fingers curled around the portion of the grip attached to the cable.

Wall Volley Tests

Since this study was concerned with the effect of grip and wrist strength upon subjects' performance on wall volley tests, wall volley tests of ability in tennis, badminton, and volleyball were selected. This particular type of test has been developed and used to measure skill in various activities. Wall volley tests have been used repeatedly in research and have undergone extensive experimentation. Tests of this type require very little equipment, are easily administered, and are valid and reliable as evidenced by relatively high validity and reliability coefficients.

Tennis wall volley test.--The Dyer Revision of the Backboard Test of Tennis Ability (7) was selected to measure tennis ability because both a high validity coefficient of .92 and a reliability coefficient of .70 were established. Dyer recommended that the reliability test-retest measure be viewed as a validity index because test-retest administration was intervened by six weeks of skill practice. The lower coefficient of .70 reflected improvement in skill. This test is described in Appendix C.

Badminton wall volley test.--Miller's Badminton Wall Volley Test (9) was selected to measure badminton skill because it was specifically developed for college women (Appendix D). The test is both valid and reliable as evidenced by the coefficients of .83 and .94 respectively. The criterion of validity was the result of a round-robin tournament.

Volleyball wall volley test.--Clifton's Single Hit Volley Test for Women's Volleyball (6) was selected to measure volleyball skill because it was developed for college women (Appendix E). The test has a relatively high validity coefficient of .74 and a reliability coefficient of .80.

Experimental Design

Administration of Strength Tests

Six cable-tension tests were administered: right wrist flexion, right wrist extension, right grip, left wrist flexion, left wrist extension, and left grip. Three trials were recorded for each test. The sum of the three trials served as the criterion for each measure. Each subject was individually scheduled for testing. The investigator was the sole administrator, with the exception that an assistant who was thoroughly familiar with testing procedures administered the scheduled tests for one day.

Cable-tension tests were administered three times. The initial measures were followed, as has been suggested in the literature, two weeks later by criterion measures. Two weeks later final measures were recorded. Procedures were identical for initial, criterion, and final tests.

An order was established for the administration of the six different cable-tension tests that would balance any possible effects that might be results of fatigue, learning, warm-up, or unknown variables. Twenty-four combinations were established for the order of testing (Appendix G). Combination number I consisted of the following order: left wrist flexion, left wrist extension, right wrist flexion, right wrist extension, left grip, and right grip. The first subject was tested in the order presented in combination number I. The second subject was tested in the order presented by combination number II. This process was continued until all twenty-four possible combinations had been used and the process was repeated until all strength measures were recorded.

Administration of Wall Volley Tests

The tennis, badminton, and volleyball wall volley tests were administered at three respective stations simultaneously. The investigator and two assistants acted as timers and supervised their respective stations. The subjects rotated the duties of counting the number of legal hits, watching for foot faults, and retrieving the projectiles.

Twenty-four students met for the first testing session. The investigator described and demonstrated each test. A period for questions was followed by a brief period of practice in each of the activities.

Following the practice period, the subjects were divided into three groups. Group I started with the tennis test, Group II with the badminton test, and Group III with the volleyball test. The first person in each line of each group took the respective test, the second person scored, the third judged foot faults, and the fourth retrieved. After completing trial number one of the test, the subject went to the rear of the line and rested. The order in line rotated so that all subjects performed all activities at each testing station. Upon completion of the specified number of trials, the subjects rotated to the next station so that those initially at Station I went to Station II, those at Station II went to Station III, and those at Station III proceeded to Station I.

A second wall volley testing session was scheduled for those who were unable to attend the first. The instructions and procedures were identical to the first. The participants who were unable to meet either of the above sessions were either tested individually or in groups of two or three. In this case, assistants were employed to act as scorers, foot fault judges, and retrievers.

The final wall volley tests were not administered until after the final strength scores were obtained. A letter announcing the testing date and time was sent to each participant. As was true in the initial testing, some subjects were tested individually or in small groups. The instructions and procedures were identical to the initial tests.

Selection of Experimental and Control Groups

The subjects were divided, on the basis of the criterion strength level, into a control and an experimental group. The criterion strength measures were used as the basis for placement because they have been found to be more reliable measures of the current level of strength (8). The strength level was determined by summing the three trials of six tests to produce a composite strength score. The criterion strength scores were matched as nearly as possible to produce equality in levels of strength between two subjects. Once matched they were randomly placed in either the control or experimental group.

The experimental group was subjected to two weeks of strength training while the other group served as a control to determine the effect of strength training on wall volley performance. Since the tests were selected to measure the strength of muscle range used in wrist flexion and extension and grip, the strength training was designed to be comparable to the testing procedures. A cable pulling assembly and grip apparatus similar to that used in the strength testing was provided for the strength training sessions. Each subject was scheduled to meet Monday through Friday for two weeks.

The subjects trained individually. During each session, six repetitions held for six seconds (10) were performed on the following exercises: right grip, right wrist flexion, right wrist extension, left grip, left wrist flexion, and left wrist extension. During exercise bouts, the subjects held a position analogous to testing procedures and exerted tension on the pulling assembly by extending or flexing the wrist or by squeezing the grip apparatus. The investigator supervised the first training session and others thereafter where scheduling permitted.

Order of Testing

The entire schedule consumed seven weeks, as follows:

	One Week	Two Weeks	One Week	Two Weeks	One Week
	Initial		Criterion		Final
Control Group	Strength Measures & Wall Volley Tests	No Activity	Strength Measures	Strength Training	Strength Measures & Wall Volley Tests
	Initial		Criterion		Final
Experimental Group	Strength Measures & Wall Volley Tests	No Activity	Strength Measures	No Activity	Strength Measures & Wall Volley Tests

The initial strength measures and wall volley tests were administered during the first two weeks of testing. Each subject was scheduled so that the initial strength measure was followed two weeks later by the criterion strength measure. After all of the criterion measures were recorded, the sbujects were divided into a control and an experimental group. The experimental group trained with isometric exercises analogous to testing procedures for two weeks. During the training period, the other group served as a control. After the two weeks of strength training, both groups completed the final strength tests and wall volley tests.

Analysis of Data

The data were composed of scores from an initial and a final administration of tests of ability in tennis, badminton, and volleyball, and from an initial, criterion, and a final administration of six cable-tension tests. Statistical treatment included the computation of means, standard deviations, and correlation coefficients for all variables. An analysis of variance for repeated measures was also computed. When *F* scores were significant, a *t* test to determine a critical difference was computed. A *t* ratio for uncorrelated means was computed to determine between group differences.

Test of Hypotheses

To determine existing differences among initial, criterion, and final means of the strength measures an analysis of variance was computed and *t* tests were computed to determine where differences among the three means might exist. The null hypothesis that there were no significant difference among the initial, criterion, and final means of the strength measures was tested, and the .05 level was selected as the basis for rejection. The control and experimental groups' scores were considered separately.

To determine existing differences between initial and final means of wall volley scores, an analysis of variance was computed to determine whether these differences were significant. The null hypothesis that there was no significant difference between the initial and final means of the wall volley scores was tested and the .05 level was selected as the basis of rejection. The experimental and control groups' scores were considered separately.

To determine existing differences between the means of the experimental and control groups' scores on all tested variables, *t* ratios were computed. The null hypothesis that there was no significant difference between the means of the experimental and control groups' initial measures of strength, criterion measures of strength, final measures of strength, initial wall volley scores, and final wall volley scores was tested and rejected at the .05 level.

To determine existing relationships among measures of strength and measures of skill in tennis, badminton, and volleyball, a simple correlation matrix was established. The null hypothesis that the relationship among all strength measures and wall volley measures was not significantly different from zero was tested, and the .05 level was selected as an indicator that relationships were significantly different from zero.

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CHAPTER IV

RESULTS AND DISCUSSION

Preview

This chapter presents an analysis of data and an interpretation of the findings related to the effect of grip and wrist strength on wall volley performance in tennis, badminton, and volleyball. The tests were chosen to determine if there were statistical relationships between strength measures and wall volley scores and to determine if there were statistically significant changes in wall volley performance as a result of strength training. An analysis of variance for the control group and for the experimental group was computed to determine if significant differences existed among the initial, criterion and final strength measures and to determine if significant differences existed between the initial and final wall volley scores. The critical difference was computed to determine if significant differences existed between the control group and the experimental group on the initial strength measures, criterion strength measures, final strength measures, initial wall volley scores, and final wall volley scores.

Results

Strength Tests

The source of variance, degrees of freedom, sum of squares, mean squares, and F ratios for the control group's repeated strength measures are presented in Table I; the corresponding information relevant to the experimental group is presented in Table III. Lindquist (8) stated that when sets of observations are equal in number, the critical difference may be computed rather than the t for any differences. All differences between means greater than the critical difference may be considered significant. The significant F ratios that appeared in Tables I and III were followed by a test of critical differences, $d = t\sqrt{\frac{2ms\ w}{N}}$, to determine where significant differences existed. The means and differences among means for the control group are displayed in Table IV. Table IV contains the same information relevant to the experimental group.

Control group.--An examination of the F ratios in Table I reveals that a significant difference existed among the control group's initial, criterion, and final measures of strength on the following tests: right wrist extension, left wrist flexion, and right grip. To determine where the significant differences existed, the above mentioned critical difference was computed and compared to differences among the means. A significant difference existed between the initial and criterion measures of right wrist extension and left wrist flexion. The criterion and final measures of right grip reflected a significant difference between tests. An examination of the means in Table VII indicates that the difference was a change in the positive direction. No significant difference existed among the repeated measures on the following control group strength tests: right wrist flexion, left wrist extension and left grip.

TABLE I

ANALYSIS OF VARIANCE AMONG INITIAL, CRITERION, AND FINAL STRENGTH SCORES FOR CONTROL GROUP

Right Wrist Flexion

Source	df	SS	MS	F
Trials	2	147.840	73.920	2.82
Subjects	14	2161.550		
Trials X S's	28	732.110	26.146	
Total	44	3041.500		

Right Wrist Extension

Source	df	SS	MS	F
Trials	2	219.280	109.640	19.90*
Subjects	14	546.810		
Trials X Subjects	28	154.249	5.508	
Total	44	920.339		

$F_{2,28} > 3.34 = p < .05$[a]

[a]Winer, B. J., Statistical Principles in Experimental Design, McGraw-Hill, 1962, p. 642.

TABLE I --*Continued*

Left Wrist Flexion

Source	df	SS	MS	F
Trials	2	304.820	152.410	5.83*
Subjects	14	2728.530		
Trials X Subjects	28	726.900	25.960	
Total	44	3760.250		

Left Wrist Extension

Source	df	SS	MS	F
Trials	2	7.666	3.833	.13
Subjects	14	1467.723		
Trials X Subjects	28	829.966	26.641	
Total	44	2305.355		

*$F_{2,28} > 3.34 = p < .05$[a].

[a] Winer, B. J., *Statistical Principles in Experimental Design*, New York, McGraw-Hill, 1962, p. 642.

TABLE I --*Continued*

Right Grip

Source	df	SS	MS	F
Trials	2	855.630	427.815	6.94*
Subjects	14	2014.490		
Trials X Subjects	28	1720.800	61.457	
Total	44	4590.920		

Left Grip

Source	df	SS	MS	F
Trials	2	265.260	132.630	2.02
Subjects	14	2154.870		
Trials X Subjects	28	1817.420	64.907	
Total	44	4237.550		

*$F_{2,28} > 3.34 = p < .05$[a].

[a]Winer, B. J., *Statistical Principles in Experimental Design*, New York, McGraw-Hill, 1962, p. 642.

TABLE II

DIFFERENCES AMONG CONTROL GROUP MEANS ON STRENGTH VARIABLES

Right Wrist Extension

Means		A_2	A_3
$\overline{X}_1$	20.41	A_1 3.87*	5.21*
$\overline{X}_2$	24.28	A_2	1.34*
$\overline{X}_3$	25.62		

*$\underline{d} > 1.76 = p < .05$.

Left Wrist Flexion

Means		A_2	A_3
$\overline{X}_1$	49.47	A_1 5.88*	5.09*
$\overline{X}_2$	55.35	A_2	.79
$\overline{X}_3$	54.56		

*$\underline{d}$ 3.81 = p .05.

Right Grip

Means		A_2	A_3
$\overline{X}_1$	52.81	A_1 3.52	10.50*
$\overline{X}_2$	56.33	A_2	6.97*
$\overline{X}_3$	63.31		

*$\underline{d} > 5.87 = p < .05$[a]

[a]Winer, B. J., Statistical Principles in Experimental Design, New York, McGraw-Hill, 1962, p. 642.

Experimental group.--As evidenced by the *F* ratios in Table III, significant differences existed among the experimental group's initial, criterion, and final measures of strength on the following cable-tension tests: right wrist flexion and extension, left wrist flexion and extension, right grip and left grip. The application of the critical difference test to determine where differences existed revealed a significant difference between the initial and criterion and between the criterion and final measures of strength on all six cable-tension tests administered to the experimental group. The differences reflected an increase in the scores between repeated measures.

TABLE III

ANALYSIS OF VARIANCE AMONG INITIAL, CRITERION, AND FINAL STRENGTH SCORES FOR EXPERIMENTAL GROUP

Right Wrist Flexion				
Source	df	SS	MS	F
Trials	2	1149.250	574.625	30.00*
Subjects	14	4783.970		
Trials X Subjects	28	536.190	19.149	
Total	44	6469.410		

*$F_{2,28} > 3.34 = p < .05$[a].

[a]Winer, B. J., *Statistical Principles in Experimental Design*, New York, McGraw-Hill, 1962, p. 642.

TABLE III --Continued

Right Wrist Extension

Source	df	SS	MS	F
Trials	2	625.005	312.502	30.62*
Subjects	14	1413.582		
Trials X Subjects	28	284.951	10.176	
Total	44	2323.538		

Left Wrist Flexion

Source	df	SS	MS	F
Trials	2	869.420	434.710	42.70*
Subjects	14	6995.840		
Trials X Subjects	28	285.020	10.179	

*$F_{2,28} > 3.34 = p < .05$[a].

[a] Winer, B. J., Statistical Principles in Experimental Design, New York, McGraw-Hill, 1962, p. 642.

TABLE III --*Continued*

Left Wrist Extension

Source	df	SS	MS	F
Trials	2	408.275	204.137	62.21*
Subjects	14	4929.480		
Trials X Subjects	28	91.872	3.281	
Total	44	5429.627		

Right Grip

Source	df	SS	MS	F
Trials	2	29302.59	1151.295	51.11*
Subjects	14	7164.370		
Trials X Subjects	28	630.070	22.602	
Total	44	10097.030		

*$F_{2,28} > 3.34 = p < .05$[a]

[a] Winer, B. J., *Statistical Principles in Experimental Design*, New York, McGraw-Hill, 1962, p. 642.

TABLE III --Continued

Left Grip

Source	df	SS	MS	F
Trials	2	1671.090	835.545	20.13*
Subjects	14	6178.320		
Trials X Subjects	28	1162.060	41.502	
Total	44	9011.470		

*$F_{2,28} > 3.34 = p < .05$[a]

[a]Winer, B. J., Statistical Principles in Experimental Design, New York, McGraw-Hill, 1962, p. 642.

TABLE IV

DIFFERENCES AMONG EXPERIMENTAL GROUP MEANS ON STRENGTH VARIABLES

Right Wrist Flexion

Means	A_2	A_3
$\overline{X}_1$ 49.53	A_1 4.07*	12.16*
$\overline{X}_2$ 53.60	A_2	8.09*
$\overline{X}_3$ 61.60		

*$d > 3.27 = p < .05$[a]

[a]Winer, B. J., Statistical Principles in Experimental Design, New York, McGraw-Hill, 1962, p. 642.

TABLE IV --Continued

Right Wrist Extension

Mean		A_2	A_3
$\bar{X}_1$ 23.73	A_1	3.27*	9.01*
$\bar{X}_2$ 27.00	A_2		5.74*
$\bar{X}_3$ 32.74			

*$\underline{d} > 2.39 = p < .05$.

Left Wrist Flexion

Mean		A_2	A_3
$\bar{X}_1$ 49.03	A_1	5.42*	10.76*
$\bar{X}_2$ 54.46	A_2		5.34*
$\bar{X}_3$ 59.80			

*$\underline{d} > 2.39 = p < .05$.

[a]Winer, B. J., Statistical Principles in Experimental Design, New York, McGraw-Hill, 1962, p. 642.

TABLE IV --Continued

Left Wrist Extension

Mean	A_2	A_3
$\overline{X}_1$ 21.87	A_1 2.81*	6.92*
$\overline{X}_2$ 24.78	A_2	
$\overline{X}_3$ 28.79		

*$\underline{d} > 1.35 = p < .05$

Right Grip

Mean	A_2	A_3
$\overline{X}_1$ 56.20	A_1 6.05*	17.27*
$\overline{X}_2$ 62.25	A_2	11.22*
$\overline{X}_3$ 73.47		

*$\underline{d} > 3.55 = p < .05$[a]

[a] Winer, B. J., Statistical Principles in Experimental Design, New York, McGraw-Hill, 1962, p. 642.

TABLE IV --Continued

Left Grip

Mean		A_2	A_3
$\overline{X}_1$	53.80	A_1 6.58*	14.89*
$\overline{X}_2$	60.38		8.31*
$\overline{X}_3$	68.69		

*$\underline{d} > 4.82 = p < .05$[a]

[a]Winer, B. J., Statistical Principles in Experimental Design, New York, McGraw-Hill, 1962, p. 642.

Wall Volley Tests

The source of variance, degrees of freedom, sum of squares, mean squares, and $\underline{F}$ ratios for the control group's repeated wall volley measures are presented in Table V; the corresponding information relevant to the experimental group is presented in Table VI.

Control group.--No significant difference existed between the control group's initial and final tennis tests, or between the initial and final volleyball tests. A significant difference did exist between the control group's initial and final badminton tests. The difference was a change in the positive direction.

TABLE V

ANALYSIS OF VARIANCE BETWEEN INITIAL AND FINAL WALL VOLLEY SCORES FOR CONTROL GROUP

The Dyer Revision of the Backboard Test of Tennis Ability

Source	df	SS	MS	F
Trials	1	116.033	116.033	3.60
Subjects	14	1262.800		
Trials X Subjects	14	449.467	32.104	
Total	29	1828.300		

Miller's Badminton Wall Volley Test

Source	df	SS	MS	F
Trials	1	418.133	418.133	10.32*
Subjects	14	2777.200		
Trials X Subjects	14	565.867	40.419	
Total	29	3761.200		

*$F_{1,14} > 4.60 = p < .05$[a].

[a]Winer, B. J., Statistical Principles in Experimental Design, New York, McGraw-Hill, 1962, p. 642.

TABLE V --Continued

Clifton's Single Hit Volley Test for Women's Volleyball

Source	df	SS	MS	F
Trials	1	36.300	36.300	2.46
Subjects	14	1027.800		
Trials X Subjects	14	206.200	14.728	
Total	29	1270.300		

Experimental group.--As evidenced by Table VI, a significant difference existed between the experimental group's initial and final wall volley scores in tennis, badminton, and volleyball. An examination of the experimental group's wall volley means found in Table VIII indicates that increases in scores occurred on the final wall volley tests.

TABLE VI

ANALYSIS OF VARIANCE BETWEEN INITIAL AND FINAL WALL VOLLEY SCORES FOR EXPERIMENTAL GROUP

The Dyer Revision of the Backboard Test of Tennis Ability

Source	df	SS	MS	F
Trials	1	418.133	418.133	14.82*
Subjects	14	2171.800		
Trials X Subjects	14	394.867	28.204	
Total	29	2984.800		

Miller's Badminton Wall Volley Test

Source	df	SS	MS	F
Trials	1	2784.033	2784.033	39.36*
Subjects	14	4776.800		
Trials X Subjects	14	1203.467	85.961	
Total	29	8764.300		

*$F_{1,14} > 4.60 = p < .05$[a]

[a] Winer, B. J., Statistical Principles in Experimental Design, New York, McGraw-Hill, 1962, p. 642.

TABLE VI --Continued

Clifton's Single Hit Volley Test for Women's Volleyball

Source	df	SS	MS	F
Trials	1	730.133	730.133	21.43*
Subjects	14	3905.667		
Trials X Subjects	14	476.867	34.061	
Total	29	5112.667		

$*F_{1,14} > 4.60 = p < .05$[a]

[a] Winer, B. J., Statistical Principles in Experimental Design, McGraw-Hill, 1962, p. 642.

Control and Experimental Group Differences

The control and experimental groups' means and standard deviations for each of the strength measures are presented in Table VII. The *t* ratios resulting from the tests for differences between group means are displayed in Table VII also. The corresponding information relevant to wall volley scores is presented in Table VIII. Nine of the twenty-four *t* ratios computed were significant.

Initial measures of strength.--An examination of the results found in Table VII indicates that no significant differences existed between the two groups' means on any of the initial strength measures.

Criterion measures of strength.--The only significant difference that existed between the control and experimental groups' means on criterion measures of strength was left grip.

Final measures of strength.--The only final strength measure on which the control and experimental and control groups' means did differ significantly was left wrist flexion.

TABLE VII

DESCRIPTIVE STATISTICS AND t RATIOS FOR GROUPS ON STRENGTH MEASURES

Tests	Experimental Group		Control Group		t Ratio
	Mean	SD	Mean	SD	
IRWF	49.53	9.72	45.81	5.61	1.24
CRWF	53.60	12.23	50.00	9.86	.89
FRWF	61.69	10.51	49.19	8.00	3.54*
IRWE	23.73	5.48	20.41	4.37	1.77
CRWE	27.00	5.30	24.28	4.08	1.53
FRWE	32.75	7.42	25.62	3.32	3.28*
ILWF	49.03	12.25	49.47	10.58	.10
CLWF	54.46	13.12	55.35	9.19	.21
FLWF	59.80	11.74	54.56	5.86	1.50
ILWE	21.87	10.90	20.97	10.93	.22
CLWE	24.78	10.65	21.01	4.37	1.22
FLWE	28.79	10.24	21.87	3.82	2.37*
IRG	56.02	12.72	52.81	9.15	.81
CRG	62.25	13.85	56.33	10.28	1.28
FRG	73.47	12.88	63.31	7.72	2.53

TABLE VII --*Continued*

Tests	Experimental Group		Control Group		*t* Ratio
	Mean	SD	Mean	SD	
ILG	53.80	11.64	46.25	9.30	1.90
CLG	60.38	12.19	50.97	8.73	2.35*
FLG	68.69	14.33	51.75	10.11	3.62*

$*t_{1,14} > 2.15 = p < .05$[a]

[a]Guilford, J. P., *Fundamental Statistics in Psychology and Education*, New York, McGraw-Hill, 1965, p. 580.

[b]Legend: R - right
L - Left
F - flexion
E - extension
G - grip

Initial wall volley tests.--The *t* ratios shown in Table VIII revealed that there were no significant differences between the control and experimental groups' means on the initial tennis, badminton, and volleyball wall volley tests.

Final wall volley tests.--As evidenced by Table VIII, significant differences existed between the two groups on the final wall volley scores in tennis, badminton, and volleyball. By referring to Table VI, it can be seen that the experimental group means increased significantly on all wall volley tests.

TABLE VIII

DESCRIPTIVE STATISTICS AND t RATIOS FOR GROUPS ON WALL VOLLEY MEASURES

Tests	Experimental Group		Control Group		t Ratio
	Mean	SD	Mean	SD	
TI	39.47	8.72	34.33	7.80	1.64
TF	46.93	9.75	38.27	7.30	2.66*
BI	40.67	11.07	33.87	10.56	1.66
BF	59.93	16.62	41.33	10.55	3.54*
VI	30.40	12.45	27.20	7.17	.83
VF	40.27	11.71	29.40	5.56	3.14*

*$t_{1, 14} > 2.15 = p < .05$[a].

[a] Guilford, J. P., Fundamental Statistics in Psychology and Education, New York, McGraw-Hill Company, 1965, p. 580.

Relationships Among Variables

The relationship of strength to wall volley measures was of interest; therefore, the Pearson r statistic was computed to determine whether relationships existed. These are shown in Table IX, and were computed by combining the control and experimental groups' scores.

Also of interest were relationships among repeated strength measures and between wall volley initial and final tests. The r's provide estimates of the reliability of these tests. The comparisons relative to the strength scores are shown in Table X.

Strength and wall volley tests.--According to Table VII, significant relationships existed between the initial tennis wall volley tests and the following measures of strength: initial, criterion, and final right wrist flexion; criterion and final right wrist extension; final right grip; and final left grip. All other eleven measures of strength were not significantly related to the initial tennis tests. The final tennis scores were significantly related to the following strength measures: initial, criterion, and final right wrist flexion; criterion right wrist extension; initial and final right grip; and final left grip. The remaining nine strength measures; initial and final right wrist extension, all left wrist flexion, all left wrist extension, and criterion right grip, were not significantly related to the final tennis scores.

The initial badminton scores were significantly related to the following strength measures; final left wrist flexion, initial left extension, and final left grip. The other fifteen strength measures were not significantly related to the initial badminton tests. Final right wrist flexion and extension, final left wrist flexion, final right grip, criterion left grip, and final left grip were significantly related to the final badminton scores; the remaining twelve strength measures were not significantly related.

Seven of the eighteen strength measures were significantly related to the initial volleyball scores; the measures were criterion and final right wrist flexion: initial, criterion, and final left wrist flexion; and criterion right and left grip. The final volleyball scores were significantly related to the following strength measures: initial, criterion, and final right wrist flexion; initial, criterion, and final right wrist extension; final left wrist flexion; initial, criterion, and final right grip; and initial, criterion, and final left grip.

In summary, volleyball skill exhibited the largest number of significant relationships to strength of the three sports in question. Tennis skill was second, yielding sixteen significant relationships to strength. Nine significant relationships existed between badminton skill and strength.

TABLE IX

COEFFICIENTS OF CORRELATION BETWEEN STRENGTH VARIABLES AND WALL VOLLEY MEASURES

Tests	IT	FT	IB	FB	IV	FV
LRWF	.45*	.41*	.10	.32	.34	.47*
CRWF	.37*	.44*	.06	.36	.51*	.54*
FRWF	.48*	.58*	.20	.50	.43*	.58*
IRWE	.25	.28	.04	.18	.29	.44*
CRWE	.44*	.49*	.15	.35	.29	.43*
FRWE	.37*	.35	.15	.47*	.26	.54*
ILWF	.19	.19	.23	.26	.45*	.32

TABLE IX --Continued

Tests	IT	FT	IB	FB	IV	FV
CLWF	.09	.11	.32	.28	.51*	.28
FLWF	.19	.24	.47*	.51*	.49*	.45*
ILWE	.01	.09	-.37*	-.18	.11	.01
CLWE	.23	.32	-.26	-.03	.11	.24
FLWE	.21	.30	-.17	.08	-.01	.19
IRG	.32	.39*	.10	.32	.27	.37*
CRG	.24	.32	.33	.25	.40*	.41*
FRG	.44*	.47*	.32	.48*	.28	.53*
ILG	.30	.44*	-.02	.33	.36	.50*
CLG	.34	.50*	.29	.40*	.41*	.50*
FLG	.49*	.54*	.48*	.60*	.24	.53*

*$r_{2,28} > .36 = p < .05$[a].

[a]Guilford, J. P., Fundamental Statistics in Psychology and Education, New York, McGraw-Hill Company, 1965, p. 581.

Reliability among repeated strength measures.--The reliability coefficients for repeated measures of right wrist flexion ranged from .73 to .81. The range for right wrist extension was .72 to .79. The reliability for repeated measures of left wrist flexion ranged from .84 to .87. Left wrist extension reliabilities among repeated measures ranged from .73 to .95. Right grip strength reliability among repeated measures ranged from .67 to .77. Reliability coefficients among repeated measure of left grip ranged from .50 to .81. In general the reliability was highest among the criterion and final measures.

TABLE X

CORRELATION COEFFICIENTS AMONG INITIAL, CRITERION, FINAL STRENGTH MEASURES

Right Wrist Flexion

Test-Retest	Criterion	Final
Initial	.73*	.73*
Criterion		.81*

Right Wrist Extension

Test-Retest	Criterion	Final
Initial	.79*	.72*
Criterion		.76*

*$\underline{r}_{2,28} > .36 = p < .05$[a]

[a]Guilford, J. P., Fundamental Statistics in Psychology and Education, New York, McGraw-Hill, 1965, p. 581.

TABLE X --Continued

Left Wrist Flexion

Test-Retest	Criterion	Final
Initial	.84*	.84*
Criterion		.87*

Left Wrist Extension

Test-Retest	Criterion	Final
Initial	.79*	.73*
Criterion		.95*

Right Grip

Test-Retest	Criterion	Final
Initial	.61*	.77*
Criterion		.73*

*$r_{2,28} > .36 = p < .05$[a]

[a] Guilford, J. P., Fundamental Statistics in Psychology and Education, New York, McGraw-Hill, 1965, p. 581.

TABLE X --Continued

Left Grip

Test-Retest	Criterion	Final
Initial	.50*	.67*
Criterion		.81*

$^{*}\underline{r}$ 2,28 $> .36 = p < .05$[a]

[a]Guilford, J. P., Fundamental Statistics in Psychology and Education, New York, McGraw-Hill, 1965, p. 581.

Reliability between repeated wall volley tests.--The relationships between the initial and final wall volley measures of tennis, badminton, and volleyball were estimated to be .65, .67, and .73 respectively. These significant relationships indicated that the wall volley tests were reliable measures of skill.

Tests of Hypotheses

Hypothesis I stated that there would be no significant difference among the initial, criterion, and final measures of strength. The control and experimental groups were considered separately. The results indicated that significant differences existed between the control group's initial and criterion measures of right wrist extension and left wrist flexion. A significant difference existed between the criterion and final measures of right grip. Hypothesis I relative to the control group's measures of right wrist extension, left wrist flexion, and right grip was rejected. Since significant differences existed among all of the experimental group's initial, criterion, and final measures of strength, Hypothesis I relative to the experimental group was rejected.

Hypothesis II stated that there would be no significant difference between the initial and final means of the wall volley scores. The groups were considered separately. Since a significant difference existed between the initial and final measures of the control group's badminton scores, Hypothesis II relative to the control group's initial and final measures of badminton was rejected. Since the results indicated that the experimental group's means differed significantly between all of the initial and final wall volley tests, Hypothesis II relative to the experimental group was rejected.

Hypothesis III stated that there would be no significant difference between the means of the experimental and control group's initial measures of strength, criterion measures of strength, final measures of strength, initial wall volley scores, and final wall volley scores. The results indicated that the groups did not differ significantly at the initial and criterion stages of [illegible] therefore Hypothesis III relative to the initial measures that the group means differed significantly on all tested variables except left wrist flexion, Hypothesis III was rejected for all variables except left wrist flexion.

Hypothesis IV stated that the correlation among all strength variables and wall volley scores would not differ significantly from zero. Since significant coefficients of correlation appeared in Table IX, Hypothesis IV was rejected.

Discussion

Strength Tests

The findings of this study relative to the existence of critical differences between the experimental groups initial and criterion measures of strength are in accord with other investigations (5). This finding agrees with Kroll's reported increases in recorded levels of right wrist flexion strength in cable-tension test-retest situations utilizing male subjects. He hypothesized that the increases were a result of learning and/or physiological stimulation. Since these increases did occur, Kroll recommended that care be taken in selecting reliable criterion measures of strength when strength increases were to be investigated. Unlike Kroll's findings, and unlike the strength increase pattern shown by the experimental group in this study, the control group of this investigation did not increase in strength from the initial to the criterion measures. Although the control group failed to evidence strength increases on four of the criterion measures, the attainment of the purposes of this investigation was entirely possible. The criterion measures were recorded specifically to obtain reliable measures that would indicate current levels of the subject's strength prior to the isometric strength training schedule. In this way increases in strength that appeared in the final measures could be interpreted as real strength increases rather than increases in strength that might be attributable to testing artifact. The failure of the control group to yield increases in strength scores on four measures is unexplainable within the scope of this study; however it appears that the level of strength recorded for the control group on the initial and criterion measures was the current level of strength for those subjects. Since group placement was not designated until after the criterion measures were recorded, the Hawthorne Effect is not an adequate explanation. Delayed learning, which was described by Kroll as the failure of the subjects to learn how to exert maximum tension on the initial measures, probably was not a factor in this study. Any delayed learning should have occurred in both groups due to the fact that they did not have a group identification at the time of testing. Fatigue could not have been a contributing factor since care was taken to eliminate a fatigue pattern by rotating the order of test administration.

Numerous studies have supported the hypothesis that isometric exercise results in strength increases. Since the experimental group's treatment period intervened the criterion and final cable-tension tests, strength increases were expected between the experimental group's criterion and final measure of strength. The results were consistent with the conclusions expressed in the research literature.

Since care was taken to establish reliable criterion measures of strength no significant increases in recorded levels of strength should have occurred that were not results of the overload principle utilized in isometric strength training. The control group did not participate in the strength training program, and as was expected, no significant increases occurred on the final measures of strength. The one exception to this was the control group's increase in right grip strength on the final measure. The cause of this unexpected increase in right grip strength is unknown.

Wall Volley Measures

The fact that the experimental group improved significantly on all three wall volley tests whereas the control group improved significantly on only the badminton wall volley tests, appears to justify an interpretation that increases in strength enhance wall volley performance. In fact, it seems justifiable to state that the experimental group's improvement on all final wall volley tests might well be atrributed to strength training. None of the subjects were exposed to skill practice in the sports of tennis, badminton, and volleyball. Further, none of the subjects were allowed to practice the tests. Any improvement in performance would be related to strength increases. This is further verified by the control group's failure to exhibit a significant increase on the final wall volley tests. Since the only differentiating factor between the groups was that the experimental group had strength training and the control group did not, strength increases appear to be a quite rational explanation for the superiority of the experimental group over the control group on all wall volley tests.

Control and Experimental Group Differences

Differences between groups on final measures may be interpreted in view of the fact that care was taken to equate the groups initially as closely as possible. All subjects, according to their self-evaluations, were of average or above average skill in the sports of tennis, badminton, and volleyball. Subjects were matched on the basis of a composite level of criterion strength scores. After the subjects' strength levels were matched, their placement in each group was by random selection. In view of this it is not surprising that the groups did not differ significantly at the initial or criterion stage of testing. The significant differences between groups at the final stage of testing can be interpreted to be a result of strength training. The only factor on which the experimontal group was not significantly superior was left wrist flexion. The fact that the groups did not differ significantly on left wrist flexion is difficult to explain within the limits of this study. It may have been a significant difference that was due to chance alone.

Voyt (9), in a similar study, reported no significant differences in the tennis skills of an experimental group that had had strength training, and a control group that had not had strength training. These nonsignificant differences that were found between Voyt's groups were contradictory to the significant differences found between the groups in this study. However, Voyt did not employ criterion strength measures. Her findings reflected strength increases for both control and experimental groups. Since increases are to be expected in cable-tension test-retest situations, the control group might have evidenced an increase due to delayed learning. The control group strength increase might also have been due to the practice that occurred in the initial test. Perhaps a better estimate of between-group differences could have been attained by Voyt had reliable criterion strength estimates been employed.

The same criticism may be extended to Lindburg's (7) study. He reported no improvement in standing broad jumping ability after a period of strength training. Since the strength training group reflected significant strength increases and yet did not improve significantly on standing broad jumping ability, he concluded that the treatment was not beneficial to broad jumping performance. Perhaps the strength increase was a result of the strength test-retest schedule. If this phenomenon is a result of learning as Kroll has hypothesized, then it is possible that the group did not have a statistically significant increase in strength.

Relationships Among Variables

The results of this study indicated that strength was significantly related to skill and that the reliability of repeated measures was relatively high. Forty-five of the one-hundred-eight correlations among strength measures and wall volley scores were significant. As strength increased and wall volley performance improved the number of significant relationships increased. This perhaps indicated the relative importance of strength to skill. More significant relationships might have occurred in even greater magnitudes had both groups improved in skill and strength or had the correlations been computed for the groups separately.

Twenty significant correlation coefficients between volleyball and strength were found. Sixteen existed between tennis and strength, and nine were evidenced between badminton and strength. These findings could be explained by the fact that most of the subjects were right-handed and the nondominant side would not be expected to affect a racket sport as readily as the dominate side. If this is true, then volleyball should and did have a greater number of significant relationships since both limbs are used in the execution of most skills in the sport. Perhaps strength is not as highly related to badminton as to tennis because of the lighter projectile used in badminton. The angle of contact differs also. Since the badminton racket face is tilted upward, less force is required to achieve distance (1).

The results of this study relative to relationships between wall volley scores and strength variables indicate that grip and wrist strength are related to skill. The magnitude among significant relationships ranged from .37 to .60. Hook (4) reported relationships that ranged from .22 to .67 between strength measures and total ability in baseball. The results of the two studies are relatively similar. However, Hook reported slightly higher relationships between strength measures and individual components of baseball ability which would indicate strength is related to some specific skills more than others. Lamp also found low but consistent relationships between grip strength and specific skills of volleyball.

Hinton and Rarick (3) attempted to determine the correlation between Rogers' test and the Cubberly and Cozens' Test of Basketball Achievement through the use of multiple correlations. A correlation of .55 between arm strength and basketball achievement proved to be the highest relationship between any two variables. Although direct comparisons between the present study and the one in question are inappropriate, the results relative to magnitude are similar.

The relationship between variables in test-retest situations indicates that the tests utilized in this study are of singificant magnitude to be considered reliable; therefore conclusions resulting from this study have a substantial basis.

In summary, the findings of this study revealed significant increases of the experimental group measures over the control group's performance on the final tests of both strength and wall volley skills. These measures were attributed to the strength training of the experimental group. The variables of strength and wall volley skill were significantly related.

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CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This study was designed to determine the effect that grip and wrist strength has upon performance on selected wall volley tests. Thirty college women who had previously experienced the sports of tennis, badminton, and volleyball were subjects in the investigation. Data utilized in accomplishing the objectives of this study were composed of scores derived from the administration of cable-tension strength tests, tennis, badminton, and volleyball wall volley tests.

Initial wall volley tests and strength measures were administered during the first week of testing. Criterion strength measures were administered two weeks after the initial measures. The criterion measures were recorded for the purpose of having a reliable estimate of strength. The experimental design was a two-group design in which the groups were matched on the basis of criterion wrist and grip strength. Following group placement, the experimental group was subjected to two weeks of isometric strength training of the grip and wrist flexors and extensors. At the conclusion of the treatment period, final wall volley and strength tests were administered to both groups.

Statistical treatment included the computation of means, standard deviations, $\underline{F}$ ratios for repeated measures, critical differences when appropriate, $\underline{t}$ ratios for between-group differences, and Pearson product-moment coefficients of correlation. The .05 level was used as the decision rule for rejection of the null hypothesis. These statistics were used to examine differences between the experimental and control groups, differences of each group's performance on repeated tests, and relationships among the variables.

The results revealed that the experimental group means increased significantly among the initial, criterion, and final measures of strength. The control group evidenced increases on only two measures of strength between the initial and criterion tests. As was expected, the control group did not exhibit a general increase between the criterion and final strength measures. The experimental group improved significantly on all wall volley tests between the initial and final tests while the control group improved only in badminton.

The control group and the experimental group did not differ significantly on the initial and criterion measures of strength, but the experimental group did significantly surpass the control group on all of the final strength measures except left wrist flexion. No significant differences existed between the groups on the initial wall volley measures, but the experimental group was superior on all final measures.

Forty-five of the one-hundred-eight coefficients of correlation were significant. The results indicated that skill in tennis was significantly related to grip and right wrist strength. Skill in badminton was related to grip and wrist strength. Skill in volleyball was related to right wrist strength, left wrist flexion, and grip. Based on the number of significant relationships, volleyball skill seemed to be the most highly related to grip and wrist strength of the three sports that were investigated. Badminton, although related to strength, evidenced the fewest number of significant relationships to grip and wrist of the sports involved in the study.

Conclusions

Within the limitations of this study, the results justify the following conclusions:

1. Increased strength enhances skill performance on wall volley tests of tennis, badminton, and volleyball. Since these wall volley tests were designed to evaluate game skill, it might be concluded that strength increases will enhance overall skill in tennis, badminton, and volleyball.

2. Isometric exercise results in significant strength increases.

3. Skill in tennis, badminton, and volleyball is related to grip and wrist strength.

Recommendations

As a result of this study the following recommendations are presented:

1. Students having difficulty in the sports of tennis, badminton, and volleyball should be tested to determine if grip and/or wrist strength is weak.

2. Training designed to increase grip and wrist strength should be included in the training program for females participating in the sports of tennis, badminton, and volleyball.

3. A similar study should be conducted utilizing junior and senior high school girls. Since skill has been reported to be more general during the developmental stages than in adults, strength might be more of a component of skill at this age than in adults.

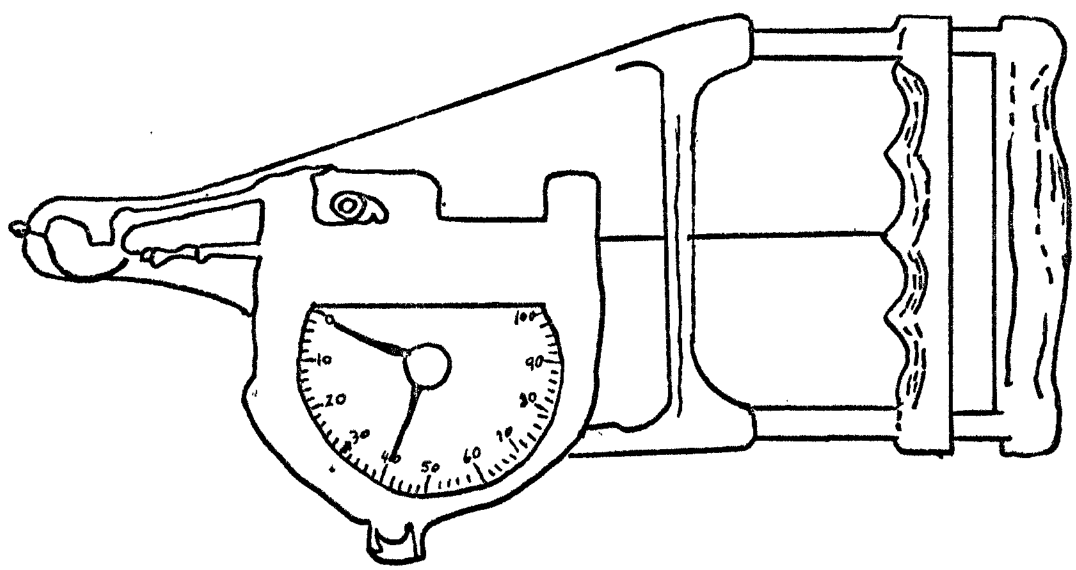
4. Since the significance of strength in the learning process of tennis, badminton, and volleyball may be less in male subjects, a similar study should be conducted utilizing male subjects.

5. Further investigation should be conducted to examine the strength element and its relationship to varying levels of skill.

6. Further investigation should be conducted to examine the strength element and its relationship to specific skills within sports.

APPENDIX A

ADJUSTABLE HAND GRIP AND TENSIOMETER



APPENDIX B

EXPERIENCE QUESTIONNAIRE

NAME________________________CLASS_____TEACHER_____________AGE___

CLASSIFICATION___________WEIGHT_________HEIGHT_____________

This questionnaire is designed to determine your present experience and skill in badminton, tennis, and volleyball.

EXPERIENCE: Where possible, indicate the degree of experience for each category. For instance, if you had a six weeks tennis unit in the 7th, 8th, and 9th grade in junior high school, you might place the numbers 7, 8, and 9 in the blank corresponding to "JUNIOR HIGH TENNIS." If you won any district or state tournaments in a sport, indicate this.

	TENNIS	BADMINTON	VOLLEYBALL
JUNIOR HIGH			
HIGH SCHOOL			
HIGH SCHOOL VARSITY			
COLLEGE			
COLLEGE VARSITY			
PRIVATE LESSONS			
PLAYGROUND			
CAMP			

APPENDIX B --Continued

SKILL LEVEL: Rank yourself according to the degree of skill you think you have achieved in each activity. Examples of each category are listed below.

HIGHLY SKILLED: You have been selected by a coach for a varsity high school or college team, or you have played in tournaments and placed in at least one.

Good: You made good grades in the activity, or you have played in tournaments but never placed.

Average: You are capable of rallying in tennis and badminton and volleying in volleyball. You know the basic skills and strategy of the activity. You are better than some people but not as good as others who have taken a course in the activity.

Unskilled: You have never played the activity nor had any lessons; or, you had a small exposure to the activity in school but you did not get to practice and therefore were unable to develop much skill in the activity.

	TENNIS	BADMINTON	VOLLEYBALL
HIGHLY SKILLED			
GOOD			
AVERAGE			
UNSKILLED			

APPENDIX C

DYER REVISION OF THE BACKBOARD TEST OF TENNIS ABILITY

Equipment

1. Stop watch
2. Wall sapce ten feet in height and fifteen feet in width
3. Box for extra balls
4. Tennis racket
5. Tennis balls
6. Score sheets and pencil

Marking

1. A restraining line fifteen feet long was taped on the floor. The line was five feet from the wall and parallel to the wall.
2. A fifteen foot long line was taped on the wall so the top edge was three feet from the floor and parallel to the floor.

Scoring

1. Three thirty second trials separated by rest periods were administered.
2. The final score for each individual was derived by summing the number of legal hits made during the three trials. A legal hit was one in which the ball was projected against

the wall on or above the wall marking while the subject was behind the restraining line.

Testing

1. The subject held two balls and stood behind the restraining line.
2. At the signal "go", the subject dropped one ball letting it bounce at least once and then projected it against the wall as many times as possible during the thirty second time limit. A box of extra balls was placed on the non-dominate side of the player adjacent to the restraining line.

APPENDIX D

MILLER'S BADMINTON WALL VOLLEY TEST

Equipment

1. Badminton racket
2. Indoor shuttlecock
3. Stop watch
4. Pencil and score sheets
5. Wall space ten feet in width and fifteen feet in height

Markings

1. A line ten feet long was taped on the wall so that the top edge was seven feet, six inches from the floor and parallel to the floor.
2. A restraining line ten feet in length was taped on the floor so that the inside edge was ten feet from the wall and parallel to the wall.

Scoring

1. Three thirty second trials separated by rest periods were administered.
2. The final score for each individual was derived by summing the three trials. A legal hit was one in which the bird was projected against the wall on or above the wall marking while the subject was behind the restraining line.

APPENDIX D --Continued

1. The subject held a shuttlecock and stood behind the restraining line.
2. At the signal "go", the player served the shuttlecock against the wall and proceeded to project the bird against the wall as many times as possible within the thirty second time period.

APPENDIX E

CLIFTON'S SINGLE HIT VOLLEY TEST FOR WOMEN'S VOLLEYBALL

Equipment

1. Stop watch
2. Rubber volleyball
3. Score sheets and pencil
4. Wall space ten feet in width and fifteen feet in height.

Markings

1. A line ten feet in length was taped on the wall so that the top edge was seven feet, six inches from the floor and parallel to the floor.
2. A restraining line ten feet in length was taped on the floor seven feet from the wall and parallel to the wall.

Scoring

1. Two thirty second trials separated by rest periods were administered.
2. The final score for each individual was derived by summing the number of legal hits attained during the two trials. A legal hit was one in which the ball was projected against the wall on or above the wall marking while the subject was standing behind the restraining line.

APPENDIX E --*Continued*

1. The subject held the volleyball and stood behind the restraining line.
2. At the signal "go", the subject tossed the ball against the wall and proceeded to volley it against the wall as many times as possible within the time limit.

APPENDIX F

CABLE-TENSION TESTS

Wrist Flexion

Starting Position

1. The subject was seated at a table in a chair with the feet resting on the floor and the free arm resting in the lap.
2. The upper arm on the tested side was adducted and extended at the shoulder to one hundred eighty degrees. The forearm was placed between the braces and strapped in so that the forearm was held in mid-prone and supine position; the elbow was held in ninety degrees flexion. The wrist was held in mid-position of range of motion of palmer and dorsal flexion.

Attachment

1. The handle was placed in the subject's hand just above the metacarpo-phalangeal joint.
2. The cable was attached to a four-by-four board that faced the dorsal side of the hand.

Trials

1. The subject exerted tension in a horizontal plane toward mid-line.
2. Three trials were recorded; on each of the trials the subject exerted tension until a maximum reading was attained. The subject rested between trials while the measure was recorded and the dial was reset.

APPENDIX F --Continued

Wrist Extension

Starting Position

1. Same as in wrist flexion
2. Same as in wrist flexion

Attachment

1. Same as in wrist flexion
2. The cable was attached to the four-by-four board that faced the palmer side of the hand.

Trials

1. The subject exerted tension in a horizontal plane away from mid-line.
2. The number of trials and rest periods was identical to those in wrist flexion.

Grip

Starting Position

1. The upper arm on the tested side was adducted and extended at the shoulder to one hundred eighty degrees. The forearm was resting on the table and in pronation; the elbow was held in ninety degrees flexion. The wrist was held in mid-range of adduction and abduction.

APPENDIX F --Continued

Attachment

1. The grip was held between the mid-phalanx of the fingers and the metacarpo-phalangeal joint of the thumb.
2. The cable was attached to the adjustable part of the grip and to the frame of the grip assembly.

Trials

1. The subject exerted tension in a horizontal plane by flexing the fingers and thumb.
2. Three trials were recorded; on each of the trials, the subject exerted tension until a maximum reading was attained. The subject rested between trials while the strength measure was recorded and the dial was reset.

APPENDIX G

ORDER OF ADMINISTRATION OF STRENGTH TESTS

I.	LWF;	LWE;	RWF;	RWE;	LG;	RG
II.	LWF;	LWE;	RWF;	RWE;	LG;	RG
III.	LWF;	LWE;	RWE;	RWF;	LG;	RG
IV.	LWF;	LWE;	RWE;	RWF;	RG;	LG
V.	LWE;	LWF;	RWF;	RWE;	LG;	RG
VI.	LWE;	LWF;	RWF;	RWE;	RG;	LG
VII.	LWE;	LWF;	RWE;	RWF;	LG;	RG
VIII.	LWE;	LWF;	RWE;	RWF;	RG;	LG
IX.	RWF;	RWE;	LWF;	LWE;	LG;	RG
X.	RWF;	RWE;	LWF;	LWE;	RG;	LG
XI.	RWF;	RWE;	LWE;	LWF;	LG;	RG
XII.	RWF;	RWE;	LWE;	LWF;	RG;	LG
XIII.	RWE;	RWF;	LWF;	LWE;	LG;	RG
XIV.	RWE;	RWF;	LWF;	LWE;	RG;	LG
XV.	RWE;	RWF;	LWE;	LEF;	LG;	RG
XVI.	RWE;	RWF;	LWE;	LWF;	RG;	LG
XVII.	LG;	RG;	LWF;	LWE;	RWF;	RWE
XVIII.	LG;	RG;	LWF;	LWE;	RWE;	RWF
XIX.	LG;	RG;	LWE;	LWF;	RWF;	RWE
XX.	LG;	RG;	LWE;	LWF;	RWE;	RWF
XXI.	RG;	LG;	LWF;	LWE;	RWF;	RWE
XXII.	RG;	LG;	LWF;	LWE;	RWE;	RWF
XXIII.	RG;	LG;	LWE;	LWF;	RWF;	RWE
XXIV.	RG;	LG;	LWE;	LWF;	RWE;	RWF

LWF = Left wrist flexion
LWE = Left wrist extension
RWF = Right wrist flexion
RWE = Right wrist extension
LG = Left grip
RG = Right grip

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