AN ELECTROMYOGRAPHIC-CINEMATOGRAPHIC ANALYSIS OF THE TENNIS SERVE

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Chapter I

INTRODUCTION TO THE STUDY

The purpose of this study was to investigate and define the action potential of selected muscles in performing the three basic types of tennis serves. The muscles investigated were the triceps, anterior deltoid, middle deltoid, and posterior deltoid when executing the flat, slice, and twist serves.

Tennis coaches have not determined to what extent the predominant muscles are active in the performance of the tennis serve or how the prime movers react when executing the three basic types of tennis serves. This lack of information motivated this special study.

Tennis teachers (Kenfield, 1963; Pearce and Pearce, 1971; Stow, 1963) are in agreement that the tennis serve is the most complex and difficult stroke to master. The literature (Brent, 1974; Kenfield, 1963; Lumiere, 1964; Murphy and Murphy, 1962; Stow, 1963) suggests that there are three basic variations of the tennis serve: the flat, slice, and twist. Each serve requires different body movements which create different effects on the flight of the ball.

Specialists in the area of tennis (Barnaby, 1963; Lufler, 1964; Murphy, 1968; Sebolt, 1970) accept the concept of serving variability; however, research in this area has been greatly neglected. Numerous investigations (Broer and Houtz, 1967; Gould, 1965; Owens and Lee, 1968; Plagenhoef, 1971) select the tennis serve as an experimental variable and then neglect to control for the type of serving motion. The lack of proper controls promotes inferior scientific investigations.

Research by Broer and Houtz (1967), in the area of tennis, acknowledges the fact that specific muscles are needed to produce an efficient tennis serve. The literature (Basmajean, 1957; Scott, 1963; Thompson, 1969) does indicate that the serve is performed by three distinct movement patterns; however, it fails to acknowledge that each of these movement patterns may require the use of muscles to different degrees.

Scientific techniques such as electromyography and cinematography are now being used to determine muscular efficiency as utilized in specific movement patterns. Electromyography, as defined by Broer and Houtz (1967), is a technique which picks up, amplifies, and records minute electrical activity in a muscle. Bierman and Yamshon (1948) stated that electromyographic techniques make possible a more quantitative and accurate evaluation of muscular action potential than any method previously used. Electromyography will determine the degree of muscle involvement of selected muscles throughout the range of motion. Cinematography or high speed photography makes possible the analysis of complex body movements which normally occur so rapidly that without this sophisticated technique, detailed analysis is impossible (Kitzman, 1964). By synchronization of electromyography and cinematography, the researcher is able to precisely analyze human movements. The electromyograms gathered through the range of motion can be exactly matched frame by frame with the photography to determine the muscle involvement at each position of the service stroke.

DELIMITATIONS OF THE STUDY

The following delimitations were placed upon the investigation:

1. The study was limited to ten college male varsity tennis players.

2. The study was limited to the three basic types of serves.

3. The study was limited to the investigation of muscles in the upper arm and shoulder, specifically, the anterior deltoid, middle deltoid, posterior deltoid, and triceps.

LIMITATIONS OF THE STUDY

The limitations of the study were:

1. The control of certain variables which may have affected the subjects' performance such as diet, fatigue, sleep, and emotional state.

2. The small number of subjects used in the investigation.

BASIC ASSUMPTIONS OF THE STUDY

1. The instrumentation used to measure muscle action potential was a valid measure of muscular involvement.

2. Cinematographical analysis would measure the different stroke patterns and ball velocity.

3. The proper ball toss for each of the three types of serve was performed.

DEFINITION OF TERMS

1. Flat serve - a basic type of serve in which the ball has very little spin, and the racket meets the ball in a verticle position. (Appendix A, illustration 1 for the correct position of ball toss)

2. Motor point - the exact location where the motor nerve enters the muscle.

3. Muscle action potential - electrical current exhibited by an active muscle.

4. Slice - a basic type of serve that causes the axis of ball rotation to be mostly vertical; the racket face is beveled slightly to aid in imparting spin on the ball. (Appendix A, illustration 2 for the correct position of the ball toss)

5. Twist - a basic type of serve in which the racket travels upward and outward (from the eight o'clock position to the two o'clock position) as contact with the ball is made. (Appendix A, illustration 3 for the correct position of the ball toss)

NEED FOR THE STUDY

Tennis skill tests are designed to measure a participant's ability. One segment of most skill tests (DiGennaro, 1969; Glassow and Broer, 1938) reviewed was the serve; however, the type of serve was not defined.

The scientific literature (Campbell, 1974; Holcomb, 1962; Sebolt, 1970) reviewed revealed several studies which used the tennis serve as an experimental variable; however, none of these investigations recognized the serve as being either a flat serve, slice serve, or twist serve. This indicates a possible lack of proper control when the tennis serve is used as an experimental variable. If a difference in muscle action potential is found, then specific serving patterns should be defined in research to ensure quality investigations.

Proper execution and refining of complex motor skills can be a monumental task. By following sophisticated training programs specifically designed for the exact movements, the execution of the motor skill should improve. Through the analysis of muscular involvement within the range of motion when hitting the three basic serves, precise training programs can be designed and followed to increase efficiency of movement. Because of specific serving patterns, each basic serving motion may require a unique training program.

Chapter II

REVIEW OF THE LITERATURE

The following review of literature is grouped in four areas: (1) General Aspects of the Tennis Serve, (2) Lack of Proper Controls When the Tennis Serve Is Used as an Experimental Variable, (3) Cinematography and Electromyography as Means of Research Instrumentation and (4) The Synchronization of Cinematography and Electromyography as a Research Instrument Model for Precise Motor Analysis.

GENERAL ASPECTS OF THE TENNIS SERVE

Brent (1974) and other researchers (Lumiere, 1964; Official Encyclopedia of Tennis, 1972; Pearce and Pearce, 1971; Stow, 1963) state that of all strokes in tennis, the serve is considered the most important. Kenfield (1963) considers the serve the hardest to teach and the most difficult to master due to its complexity. Stow (1963) and numerous authorities (Mace, 1952; Murphy, 1971; Official Encyclopedia of Tennis, 1972; Sebolt, 1970) agree that an effective serve enhances the player's chance to score. Sebolt (1970) states that an effective serve possesses the qualities of pace, spin, and placement. The serve is the only stroke in tennis which the player has complete control over the ball as well as the only shot made that the ability of the opponent does not affect. Each point begins with a serve, thus an effective service can score a point outright or enhance the server's percentage of winning the point (Brent, 1974). The importance of an effective serve is illustrated by considering that a player who scores most of his service games will seldom lose the match.

The three basic variations of the tennis serve are the flat serve, slice serve, and twist serve (Brent, 1974; Kenfield, 1963; Lumiere, 1964; Murphy, 1971; Stolle, 1967). The variations in the three serves are created by (a) the angle of the racket when contact is made with the ball, (b) the position of contact in relation to the server's body, and (c) the force and follow-through of the racket(Brent, 1974; Kenfield, 1963; Lumiere, 1964; Murphy, 1971; Stolle, 1967).

The flat serve has very little, if any, spin placed on the ball due to the position of the racket on the ball. The racket meets the ball squarely with the racket shaft in a verticle position creating a straight-line extension of the racket arm (Brent, 1974; Official Encyclopedia of Tennis, 1972; Pearce and Pearce, 1971). The flat service follow-through should follow the line of the ball's flight with the racket finishing to the left of the body (Stolle, 1967; Stow, 1963).

The ball toss for the flat serve is slightly farther to the right than the twist serve but not as far as the slice serve (Official Encyclopedia of Tennis, 1972; Stow, 1963). The ball should be well in front of the body in line with the right shoulder (King, 1970; Van DerMeer, 1965).

The slice serve axis of ball rotation is mostly vertical. It has very little upward thrust and a great deal of side spin (Official Encyclopedia of Tennis, 1972; Stolle, 1967; Van DerMeer, 1974). The racket face is beveled slightly to aid in imparting the side spin which adds control (McCloy, 1946; Sebolt, 1970). The racket will pass over the upper right hand surface of the ball as the racket moves right to left finishing in a position across the body on the left side (Brent, 1974; Sebolt, 1970).

The ball is tossed well to the right with the racket position being perpendicular to the court. The arm position is much closer to being horizontal than in either of the two other serves (Brent, 1974; Official Encyclopedia of Tennis, 1972; Sebolt, 1970).

The twist is executed by bringing the racket face across the ball from left to right (Brent, 1974; King, 1970; Stolle, 1967; Stow, 1963; Van DerMeer, 1965). The racket must contact the ball at the eight o'clock position and travel upward and outward toward the two o'clock position (Brent, 1974). The ball is tossed over the server's head slightly behind him toward the left (Brent, 1974; Murphy and Murphy, 1962; Van DerMeer, 1965).

Conflict exists in the literature relative to the follow-through of the twist serve. Brent (1974), Lumiere (1964), and Chaplean (1964) agree that the follow-through on the twist serve finishes to the outside of the body on the right side, and the right arm follows through past the right leg for a right-handed server. Several tennis scholars (Official Encyclopedia of Tennis, 1972; Sebolt, 1970) concur that the follow-through continues forward and down across the body ending on the left side of the server. Murphy and Murphy (1958) state that the follow-through usually finishes behind a player's right knee, but many bring the racket toward the center of their body. They attribute this either to force of habit or from a desire to advance to the net quickly. Sebolt (1970) includes a pictorial sequence of the twist service from the ready position to the completed follow-through confirming the follow-through to be completed on the left side of the body.

Murphy (1971), Van DerMeer (1974), and others (Brent, 1974; Pearce and Pearce, 1971) recommend the continental grip for serving. This grip creates more wrist movement, thus creating greater spin on the ball.

LACK OF PROPER CONTROLS

Scott (1963) gives a detailed written description of the tennis serve categorizing it by a general serve description, muscular analysis, and mechanical analysis. The serve described is specified as being the type that is relatively simple and basic in style. No further analysis of the specific serving pattern is presented.

An electromyographic study conducted by Broer and Houtz (1967) made analysis of overhand patterns, specifically, the overhand throw, badminton clear, and the tennis serve. The tennis serve information in this study made no reference concerning pattern or type of service stroke under consideration; however, the cinematographical analysis included with the study appears to be the flat serve.

Cooper and Glassow (1963) discuss the serving motion as a movement pattern. They state it is an overarm type movement and then proceed to kinesiologically describe the basic movement pattern. The specific serve discussed by the authors was not determined, nor was the mention of the existence of the various serving patterns.

A motion analysis investigation was conducted by Plagenholf (1971) which considered the tennis serve as performed by Rod Laver and

Ken Rosewall. The investigation was primarily concerned with information relevant to the optimum serving pattern. The study did not mention the type of serve pattern used for the investigation. It was concluded that the results would probably indicate that Laver's timed sequence of body segments is close to perfection.

In determining the velocities and angles of projection for the tennis serve, Owens and Lee (1964) did not consider spin imparted to the ball when serving. Since this element was not considered, the type of serve was not established in this investigation.

Johnson's (1957) analytical study of the tennis serve of advanced women players considered the slice serve. The specific purpose of the study was divided in the following ways: (1) to determine the relationship between speed and accuracy of the slice serve; (2) to analyze and compare the serving movements of these players; (3) to compare the serves, measured in terms of speed and accuracy, with the movements used in serving; and (4) to propose a practice serving target for advanced women players. It was concluded that there was no relationship between the speed and accuracy of the slice serves hit by these advanced women tennis players. Apparently, speed and accuracy are independent factors. In general, the fundamental gross movements used in serving were similar in all subjects. However, greater consistency was noted among the serves of one individual (than between individuals).

DiGennaro (1969) designed tests to measure a student's achievement level in the performance of the tennis forehand drive, backhand drive, and serve. In performing the service test, the tester hands the ball to the subject who has assumed his service stance at marked service position. The subject should attempt to execute a legal overhead serve, aiming to place the ball as close as possible to the circular center of the service target. A restraining rope should be placed at a height of three feet above the top of the net. The test design makes no mention of the specific type of serve being tested.

Glassow and Broer (1938) outline tennis skill serving tests designed by Hartley, Anderson, Beal, and others. The tests vary in procedure and number of service attempts. Each good serve, defined as a service attempt which lands in the proper service court, in all of the tests, is scored as one point. The Driver Tennis Serve Test is the only skill test mentioned by the authors which attempted to place importance on velocity as well as accuracy. Driver's test procedure for the serve includes a wire ten feet from the floor. In order for a serve to be scored good, the ball must go over the net and under the wire and fall in the service court. None of the above tests made any statement concerning the specific tennis serve being evaluated except Hartley. Hartley's test is divided into elementary, intermediate, and advanced categories. The elementary level required the server to perform the correct service swing. No explanation was discussed concerning the type serve or service swing pattern. The intermediate level considered only good trials, and the advanced participants were required to use the cut serve (slice) getting height and placement in five of ten trials.

Sebolt (1970), in investigating the relationship of ball velocity and tennis playing ability of college men, devised a maximum velocity test to measure the velocity of a tennis ball as it is served with maximum force. The type of serve performed for this test was not stated.

CINEMATOGRAPHY AND ELECTROMYOGRAPHY AS MEANS OF RESEARCH INSTRUMENTATION

Due to the complex body movements and speed required in performing the various tennis serves, the skill readily lends itself to motion analysis. Analysis of motion may be conducted by the employment of cinematography and/or electromyography.

Numerous sources (Anderson, 1970; Campbell, 1974; Hinson, 1969; Hobart, 1967; O'Connell and Gardner, 1963) confirm the acceptability and reliability of these methods of motion analysis. Studies conducted (Garrison, 1963; Hobart, 1972; Kitzman, 1964; Mahler, 1971) synchronizing the two procedures of electromyography and cinematography further emphasize the validity of this analysis procedure.

Cinematography is the process of photographing human movements for the purpose of recording the events associated with muscular action. Cinematography enables the researcher to make careful analysis of events that occur so rapidly that careful analysis is impossible by observation alone (Kitzman, 1964).

The following are selected studies of physical activity which have employed cinematography as a means of movement analysis. A cinematographic analysis of accuracy in the tennis forehand drive was conducted by Blievernicht (1966); no electromyographic analyses were made in this study. The problem was designed to determine the method or methods used by two highly skilled subjects to direct the ball to the right and to the left sides of the court. A 16mm Kodak Cine Special

Movie Camera was used for the study. The overhead views of twenty-five trials were examined on a Recordak film analyzer. Twelve measurements were analyzed from the overhead trials. Blievernicht (1966) concluded that racket angle, position of the ball in relation to the body, and the left foot direction were factors in obtaining accuracy. The wrist angle or range of angles were not associated with a drive direction. All joint actions involved in the tennis forehand pattern of movement seemed to aid in compensatory movement to move the racket to the desired angle and position in space.

A study of two techniques of performing a standing front dive was conducted by Jones (1970) through the use of cinematography. The purpose was to determine the effects of eliminating the vertical arm lift upon the diving mechanics of a standing front dive in an open pike position. Analysis of data indicated that the elimination of the vertical arm thrust did not markedly affect the primary variables of the standing front dive in an open pike position.

Campbell (1974) conducted a study to determine the world's fastest server. Through the use of high speed photography and a grid with one foot interval marks, distance and time were established including the speed of each legal serve. The frames evaluated began with ball contact and the next succeeding frames. The eight subjects selected for the study were considered by their fellow players to be the fastest servers. Colin Dibley, an Australian professional tennis player, was determined to possess the world's fastest serve with a calculated speed of 148 miles per hour.

The science of electromyography has evolved during the last fifty years. The basic purpose of electromyography is to record electrical changes which occur in specific muscles prior to and during muscular contraction. Electromyogram readings register the specific muscle action potential or the electrical current exhibited by an active muscle through the range of motion (Bearn, 1961).

The two main types of electrodes used for the study of muscle dynamics are surface (or "skin") electrodes and inserted (wire and needle) electrodes (Bearn, 1961). Surface electrodes are generally used in research problems outside the field of medicine because of their convenience, easy application with little training, little discomfort to the subject, and reduced anxiety in the subject over needle electrodes. When surface electrodes are used, proper technique in applying the electrodes is extremely important in order to reduce electrical interference or artifact. Broer and Houtz (1967) employed surface electrodes in their electromyographic study of patterns of muscular activity. Gollnick and Karpovich (1964) confirmed the use of surface electrodes for investigating locomotion and some athletic movements.

Slaughter's (1959) electromyographic study of arm movements details skin preparation and electrode placement for surface electrodes. The muscles studied were the long head of the biceps brachii, the short head of the biceps brachii, long head of the biceps brachii, and the pronator teres. Bierman and Yamshon (1948) used surface electrodes with an electroencephalograph machine and an ink recorder in studying muscle action potential of the biceps and brachii and found the surface electrodes to be satisfactory.

Walters and Partridge (1957), and Hinson (1969) used the same technique as Bierman and Yamshon (1948) and agreed that it was a satisfactory method. O'Connell and Gardner (1963) discussed using surface electrodes, also including a detailed preparation of the subject, size, and choice of electrodes and information related to electromyographs' interpretation.

The most common means of reading electromyographic data is the cathode ray tube or the ink writing recorder. Numerous researchers (Bierman and Yamshon, 1948; O'Connell and Gardner, 1963; Walters and Partridge, 1957) have used electroencephalographs with success. Basmajean (1957), in extensive studies, used this procedure and showed it to be a valid and reliable method to conduct research.

Employing a small number of subjects has been accepted in electromyographic research due to the repeated measures taken on the subjects at the research site. Several electromyographic studies (Broer and Houtz, 1967; McCloy, 1946) have used only one subject with numerous other investigators (Garrison, 1963; Gollnick, 1964; Kitzman, 1964; Slater-Hammel, 1948, 1949) employing between four and seven.

Electromyographic records have been evaluated both quantitatively and qualitatively. Both methods of evaluation have proven beneficial; however, the most efficient method depends upon the research being conducted.

Basmajean (1957) states that most electromyographic records must be considered by both criteria. Employing both quantitative and qualitative evaluation imposes a discipline more sophisticated than quantitative results alone; also, it is more reliable.

The assigning of scales to electromyographic records for purposes of evaluation has proved extremely practical. Arbitrary units or levels, such as nil, negligible, slight, moderate, marked, and very marked, have been accepted. Bearn (1961) and others (Flint and Gudgell, 1965; Hinson, 1969; Kitzman, 1964) have designed similar scales in evaluating EMG data.

Two of the initial EMG studies concerning athletic performances were conducted by Slater-Hammel. The first investigation was conducted in 1948 and studied contraction movement relationship in the golf stroke. Four male subjects who were considered good performers were used for the study. The relation between muscular contraction and movement pattern was found to vary greatly from the traditional kinesiological analysis. Slater-Hammel's ensuing study (1949) again employed an EMG contraction movement study, but this study involved the tennis forehand stroke. Five good tennis players were used as subjects in the study. The subjects were instructed to hit a regulation tennis ball suspended on an elastic cord approximately four feet from the floor. Of the eight musculatures investigated, five were reported to contract between forward movements of the arm and ball contact. The pectoralis major and anterior deltoid contracted on all five subjects, and the latissimus dorsi contracted on four of the five subjects.

Several electromyographic studies have been conducted investigating abdominal muscles during exercise or specifically the sit-up.

Electromyographic records were obtained on the upper and lower segments of the right abdominis and the right external oblique muscles while performing seventeen exercises. The purpose of this study by Flint and Gudgell (1965) was to analyze some of the more popular and traditional exercises used for strengthening abdominal muscles and to determine the ones which generate the greatest action potentials from the abdominal muscles. Walters and Partridge (1957) reported that minimizing the action of the hip flexors caused more effort for the abdominal muscles when performing the sit-up exercise.

In Hinson's (1969) study of four types of push-ups in exercise for women, the muscles monitored and evaluated were the triceps brachii, anterior deltoid, pectoralis major, trapezius, serratus anterior, rectus abdominis, and external oblique. It was concluded that more muscular activity did occur in one method over the others; also, that the low strength subjects had a greater level of muscular involvement than did the high strength subjects.

Broer and Houtz (1967) analyzed patterns of muscular activity in selected skills to determine if patterns of movement were common to various complex sport skills and to analyze the selected muscles during performance of a highly skilled female subject. The investigation concluded: (1) there did not appear to be basic muscular activity patterns, (2) not any movement initiates centrally and proceeds peripherally, (3) in single arm activities, the contralateral limb warrants closer attention when attempting to correct faulty techniques, (4) the performing portion of the body is only as efficient as the stabilizing or positioning of the contra-lateral segment, (5) in a complex or coordinated movement, the agonist's action does not appear to relax the so-called antagonist muscle, and (6) where weight is transferred from one leg to another during a forceful activity, it appears that the body is pushed from one leg to the other.

An electromyographic study was conducted by Slaughter (1959) involving arm movements. In reviewing the electromyograms of the four subjects, the patterns appeared to be quite similar; however, the magnitude of the electromyograms showed considerable variation among the subjects. Slaughter concluded both heads of the biceps brachii aid the movements that require arm extension and arm flexion.

Bierman and Yamshon (1948) investigated muscle action potential of the deltoid and reported that all three parts of the muscle act in forward flexion, abduction, and hyper-extension of the arm. The researchers concluded that the anterior portion acts in inward rotation and the posterior portion in outward rotation. The anterior portion acts as it is moved backward in abduction, and the middle portion acts during all abduction.

In studying some of the muscles acting on the upper extremity of man, Scheving and Pauly (1959) agreed that the three parts of the deltoids are active in all movements of the arm. Inman, Saunders, and Abbott (1944) in their research on the shoulder joint, suggested the pectoralis major to be active during flexion and adduction of the humerus. Scheving and Pauly concurred with Inman, Saunders, and Abbott by reporting that during flexion the greatest potentials were recorded in the pectoralis major with strength response and frequency increasing as resistance was applied.

Bearn's (1961) investigation of the trapezius, deltoid, pectoralis major, biceps, and triceps muscles during static loading of the upper limb, indicated little activity in the trapezius and deltoid until the subjects were instructed to elevate the shoulder with minimal effort. The shoulder shrug produced a burst of activity in the trapezius as well as all parts of the deltoid. The other muscles monitored were electromyographically silent with arms hanging loosely to the side.

Numerous arm and shoulder muscles were monitored by Kamon (1966) in his investigation of static and dynamic postures of the body supported on the arms. The most active muscles were reported to be the anterior deltoid and the depressors, triceps brachii, pectoralis major, latissimus dorsi, and trapezius.

Yamshon and Bierman (1943) investigated the biceps brachii for different actions of the long and short heads. It was concluded that the amount of action potential was dependent upon the position of the body, speed of the motion, and the degree of resistance. One muscle may initiate the movement, while another completes it, and the motion of the arm at the shoulder joint shows evidence of electrical potentials in the biceps brachii.

In the work of Basmajean and Latif (1957) on the flexors of the elbow, they reported the long and short heads of the biceps similar in action but not identical. The long head appeared to be more active during movement. The biceps were also instrumental in flexion of the shoulder joint.

McCloy (1946) studied the triceps brachii (lateral and long heads) and the pectoralis major (clavicular and sternal heads). The subject held a fifteen pound dumbbell in his hand and bent his trunk about forty-five degrees and raised his arm backward and laterally. The lateral head of the triceps brachii recorded strong contractions, and the long head of the triceps brachii recorded less strong action potentials than the lateral head. The subject then, from the same starting position, raised his arm backward and medialward; the lateral head of the triceps brachii recorded negligible action potentials, and the long head recorded strong contractions. The third evaluation showed the subject, from the starting position, with raised arm lateralward to the horizontal; the clavicular head of the pectoralis major recorded fairly strong action potentials, and the sternal head of the pectoralis major recorded negligible action potentials.

THE SYNCHRONIZATION OF CINEMATOGRAPHY AND ELECTROMYOGRAPHY AS A RESEARCH INSTRUMENT MODEL FOR PRECISE MOTOR ANALYSIS

A study of the baseball batting swing was conducted by Kitzman (1964) using electromyography synchronized with cinematography to obtain a record of the movement patterns. Two highly skilled and two unskilled subjects were used in the study. The system used an electrical circuit containing a switch mounted on the electromyograph; a light placed on the wall behind the performer was used in conjunction with photographs taken with a Maurec Studio camera. The camera speed was 24 frames per second with exposure duration per frame at 1/192 seconds. The light switch was mechanically connected to the ink writing recorder causing the pen to deviate from a straight line when the light behind the subject was activated. The point at which the light came on was recorded on the film to be synchronized with the electromyograph recording, for both the film and the recording paper moved at a specific rate. This enabled the muscle recordings to be studied in relation to the movement patterns. It was concluded that by strengthening the left tricep brachii muscle (long heads) that right handed baseball batters could increase the force that they could transfer to the bat.

In Hobart's (1972) study, cinematographical and electromyographical analyses were used in the modifications occurring during the acquisition of a novel throwing task. By using synchronized cinematography and integrated electromyography, it was concluded that practice brought about specific and measureable modifications in the electrical activity of the muscles. The changes in electrical activity of the muscles while performing the skill directly resulted in the improvements in performance.

In studying the abdominal muscular activity during exercise, Flint and Gudgell (1965) monitored the rectus abdominis and external oblique muscles of ten women subjects during the performance of an exercise series, while simultaneously photographing the physical activity through cinematography. All records were taken at a camera speed of 12 frames per second and at sweep speeds of 2.3 and 3 milli-seconds per centimeter. The recordings were analyzed on a 16mm Kodascope Analyst projector modified for stop and interval reading. It was reported that the exercises most effective in strengthening the muscles under investigation were the v-sit, basket hand, side-lying trunk raise, backward trunk lean and curl-ups. The exercises least effective in the exercise program were the full-waist circling, vertical reach, controlled leg extension, and hip roll.

Through the use of electromyography and cinematography, Garrison (1963) analyzed the golf swing of four good golfers. Three of the four subjects revealed a decrease in muscle action potential prior to ball contact.

Herman (1962) also employed cinematography in an electromyographic study of selected muscles involved in the shot put. Six subjects were used in the study; two poor, two average, and two highly skilled subjects were compared by evaluating muscle action potentials in the upper pectoralis major, deltoid, teres major, and triceps brachii. Two of the three purposes of the study required the use of cinematography. Cinematographic analysis was used to compare findings from the electromyographic analysis with findings from a mechanical analysis of the execution of the shot put and to compare the muscle actions and movement patterns of shot put patterns differing in skill. A Cine-Special camera equipped with a 15mm wide angle lens was used to record the movements of each performer. Shutter speed was 1/4 the normal time resulting in exposure at 1/208 seconds.

It appeared from the investigation that the pattern of acceleration resulting in the greatest final velocity occurred by the shot putter's release that appeared to be a gradual increase in acceleration during the movements across the circle, with a large increase in acceleration during the final shoulder and arm thrust. Herman also reported that the muscles contributing the greatest force to a maximum effort in the movement evaluated appeared to be the upper pectoralis major, the triceps brachii, and the deltoids.

Anderson's (1970) study of ballistic movement in the tennis forehand drive used electromyographic and cinematographic analysis. A 16mm Bell and Howell Model 70-G movie camera was used to film each stroke. The camera was mounted 12 feet 3 inches directly overhead. The camera speed was 128 frames per second. Anderson concluded that there is consistency of muscle activity in average and highly skilled subjects indicating a well developed stroke pattern; between subjects and skill levels, there is great variation in muscle activity. Ballistic movement, as defined in the study, does not appear in the tennis forehand. There did not appear to be a direct relationship between increased velocity and greater decrease in muscular activity. Slope of the line of decrease in muscle action potentials provided a quantitative measure for the evaluation of electromyograms, and the use of a telemetry system provides an efficient and practical method for physical educative researchers to evaluate muscle action potentials during performance of skills.

SUMMARY OF RELATED LITERATURE

The review of literature presented in this chapter revealed the following:

General Aspects of the Tennis Serve

1. The tennis service stroke was established by authorities as an integral portion of an effective tennis game.

2. There were three basic types of serves recognized by tennis authorities: a) flat, b) slice, c) twist.

3. Scientific evidence concerning the basic types of serves was limited. Variations of serves have been confirmed through several pictorial sequences and written descriptions of observation analyses. Numerous electromyographic studies have been conducted which relate to physical activity, but none was found that related to the specific types of tennis serves.

Lack of Proper Controls When the Tennis Serve Is Used As an Experimental Variable

1. Investigations of the tennis serve in reviewed studies do not consider the basic variations of serve patterns.

2. No studies were found that investigated all three basic types of serves as experimental variables.

3. Several tennis skill tests reviewed considered speed and accuracy as test factors, but no attempt to identify specific service patterns was made.

Cinematography and Electromyography as Means of Research Instrumentation

1. Cinematography enables the investigator to carefully analyze movements which occur so rapidly that analysis by observation alone is impossible.

2. Regardless of the method of electromyography employed, it has been accepted as a valid means of measuring muscle action potential.

The Synchronization of Cinematography and Electromyography as a Research Instrument Model for Precise Motor Analysis

1. Electromyography synchronized with cinematography enables the researcher to evaluate muscle recordings in relation to physical activity movement patterns.

2. Without the synchronization of electromyography and cinematography, the precise evaluation of physical activity movements could not be as accurately conducted.

Chapter III

METHODS AND PROCEDURES

STATEMENT OF THE PROBLEM

As stated in Chapter I, the extent to which predominant muscles are active in the performance of the tennis serve or how the prime movers react when executing the three basic types of tennis serves have not been determined. The specific serving patterns under consideration were those used when executing the flat, slice, and twist serves.

SELECTION OF SUBJECTS

The subjects selected for this investigation were ten male varsity tennis players who participated in varsity competition during the 1977 college tennis season.

In order to be selected for the study, the subjects met the following criteria:

1. Subject must have been a college male varsity tennis player during the current season.

2. Subject must have possessed the knowledge to pass a written test on the basic types of serves. (Appendix B, illustration 4)

3. Subject must have demonstrated the physical ability to execute the three basic types of serves.

DELINEATION OF PARAMETERS

The specific muscles to be studied for each subject, when executing the three basic types of serves, were the anterior deltoid, middle deltoid, posterior deltoid, and triceps. The literature search (Basmajean, 1967; Broer and Houtz, 1967; Scott, 1963; Thompson, 1969) and the pilot study (Appendix B, Table 1) indicated these muscles to be most dominant in electromyographic investigations of the shoulder and upper arm in the execution of overarm movements, specifically, the tennis serve (Appendix B, Table 2 presents a muscle rankings distribution showing the most often cited muscles used in a serving motion pattern).

Respected tennis teachers (Brent, 1974; Murphy, 1971; Pearce and Pearce, 1971; Van DerMeer, 1965) recommend the continental grip for serving. The subjects selected for this investigation used the continental grip in executing the three basic types of serves.

MEASUREMENT TECHNIQUES

Electromyography synchronized with cinematography was used to measure the selected muscle involvement in the performance of the three basic tennis serves. Integrated electromyography was used to determine the amount of muscle involvement of each of the selected muscles. Cinematography was used for serving pattern and velocity analysis.

STATISTICAL ANALYSIS

The investigation evaluated the following major hypotheses:

1. There are no significant differences in muscle action potential in the anterior deltoid muscle when executing the three types of serves.

2. There are no significant differences in muscle action potential in the middle deltoid muscle when executing the three types of serves.

3. There are no significant differences in muscle action potential in the posterior deltoid muscle when executing the three types of serves.

4. There are no significant differences in muscle action potential in the triceps muscle when executing the three types of serves.

The statistical procedure used for testing of the statistical hypothesis was analysis of covariance (ANCOVA). The statistical design used in the analysis was a two factor analysis of variance in the presence of one covariate. The two factors used in the analysis of variance were the muscle type, the type of serve, and the covariate of racket speed. In probing the nature of the differences between treatment means following a significant F ratio, the Duncan Multilpe Range post hoc test was employed. In all instances, the .05 level was accepted for significance.

EQUIPMENT USED AND PROCEDURES OF INVESTIGATION

Electromyography

The electromyographic recordings were made on a three channel Honeywell Oscillograph Visicorder Model 1858 graphic data acquisition system which monitored two muscles simultaneously. Surface electrodes were used to obtain action potentials which were recorded on Honeywell visicorder recording paper.

Process and Placement of Electrodes

The skin was cleansed and a mild erythema produced by rubbing the selected muscle site with electrode paste. The discs were filled with the electrode paste and sealed in place with aeroplast and adhesive tape.

To avoid excessive stress on the electrodes during activity, the lead wires were looped and taped to the skin a few inches from the electrodes allowing for freedom of movement. The lead wires from the electrodes to the pre-amplifier box were isolated to further ensure freedom of movement.

Procedures outlined by Quiring (1967) and an Eigen A-Alpha Nerve Stimulator were used to locate the motor points of the specific muscles. The Eigen A-Alpha Nerve Stimulator precisely located the motor points to allow the investigator maximum precision on site locations. All recordings were made with a paper speed of one inch per second. EMG channel settings for data collection remained consistent for all subjects.

Cinematography

A Bell and Howell Model 70 DL 16mm movie camera was used to film each trial executed by the subjects. Camera speed was 64 frames per second with a shutter speed of 1/200 of a second. A ten millimeter ultra-circle angle lens was used. The type film was 7277 4-X Reversal ASA 400 Day-320 tungsten. The camera was placed on a tripod 26 feet to the side of the subject. The camera and electromyographic recorder were synchronized by means of an electrical circuit (with a light in the field of vision) to ensure precise analysis. (Appendix B, illustration 5)

A Vanguard Motion Analyzer (model number 11182, property of the University of North Carolina, Chapel Hill, Division of Physical Therapy) was used to analyze each serve frame to frame. This process allowed for verification of service type and the measurement of racket velocity. (Appendix B, illustration 6)

Selection and Testing Procedures

The events prior to and continuing throughout the study were standardized for the subjects involved. The following outline details the selection and testing procedures employed during the investigation:

1. Each subject was verified as a varsity participant during the 1977 tennis season. The verification was made by either checking the team roster or confirmation with the subject's coach.

2. Each subject was instructed to submit a personal information sheet and complete a written test prior to the testing session. Upon successful completion of the written test, a time was scheduled for testing.

3. Prior to each of the three testing sessions all equipment was checked to assure proper functioning and synchronization. Additional equipment included a tennis net, tennis balls, a distance grid, supplemental lighting, and a set of tennis court boundaries. All equipment was in place and functioning forty-five minutes to one hour prior to each testing session. Each of the subjects was evaluated in one of the testing sessions.

4. Prior to the subject's participation in the study, he was instructed to demonstrate each of the three types of serves under investigation. These were to be done during the five minute warm up period.

5. Each approved subject was then prepared for testing of the anterior deltoid and posterior deltoid by the procedures discussed under the section, Process and Placement of Electrodes (p. 28). Stan-

dardized instructions (Appendix B, illustration 7) were read to each subject after the initial preparations had been made.

6. Each subject was instructed to execute six twist, six slice, and six flat serves while the anterior deltoid muscle and posterior deltoid muscle were being monitored. (Appendix B, illustration 8 indicates the type of serve and the muscle being monitored for each subject.) Prior to the execution of each serve, the subject was instructed as to the type of serve desired and given the initial command to begin the serve.

7. Upon completion of the first testing series, the subject was prepared for testing evaluation of the middle deltoid muscle and triceps muscle by the procedure discussed in the section, Process and Placement of Electrodes. The subject was then instructed to perform several serves to determine the proper operation of all equipment.

8. Each subject was instructed to execute six twist, six slice, and six flat serves while the middle deltoid muscle and the triceps muscle were being monitored. (Appendix B, illustration 8 indicates the type of serve and the muscle being monitored for each subject.) Prior to the execution of each serve, the subject was instructed as to the type of serve desired and given the initial command to begin the serve.

Chapter IV

ANALYSIS OF DATA

The purpose of this study was to investigate and define the action potential of selected muscles in performing the three basic types of tennis serves. The muscles investigated were the triceps, anterior deltoid, middle deltoid, and posterior deltoid when executing the flat, slice, and twist serves.

The ten subjects used in this investigation were numbered to facilitate identification, recording, and analysis. The data were punched on IBM cards and submitted to the IBM computer of the Computing Center at Virginia Polytechnic Institute and State University for statistical analysis (Appendix C, illustration 9). Statistical Analysis Systems (1976) integrated computer programs were used for all data processing and statistical analysis.

This chapter is arranged in five sections. Each of the first four sections includes data analysis and discussion of the individual muscles examined in the investigation; the concluding section summarizes the statistical findings.

ANALYSIS OF THE ANTERIOR DELTOID

This section is concerned with the analysis of the electromyographic response in the anterior deltoid muscle. The analysis deals with the three basic tennis serves.

Selection of the Criterion Score

Multiple trials were recorded during each of the three types of tennis serves. When several trials on a particular test are provided, the question of which trial or trials to use as a criterion score arises.

Analysis of variance for repeated measures may be used to test the null hypothesis that there are no significant differences between trials. If the between trial F ratio was significant, a systematic error variance would be present, and the appropriate course of action would be to search for a measurement schedule which was free of systematic error variance due to trial effect (Safrit, 1976).

If the analysis of variance for repeated measures produces a non-significant F ratio, it would be obvious that there was no systematic error variance, and the use of the mean of all recorded trials would be justified. When a stable measurement schedule is identified, Safrit suggests the use of intraclass correlation to estimate the test reliability.

Each of the serving test items used in this study was subjected to an analysis of variance for repeated measures. This was done in order to determine if the multiple trial measurement schedule was free of systematic error variance and to estimate the intraclass reliability of the test.

In Table 3 (p. 34) it is shown that the twist serve used to record muscle action potential in the anterior deltoid muscle was found to be free of systematic error since the between trial F ratio of 1.65 was well below the 3.55 value required for significance at the .05 level.

Table 3

Analysis of Variance for All Three Trials for the Twist Serve
(Anterior Deltoid)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Between subj.	9	.5056920	.051688		
Between trials	2	.0587428	.0293714	1.65	.2198
Error	18	.3204092	.0178005		
Total	29	.8848440			

The criterion score for this test was the mean of all three trials. The intraclass correlation computed from the mean of all three trials to estimate test reliability was R = .656 (Appendix C, illustration 10).

The slice serve used to record muscle action potential in the anterior deltoid was found to be free of systematic error. The criterion score used was the mean of all three trials. Table 4 (p. 36) shows the summary for the analysis of variance and computed between trial F ratio using the mean of all three trials. The computed intraclass correlation to estimate the test reliability was R = .267.

Inspection of Table 5 (p. 37) reveals the flat serve used to record muscle action potential in the anterior deltoid muscle was free of systematic error since the between trial F ratio of .61 was less than 3.55 required for significance at the .05 level. Thus, the criterion score for this test was the mean of all three trials. The intraclass correlation computed using the mean of all three trials to estimate test reliability was R = .124.

General Description of Data

The following description of data is related to the analysis of the electromyographic response in the anterior deltoid during the execution of each of the three basic tennis serves. Table 6 (p. 38) gives the mean EMG in the anterior deltoid, the mean EMG adjusted for the covariate, the standard deviation, and the standard error of the mean for each of the three types of serve. The twist serve was found to have the highest muscle action potential, .2268 μv. The greatest standard deviation value, .1369, was also reported on the twist serve.

Table 4

Analysis of Variance for All Three Trials for the Slice Serve (Anterior Deltoid)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Between subj.	9	.2516490	.027961		
Between trials	2	.0169614	.0084807	.41	.6674
Error	18	.3691624	.0205090		
Total	29	.6377728			

Table 5

Analysis of Variance for All Three Trials for the Flat Serve (Anterior Deltoid)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Between subj.	9	.2268093	.0252010		
Between trials	2	.0268973	.0134486	.61	.5545
Error	18	.3972054	.0220669		
Total	29	.650912			

Table 6

Analysis of Electromyographic Response in the Anterior Deltoid During Execution of Three Serves

Serve	Mean Integrated EMG (MAP) µv	Mean Adjusted for Racket Speed	Stand. Dev.	Stand. Error
Twist	.2268	.2341	.1369	.0433
Slice	.1788	.1818	.0965	.0305
Flat	.1871	.1769	.0917	.0290

Test of Null Hypothesis

The first major hypothesis tested was that the mean or average electromyographic response in the anterior deltoid was the same for each of the three types of serves. Statistically, this is expressed as:

$$H_o : M_t = M_s = M_f \qquad \alpha = .05$$

Where M_t = Theoretical mean EMG response using the twist serve

M_s = Theoretical mean EMG response using the slice serve

M_f = Theoretical mean EMG response using the flat serve

Analysis of covariance was used to test the null hypothesis. The statistical components found in Table 7 (p. 40) were calculated from the ANCOVA procedure outlined in the User's Guide of Statistical Analysis Systems (1976) package.

An examination of Table 7 indicates that the integrated electromyographic response recorded from the anterior deltoid muscle produced no significant difference between the mean muscle action potential of the three types of serves. The observed F ratio for serves was .60 ($p > .05$); therefore, the major hypothesis is a tenable one.

ANALYSIS OF THE MIDDLE DELTOID

The muscle under scrutiny in this section is the middle deltoid. The researcher discussed the statistical implications of the data relative to the three basic serves that were used to record muscle action potential in the middle deltoid.

Selection of the Criterion Score

Analysis of variance was used to search the data for a stable

Table 7

Analysis of Covariance for the Anterior Deltoid

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Ft/Sec.	1	.00214141	.00214141	.27	.6108
Subject	9	.19410821	.0215675	2.71	.0368
Serve	2	.00956064	.0047803	.60	.5600
Error	17	.13542549	.00796621		
Total	29	.34123575			

measurement schedule. The twist serve in the middle deltoid produced a between trial F ratio of 1.55. This ratio was less than the ratio required for significance at the .05 level of confidence. The researcher was justified to use the mean of all three trials as the criterion score as there was no evidence of trial to trial trend. An estimate of reliability was obtained by finding the intraclass correlation from the mean of the three repeated trials. R was computed to be .804. Summary Table 8 (p. 42) categorizes the data pertinent to the middle deltoid while performing the twist serve.

An investigation of the slice serve used to record muscle action potential in the middle deltoid produced a between trial F ratio of 4.01 which was significant at the .05 level. Therefore, the data indicated that a stable measurement schedule was not obtained. Table 9 (p. 43) summarizes the data as it appeared with a systematic error variance.

Duncan's Multiple Range Test was used to find a measurement free of systematic error. Inspection of that statistical procedure indicated that there existed a stable relationship between the mean of the first trial (.139023) and the mean of the second trial (.131031). The third trial mean (.042723) was significantly different from the other two. Therefore, the criterion score for the slice serve relative to the middle deltoid was the mean of the first two trials.

Analysis of variance statistical procedure was applied to those two trial means. The summary of that data is presented in Table 10 (p. 44). A between trial F ratio of .06 indicated that the selection of the criterion measure was a tenable one. Intraclass correlation was

Table 8

Analysis of Variance for All Three Trials for the Twist Serve
(Middle Deltoid)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Between subj.	9	.5795813	.0643979		
Between trials	2	.0390593	.0195296	1.55	.2396
Error	18	.2270301	.0126127		
Total	29	.8456707			

Table 9

Analysis of Variance for All Three Trials for the Slice Serve
(Middle Deltoid)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Between subj.	9	.0816862	.0090762		
Between trials	2	.0571192	.0285596	4.01	.0362
Error	18	.1281134	.0071174		
Total	29	.2669188			

Table 10

Analysis of Variance for Two Trials for the Slice Serve
(Middle Deltoid)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Between subj.	9	.1334022	.0148224		
Between trials	1	.0003194	.0003194	.06	.8136
Error	9	.0487632	.0054181		
Total	19	.1824848			

computed on those data to approximate test reliability. The computed estimate of reliability was R = .634.

The flat serve relative to the middle deltoid also produced a between trial F ratio that was significant at the .05 level. The observed F ratio of 3.96 was greater than 3.55 required for significance. Obviously, the trials were not free of systematic error variance. Table 11 (p. 46) summarizes the implication concerned with analysis of variance for all three trials for the flat serve.

The decision as to which trials produced a stable measurement was not immediately apparent. Duncan's Multiple Range Test indicated trial one and trial two were not significantly different. The calculated difference was .074610. The statistical procedure simultaneously indicated that the means of trials two and three were significantly related. The calculated difference between these two means was .057868. Since the mean of trial two and trial three produced the least trial to trial variance, their average was used as the criterion score. Analysis of variance was computed using only values from the last two trials. Summary Table 12 (p. 47) presents those findings. An estimate of test reliability, R = .106, was obtained by calculation of intraclass correlation.

General Description of Data

The descriptive statistics analyzing the three types of serves relative to the middle deltoid are given in Table 13 (p. 48). The twist serve again registered the highest mean integrated EMG muscle action potential of .1834 μv; also the greatest variability of .1465.

Table 11

Analysis of Variance for All Three Trials for the Flat Serve (Middle Deltoid)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Between subj.	9	.1978714	.0219857		
Between trials	2	.0882189	.0441094	3.96	.0377
Error	18	.2007323	.0111517		
Total	29	.4868226			

Table 12

Analysis of Variance for Two Trials for the Flat Serve (Middle Deltoid)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Between subj.	9	.1171801	.01302		
Between trials	1	.0167432	.0167432	1.44	.2610
Error	9	.1047630	.0116403		
Total	19	.2386863			

Table 13

Analysis of Electromyographic Response in the Middle Deltoid During the Execution of Three Serves

Serve	Mean Integrated EMG (MAP) μν	Mean Adjusted for Racket Speed	Stand. Dev.	Stand. Error
Twist	.1834	.1850	.1465	.0463
Slice	.1350	.1342	.0861	.0272
Flat	.1279	.1271	.0807	.0255

Test of Null Hypothesis

The second major null hypothesis tested in this study using analysis of covariance is mathematically stated as:

$$H_o : M_t = M_s = M_f \qquad \alpha = .05$$

Therefore, the investigator imposed the condition that the difference among mean electromyographic readings for the twist serve, the slice serve, and the flat serve relative to the middle deltoid was zero. Summary Table 14 (p. 50) provides the pertinent data and shows the result of computations relative to each category.

An examination of Table 14 indicates the F value relative to serve was considerably below that needed for significance at the .05 level ($F = 3.59$); therefore, the null hypothesis that no significant difference existed between the mean EMG response of the three basic serves was held to be tenable.

ANALYSIS OF THE POSTERIOR DELTOID

This section is concerned with the analysis of the electromyographic response in the posterior deltoid muscle. The analysis was concerned with the three basic tennis serves.

Selection of the Criterion Score

In Table 15 (p. 51) the between trials F ratio of .20 was well below the required 3.55 for significance at the .05 level; therefore, there was no evidence of systematic error. The mean of all three scores was used as the criterion score for the twist serve in the posterior deltoid.

Table 14

Analysis of Covariance for the Middle Deltoid

Source	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Ft/Sec	1	.03584898	.03584898	5.27	.0347
Subject	9	.16972306	.0188581	2.77	.0337
Serve	2	.01542349	.0077117	1.13	.3452
Error	17	.11570831	.00680631		
Total	29	.33670384			

Table 15

Analysis of Variance for All Three Trials for the Twist Serve
(Posterior Deltoid)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Between subj.	9	.7924009	.0880445		
Between trials	2	.0019881	.000994	.20	.8212
Error	18	.0898377	.0049909		
Total	29	.8842267			

To estimate test reliability, the intraclass correlation was computed from the mean of all three trials. That computation produced R = .943.

The criterion score for the slice serve in the posterior deltoid was the mean of all three trials. This data point was justified since the F ratio of .03 stated in Table 16 (p. 53) was smaller than the required F of 3.55 for significance at the .05 level. The slice serve used to record muscle action potential in the posterior deltoid was found to be free of systematic error. The intraclass correlation computed from the mean of all three trials to estimate test reliability was R = .520.

Table 17 (p. 54) indicates a between trial F ratio of 2.51. No trial to trial trend was evident since 2.51 is less than the 3.55 required for significance at the .05 level. The flat serve used to record muscle action potential in the posterior deltoid muscle was discovered to be free of systematic error. The criterion score for this test was the mean of all three trials. The intraclass correlation to estimate test reliability was a computed R = .647.

<u>General Description of Data</u>

Table 18 (p. 55) describes the mean EMG in the posterior deltoid, the mean EMG adjusted for the covariate racket speed, the standard deviation, and the standard error of the mean for each of the three types of serves. The investigator found the twist serve to have the greatest mean integrated EMG muscle action potential of .0975 μv. The summary table statistically implied the slice serve to have the highest standard deviation.

Table 16

Analysis of Variance for All Three Trials for the Slice Serve
(Posterior Deltoid)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Between subj.	9	.2124885	.0236098		
Between trials	2	.0006580	.0003290	.03	.9714
Error	18	.2038584	.0113254		
Total	29	.4170049			

Table 17

Analysis of Variance for All Three Trials for the Flat Serve
(Posterior Deltoid)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Between subj.	9	.1409298	.0156588		
Between trials	2	.0277796	.0138898	2.51	.1093
Error	18	.0996223	.0055345		
Total	29	.2683317			

Table 18

Analysis of Electromyographic Response in the Posterior Deltoid During the Execution of Three Serves

Serve	Mean Integrated EMG (MAP) μv	Mean Adjusted for Racket Speed	Stand. Dev.	Stand. Error
Twist	.0975	.1019	.0713	.0542
Slice	.0887	.0923	.0887	.0281
Flat	.0858	.0938	.0722	.0228

Test of Null Hypothesis

The third major null hypothesis tested in this study was that the mean electromyographic response in the posterior deltoid was the same for the twist serve, the slice serve, and the flat serve. Statistically, this is expressed as:

$$H_o : M_t = M_s = M_f \qquad \alpha = .05$$

Where M_t = Theoretical mean EMG response using the twist serve

M_s = Theoretical mean EMG response using the slice serve

M_f = Theoretical mean EMG response using the flat serve

Analysis of covariance was used to test the null hypothesis. Summary Table 19 (p. 57) reveals the statistical analysis of covariance components.

Since the F value of .12 was below the required F value needed for significance, the null hypothesis that there was no significant difference among the EMG values for the three serves relative to the posterior deltoid was not rejected. That is, $H_o : M_t = M_s = M_f$ was held tenable.

ANALYSIS OF THE TRICEPS

The statistical implications relative to the triceps muscle during execution of the twist, slice, and flat tennis serve is discussed in this section. The researcher was concerned with the selection of a criterion score, a general description of the data, and the testing of the major hypothesis.

Selection of the Criterion Score

In Table 20 (p. 58) it is revealed that the twist serve used to

Table 19

Analysis of Covariance for the Posterior Deltoid

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Ft/Sec	1	.05060806	.05060806	4.24	.0552
Subj.	9	.12632539	.0140361	1.18	.3689
Serve	2	.00279353	.0013967	.12	.8903
Error	17	.20295571	.01193857		
Total	29	.38268269			

Table 20

Analysis of Variance for All Three Trials for the Twist Serve (Triceps)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Between subj.	9	.0987483	.010972		
Between trials	2	.0652637	.0326318	1.54	.2404
Error	18	.3802939	.0211274		
Total	29	.5443059			

record muscle action potential in the triceps muscle was found to be free of systematic error since the between trial F ratio of 1.54 was less than the 3.55 required for significance at the .05 level. Thus, the mean of all three trials was used as the criterion score. The intraclass correlation computed from the mean of all three trials to estimate test reliability was R = -.926.

The slice serve used to record muscle action potential in the triceps muscle produced a trial to trial trend significant at the .05 level. Table 21 (p. 60) shows the summary table for the analysis of variance and the computed between trial F ratio using the mean of all three trials.

The investigator used Duncan's Multiple Range Test to search the trial means for a measurement free of systematic trend (Safrit, 1976). Duncan's Multiple Range Test indicated that there was no significant difference between the first and second trial means, but the third trial mean differed with both the first and second trial mean. Analysis of variance for repeated measures was used to test the null hypothesis; the hypothesis indicated no differences between the first two trials. Table 22 (p. 61) shows the summary for the analysis of variance and the computed F ratio using the mean of the first two trials. The criterion score for this test was the mean of the first two trials. The computed intraclass correlation to estimate test reliability was R = .663.

In Table 23 (p. 62) it is observed that the flat serve used to record muscle action potential in the triceps muscle was found to be free of systematic error as the F ratio of 1.36 was less than the required F ratio of 3.55. The investigator used the mean of all three trials as

Table 21

Analysis of Variance for All Three Trials for the Slice Serve (Triceps)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Between subj.	9	.0312784	.0034753		
Between trials	2	.0127741	.006387	3.60	.0484
Error	18	.0319439	.0017746		
Total	29	.0759964			

Table 22

Analysis of Variance for Two Trials for the Slice Serve (Triceps)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Between subj.	9	.0458371	.005093		
Between trials	1	.0000042	.0000042	.0024	.9618
Error	9	.0154371	.0017152		
Total	19	.0612784			

Table 23

Analysis of Variance for All Three Trials for the Flat Serve
(Triceps)

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Between subj.	9	.0490034	.0054448		
Between trials	2	.0244712	.0122356	1.36	.2822
Error	18	.1621295	.0090071		
Total	29	.2356041			

the criterion score for this test. The computed intraclass correlation to estimate test reliability was R = -.654.

General Description of Data

Table 24 (p. 64) summarizes the descriptive statistics associated with the analysis of the electromyographic response in the triceps muscle while performing each of the three basic tennis serves. The table categorizes the serve, mean integrated EMG muscle action potential, mean adjusted for covariate, standard deviation, and standard error.

Inspection of Table 24 shows the twist serve produces the greatest mean EMG response (.1109 μv). The greatest variability (.0605) was also evident in the twist serve.

Test of Null Hypothesis

Analysis of covariance was used to test the major hypothesis that the average electromyographic response in the triceps muscle was the same for each of the three types of serves. Statistically, this is expressed as:

$$H_o : M_t = M_s = M_f \qquad \alpha = .05$$

The hypothesis was tested using the analysis of covariance procedure. Summary statistics for the three serves relative to the triceps are given in Table 25 (p. 65). Examination of the table provided evidence of a significant difference between service types in mean electromyographic response in the triceps. The F value for the test of $H_o : M_t = M_s = M_f$ was 4.02. This value exceeded the value of 3.59 needed for significance at the .05 level. Therefore, the null hypoth-

Table 24

Analysis of Electromyographic Response in the Triceps Muscle During the Execution of Three Serves

Serve	Mean Integrated EMG (MAP) μv	Mean Adjusted for Racket Speed	Stand. Dev.	Stand. Error
Twist	.1109	.1098	.0605	.0191
Slice	.0685	.0686	.0505	.0160
Flat	.0670	.0680	.0426	.0135

Table 25

Analysis of Covariance for the Triceps

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F	Prob. F
Ft/Sec	1	.01562334	.01562334	10.15	.0054
Subject	9	.03041989	.0033799	2.20	.0777
Serve	2	.01236838	.0061841	4.02	.0373
Error	17	.02617309	.00153959		
Total	29	.08458470			

esis was rejected.

Duncan's Multiple Range Test was used to compare the mean muscle action potential of the twist, slice, and flat serves. Inspection of that statistical procedure indicated there was a significant difference between the mean response of the flat serve (.0680) and the twist serve (.1098). The slice serve (.0686) and the twist serve (.1098) were also shown to be significantly different; however, there was no evidence of significance between the slice serve (.0686) and the flat serve (.0680). Table 26 (p. 67) summarizes the results of Duncan's Multiple Range Test.

SUMMARY OF STATISTICAL FINDINGS

As a result of this investigation and within the limitations of the study, the following findings are presented:

1. There were no significant differences found between the mean muscle action potential of the three basic serves relative to the anterior deltoid muscle.

2. There were no significant differences found between the mean muscle action potential of the three basic serves relative to the middle deltoid muscle.

3. There were no significant differences found between the mean muscle action potential of the three basic serves relative to the posterior deltoid muscle.

4. Significant differences were found between the mean muscle action potential of the three basic serves relative to the triceps muscle.

Table 26

Duncan's Multiple Range Test
(Triceps)

Twist	Slice	Flat
.1098	.0686	.0680

5. A significant difference was found between the muscle action potential of the twist serve and the slice serve relative to the triceps muscle.

6. A significant difference was found between the muscle action potential of the twist serve and the flat serve relative to the triceps muscle.

7. There was no significant difference found between the muscle action potential of the slice serve and the flat serve relative to the triceps muscle.

Chapter V

SUMMARY OF THE STUDY

This investigation was designed to systematically observe the extent of muscular involvement of selected arm and shoulder muscles of ten male varsity tennis players as they performed the twist, slice, and flat tennis serves. The specific muscles analyzed in this study were identified as the prime movers utilized during execution of the tennis serve, specifically, the anterior deltoid, middle deltoid, posterior deltoid, and triceps muscle.

Electromyography was used by the investigator to determine the quantity of muscular involvement as each subject performed a total of thirty six randomized serving trials. Cinematography synchronized with electromyographic instrumentation was employed to provide the identification of types of serves and the specific racket velocity of each serving trial.

Analysis of covariance was used to determine significant mean differences of the three serving conditions relative to each muscle under investigation. Duncan's Multiple Range Test was used by the investigator to determine the nature of detected statistical significance.

CONCLUSIONS

As a result of the findings of this investigation, and within the limitations of the study, the following conclusions seem justified:

1. No significant differences were found in the electromyo-

graphical responses of the anterior deltoid, middle deltoid, and posterior deltoid muscles related to the performance of the twist, slice, and flat serves. Since the muscle action potential of these muscles did not differ according to the type of serve executed, the twist serve, slice serve, and flat serve should not be considered different in terms of muscular function.

2. Significant differences were found in the electromyographical response of the triceps muscle related to the performance of the twist, slice, and flat serves, specifically, significant differences in muscle action potential were recorded between the twist and slice serves and the twist and flat serves. No significant difference in electromyographical response was found between the slice and flat serves. Since the muscular involvement of the triceps muscle varied with the type of serve being executed, the twist serve should be considered as being different in muscular function from the slice serve and the flat serve. In addition, the slice serve and the flat serve should be considered as not being different in muscular function.

DISCUSSION

The application of the findings of this investigation seem to warrant the following considerations.

From the viewpoint of muscular training of the anterior deltoid, middle deltoid, and posterior deltoid muscles, it is suggested that if a dynamic muscular training program is used to increase the muscular efficiency associated with tennis serving ability, the exercise movements of the serving arm should be general in nature. The general exercise movements could consist of either twist, slice, or flat serving motion or any combination of these patterns.

It is also indicated that in electromyographical research involving the anterior deltoid, middle deltoid, and posterior deltoid muscles related to tennis serving performance, consideration as to the specific type of serve used in the investigation is not warranted. Controls regarding the type of serve employed are not necessary.

It is important to consider muscular training of the triceps muscle. The data suggests, that if a dynamic muscular strength/endurance model is employed to increase the muscular efficiency related to the tennis serve, the movement pattern of the exercise arm should be specific to the movement pattern of the twist serve.

Electromyographical research involving the triceps muscle related to the performance of the twist, slice, and flat serves should view the twist serve as being different from the slice and flat serves in terms of muscular involvement. Specific guidelines should be incorporated in the research design to control for this difference. Electromyographical investigations should also consider the slice and flat serves the same in terms of muscular involvement.

The twist serve elicited the highest mean integrated EMG response for all four muscles. This fact indicates that the twist serve is the most physically demanding to perform, as well as the most complex movement of the three serving patterns.

The mean velocity of the three serves are similar. The mean velocity of the flat serve is somehwat higher than the other two serving patterns. This is believed to be due to the flat service having the least amount of ball spin as well as being the easiest to execute.

Tennis skill tests are designed to measure a participant's ability. One segment of most skill is the serve; however, the type of serve was not defined. This investigation seems to suggest that there is, in fact, no need to control for the type of serve when administering skill tests for beginning players.

In view of the findings associated with the prime movers in this study, investigators that consider the tennis serve need to identify the movement being evaluated. The serve under consideration should be identified as being either the flat, slice, twist, or some variation of the three.

It should be understood that training programs citing one of the prime movers may emphasize development of that muscle; however, the other prime movers will also be involved during the dynamic training procedure. In reality, this implies that one of the muscles cannot be isolated for development.

Conflict exists in the literature as to the follow-through when executing the twist serve. Verification of the serving patterns was made on all trials using the Vanguard Motion Analyzer. Verification of the follow-through for the twist serve indicated that the follow-through continues forward and down across the body ending on the left side of the server.

RECOMMENDATIONS FOR FURTHER STUDY

The following are recommendations for further experimentation:

1. To replicate this study using female varsity tennis players to determine if there is an effect due to sex.

2. To replicate this study using professional tennis players to determine if there is an effect due to an increased level of performance.

3. To conduct a study employing telemetry instrumentation which would provide electromyographic information under competitive conditions.

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APPENDIX A

Illustration 1

Flat Service Position

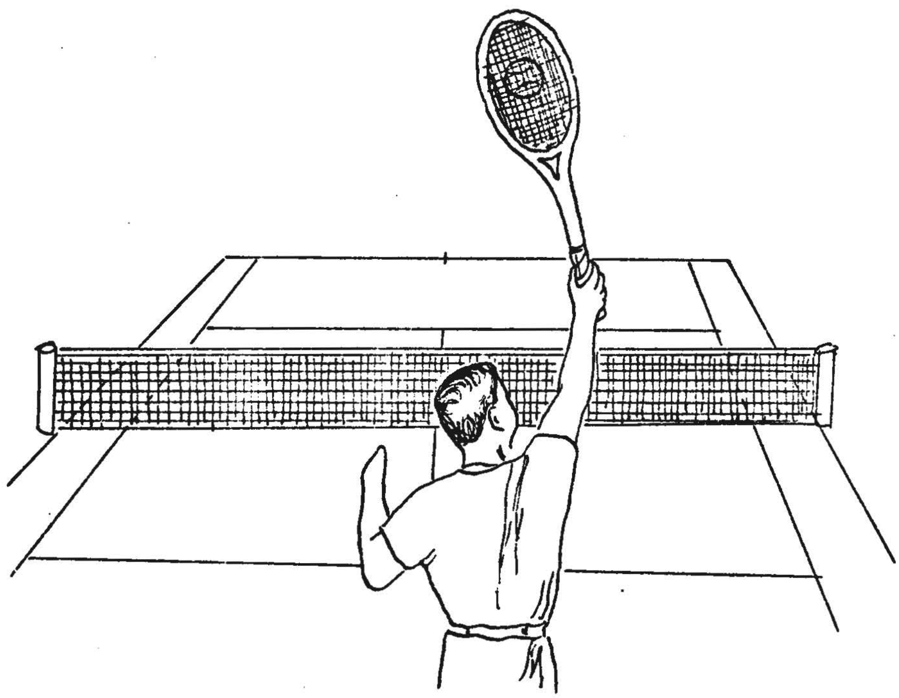


Illustration 2

Slice Service Position

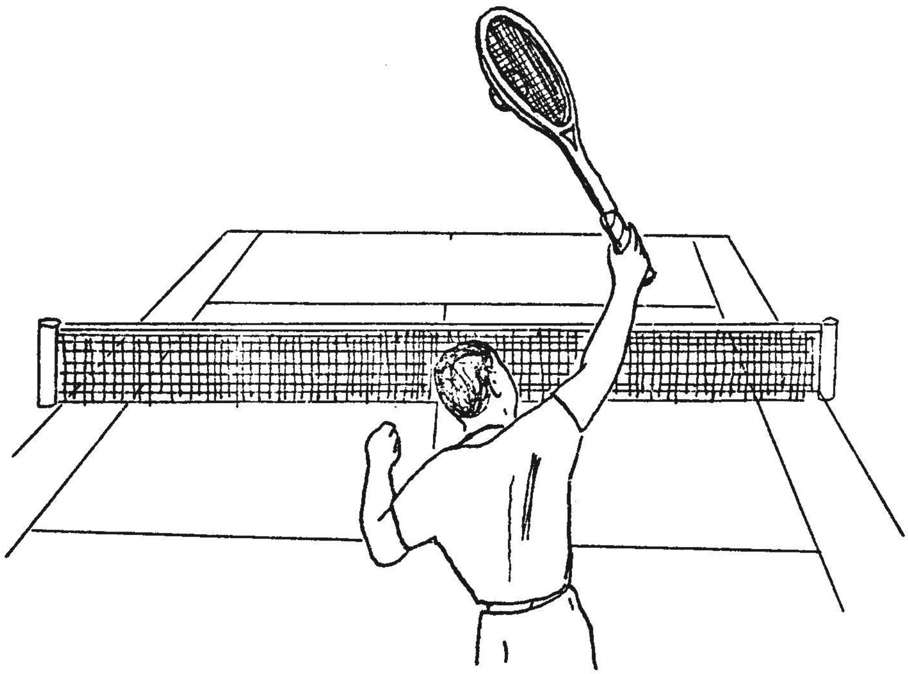
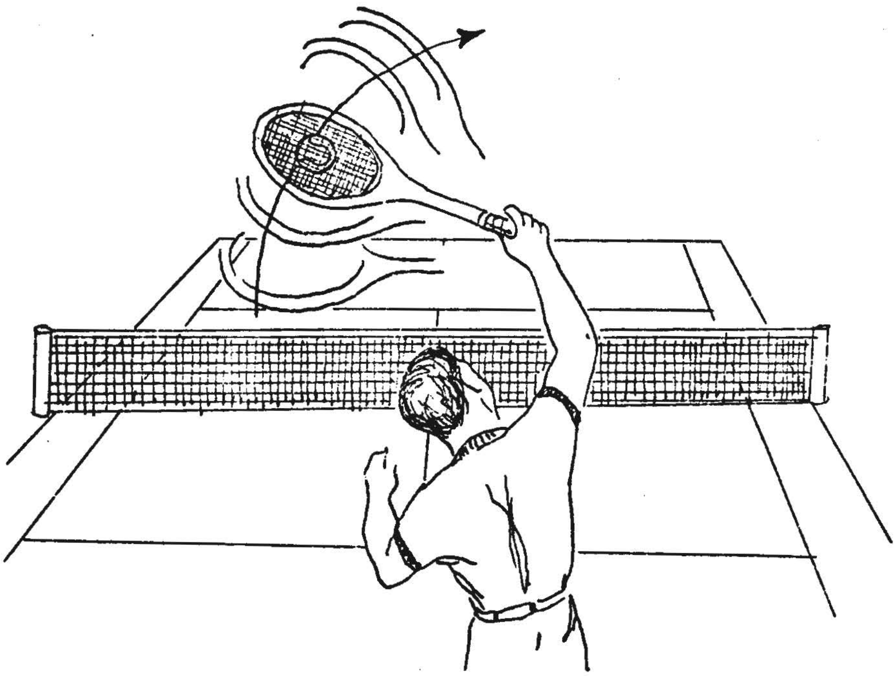


Illustration 3

Twist Service Position



Appendix B

Illustration 4

Administered Written Test

SUBJECT ______________________________ DATE __________________

NAME ______________________________ AGE _____

WEIGHT _______ HEIGHT ____

ADDRESS ____

1. When executing a flat serve, what is the racket position when ball contact is made?
2. The ball toss for the flat, twist, and slice serves vary. Which ball toss is fartherest to the right?
3. Which grip do you use in serving?
4. Where is the ball tossed when executing a twist serve?
5. Of the three basic types of serves, which one has the least spin imparted on the ball?

Answers:

1.

2.

3.

4.

5.

Table 1

Common Muscles Used in Arm Movement

MUSCLE NAME	SOURCES			
	Broer-Houtz	Thompson	Basmajean	Scott
Sternocleidomastoid	X			
Trapezius				X
Pectoralis Major		X	X	X
Serratus Anterior	X	X		X
Middle Deltoid	X		X	X
Anterior Deltoid	X	X	X	X
Posterior Deltoid	X		X	X
Biceps	X			X
Triceps	X			X
Brachioradialis				X
Flexors	X			
Wrist & Finger Extern.	X			

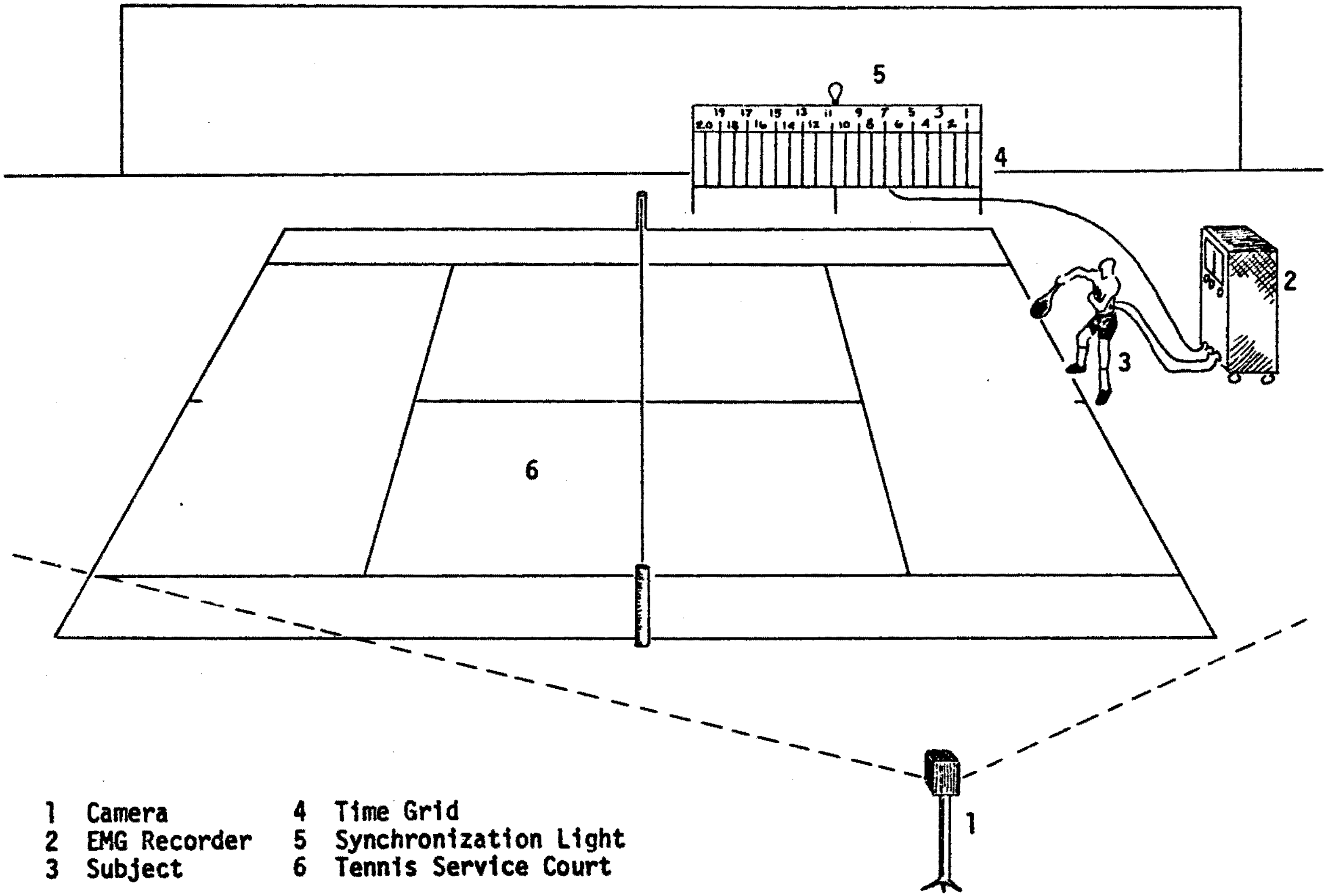
Table 2

Muscle Rankings Distribution

Muscles	Subject 1	Subject 2	Subject 3
Anterior Deltoid	1	4	2
Pectoralis Major	5	5	5
Posterior Deltoid	3	3	3
Middle Deltoid	4	1	4
Triceps	2	2	1

Illustration 5

Cinematographic Equipment



1 Camera
2 EMG Recorder
3 Subject
4 Time Grid
5 Synchronization Light
6 Tennis Service Court

Illustration 6

Racket Velocity

The analysis of all service trials as well as racket velocity was determined through the use of a Vanguard Motion Analyzer. In order to confirm the type serve for each of the 360 trials, the position of the racket prior to and immediately following ball contact was carefully evaluated frame to frame on the Vanguard Motion Analyzer. Calculations were obtained on all service trials by the formula in Appendix E. The following information was obtained on the covariate average speed of the racket head from cocked position to moment of impact (Ft/Sec) on all trials.

Average Racket Velocity of All Trials of the Twist, Slice, and Flat Serves

Type of Serve	Mean (Ft/Sec)	Standard Deviation	Standard Error of the Mean
Twist	76.3066	14.8392	1.3546
Slice	76.7037	15.0191	1.3710
Flat	77.9448	14.1881	1.2952

It can be observed that the mean racket velocity of the three types of serves are similar. The mean velocity of the flat serve however is somewhat higher than that of the other two.

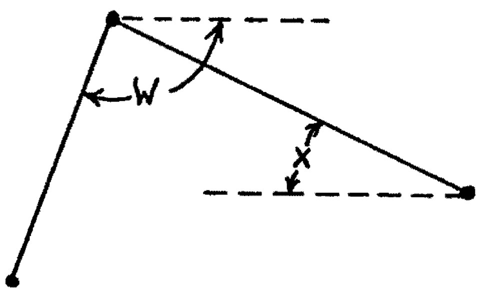
Measurement of Racket Velocity

The general measurements and formulas used to determine racket velocity are as follows:

W = angle of racket at cocked position

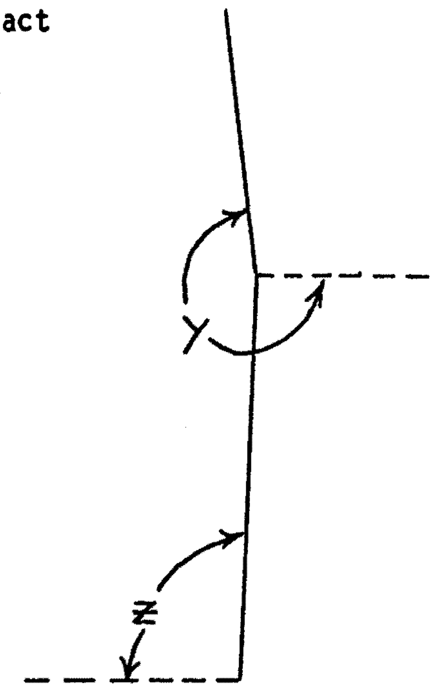
X = angle of arm at cocked position

All angles were determined from measurements of each service trial employing the Vanguard Motion Analyzer.



Y = angle of racket at contact

Z = angle of arm at contact



The angles to be calculated are:

α is the angle needed to calculate for A, C distance

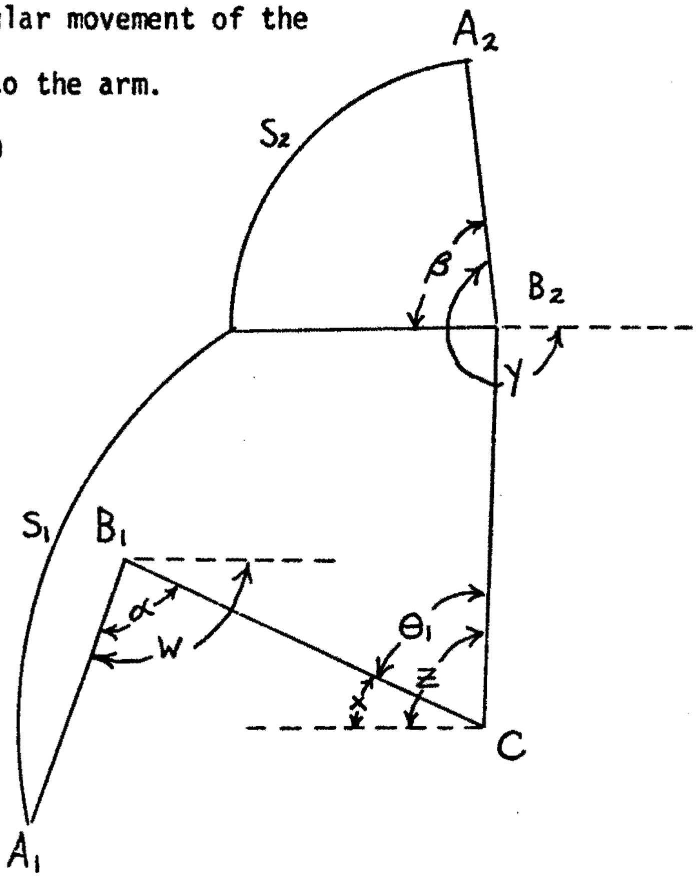
$\alpha = W - X$

θ_1 determine arm movement

$\theta_1 = Z - X$

B is the angular movement of the racket with respect to the arm.

$B = Y - W - \theta$



S_1 = the arc of the arm and racket

S_2 = the arc distance of the racket movement

$S_1 + S_2$ = distance the head of the racket moves

In order to calculate the above, the angles must be converted from degree units to radians. Divide by 57.3. The radius of the arcs must also be known, A, C, and A, B.

Below is the formula and example used to calculate racket velocity.

$$A_1C = \sqrt{(A_1B_1)^2 + (B_1C)^2 - 2(A_1B_1)(B_1C)\cos\alpha}$$

B_1C = arm length (26 inches)

A_1B_1 and A_2B_2 = racket length (19 inches)

Then $S_1 = (A_1C) \times \theta_1$ in radians

$S_2 = (A_2B_2) \times B$ in radians

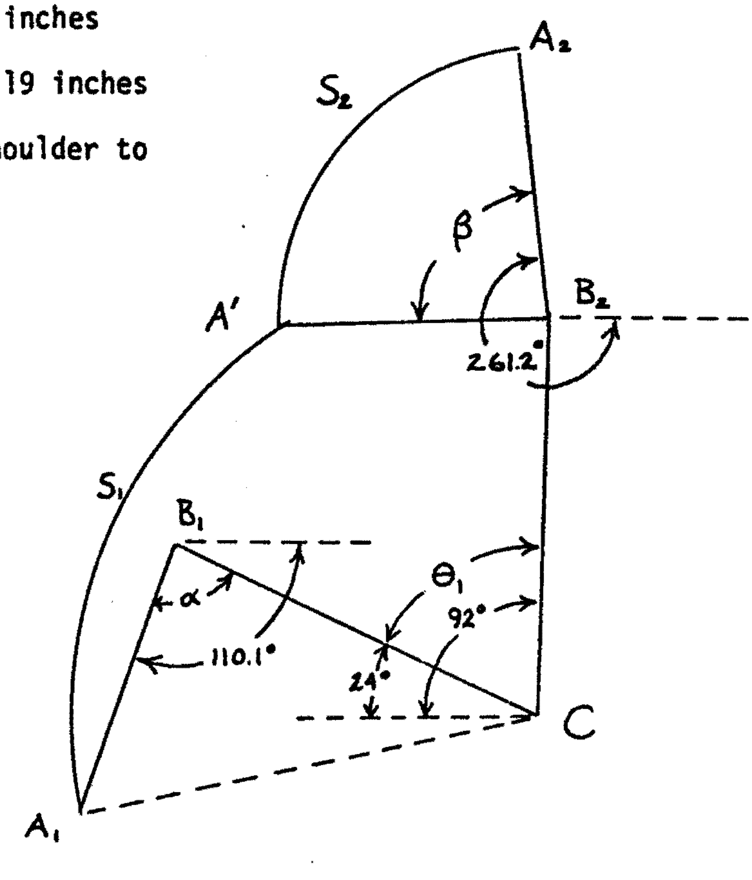
The average velocity $(\bar{V}) = \dfrac{S_1 + S_2}{t}$

Time (t) = $\dfrac{\text{\# frames}}{\text{frames/sec.}}$

BC = Arm length = 26 inches

AB = Racket length = 19 inches

AC = Distance from shoulder to racket center



Calculations used in the derivation of racket velocity are shown by the following example:

$A_1C = \sqrt{(A_1B_1)^2 + (B_1C)^2 - 2(A_1B_1)(B_1C)\cos\alpha}$

$\alpha = 86.1^{\circ}$ $\quad\alpha = 110.1^{\circ} - 24^{\circ} = 86.1^{\circ}$

$A_1C = 31.1$ inches

Distance $S_1 = \theta_1 \times A_1C$ $\quad\theta_1 = 92^{\circ} - 24^{\circ} = 68^{\circ}$ in radians

$\theta_1 = \frac{68^{\circ}}{57.3^{\circ}} = 1.18$ radians

$S_1 = 1.18 \times 31.1$ in. $= 36.69$ inches

Distance $S_2 = B \times A_2B_2$ $\quad B = 261.2^{\circ} - 110.1^{\circ} - \theta_1 = 83.1^{\circ}$

in radians $B = \frac{83.1}{57.3} = 1.45$ radians

$S_2 = 1.45 \times 19$ inches $= 27.55$

$S_1 + S_2 = 36.69 + 27.55 = 64.24$ inches

Total distance = 64.24 inches

Time to cover this distance =

$\frac{\#\text{ frames}}{\text{frames/sec.}} = \frac{4}{64} = \frac{1}{16}$ sec.

Average velocity of racket $(\bar{V}) = \frac{64.24}{1/16}$ inches= 1,028 /sec

or 85.66 feet/sec. or 58.4 mph

Illustration 7

Standardized Instructions

The following statements are given for your instruction:

1. At the conclusion of these instructions, you will be allowed exactly five minutes for warm up. During the warm up period, you will be instructed to hit all three types of serves.

2. The first two practice serves (flat) will ensure:

   (a) proper functioning of the camera

   (b) determine field of vision

   (c) synchronization of equipment

   (d) rhythm determination of instructions for subjects

3. Subject will prepare for the first series of serves.

4. Prior to each serve being executed, you will be instructed as to:

   (a) type of serve desired

   (b) beginning of serving motion

Illustration 8

Subject Serving Order, Random Assignment

Each subject executed the tennis serves according to random assignment specified by the Random Digits Table. The assigned serving order for each subject follows (in order to employ the Random Digits Table, each serve received the listed numeral assignment: 1 = slice, 2 = flat, 3 = twist):

SUBJECT 1

Anterior Deltoid	1. Twist - AD	10. Twist - PD
	2. Slice - AD	11. Flat - AD
	3. Twist - AD	12. Slice - PD
	4. Flat - PD	13. Flat - AD
Posterior Deltoid	5. Twist - AD	14. Slice - PD
	6. Twist - PD	15. Flat - AD
	7. Slice - AD	16. Slice - AD
	8. Slice - PD	17. Flat - PD
	9. Twist - PD	18. Flat - PD
Middle Deltoid	19. Slice - MD	28. Slice - T
	20. Slice - T	29. Flat - T
	21. Flat - MD	30. Twist - T
	22. Twist - T	31. Twist - MD
Triceps	23. Twist - MD	32. Twist - MD
	24. Flat - T	33. Slice - MD
	25. Flat - MD	34. Flat - T
	26. Twist - T	35. Slice - MD
	27. Flat - MD	36. Slice - T

SUBJECT 2

Anterior Deltoid	1. Slice - AD	10. Slice - PD
	2. Twist - PD	11. Twist - AD
	3. Flat - AD	12. Twist - PD
	4. Flat - PD	13. Twist - AD
Posterior Deltoid	5. Flat - AD	14. Slice - PD
	6. Flat - PD	15. Slice - AD
	7. Slice - AD	16. Slice - PD
	8. Flat - PD	17. Twist - AD
	9. Flat - AD	18. Twist - PD

Middle Deltoid	19. Twist - MD	28. Slice - T
	20. Flat - T	29. Twist - MD
	21. Slice - MD	30. Slice - T
	22. Twist - T	31. Flat - MD
Triceps	23. Flat - MD	32. Flat - T
	24. Twist - T	33. Flat - T
	25. Twist - MD	34. Slice - T
	26. Twist - T	35. Slice - MD
	27. Flat - MD	36. Slice - MD

SUBJECT 3

Anterior Deltoid	1. Slice - AD	10. Flat - AD
	2. Slice - PD	11. Flat - PD
	3. Twist - AD	12. Slice - PD
	4. Twist - PD	13. Twist - PD
Posterior Deltoid	5. Slice - AD	14. Slice - AD
	6. Flat - PD	15. Twist - PD
	7. Twist - AD	16. Flat - PD
	8. Slice - PD	17. Flat - AD
	9. Twist - AD	18. Flat - AD

Middle Deltoid	19. Twist - MD	28. Slice - MD
	20. Twist - T	29. Twist - MD
	21. Slice - MD	30. Twist - T
	22. Slice - T	31. Twist - T
Triceps	23. Twist - MD	32. Flat - T
	24. Slice - T	33. Flat - MD
	25. Flat - MD	34. Flat - T
	26. Slice - T	35. Flat - MD
	27. Slice - MD	36. Flat - T

SUBJECT 4

Anterior Deltoid	1. Slice - AD	10. Flat - PD
	2. Twist - AD	11. Twist - AD
	3. Flat - AD	12. Slice - PD
	4. Flat - PD	13. Twist - AD
Posterior Deltoid	5. Twist - PD	14. Twist - PD
	6. Slice - PD	15. Slice - AD
	7. Flat - AD	16. Slice - PD
	8. Flat - PD	17. Flat - AD
	9. Slice - AD	18. Twist - PD

Middle Deltoid	19. Slice - MD	28. Flat - T
	20. Flat - T	29. Slice - MD
	21. Twist - MD	30. Slice - T
Triceps	22. Twist - T	31. Slice - T
	23. Flat - MD	32. Twist - MD
	24. Twist - T	33. Slice - T
	25. Slice - MD	34. Flat - T
	26. Twist - T	35. Flat - MD
	27. Flat - MD	36. Twist - MD

SUBJECT 5

Anterior Deltoid	1. Slice - AD	10. Twist - PD
	2. Twist - PD	11. Slice - PD
	3. Slice - AD	12. Twist - AD
	4. Twist - PD	13. Flat - AD
Posterior Deltoid	5. Slice - AD	14. Twist - AD
	6. Slice - PD	15. Flat - AD
	7. Slice - PD	16. Flat - PD
	8. Flat - PD	17. Flat - AD
	9. Twist - AD	18. Flat - PD

Middle Deltoid	19. Flat - MD	28. Twist - T
	20. Flat - T	29. Slice - MD
	21. Twist - MD	30. Flat - T
	22. Flat - T	31. Twist - MD
Triceps	23. Slice - MD	32. Slice - T
	24. Twist - T	33. Slice - T
	25. Slice - MD	34. Slice - T
	26. Twist - T	35. Flat - MD
	27. Twist - MD	36. Flat - MD

SUBJECT 6

Anterior Deltoid	1. Twist - AD	10. Slice - PD
	2. Flat - PD	11. Flat - AD
	3. Flat - AD	12. Slice - PD
	4. Twist - PD	13. Twist - AD
Posterior Deltoid	5. Flat - AD	14. Slice - PD
	6. Flat - PD	15. Twist - PD
	7. Slice - AD	16. Twist - PD
	8. Flat - PD	17. Slice - AD
	9. Twist - AD	18. Slice - AD

Middle Deltoid	19. Slice - MD	28. Slice - T
	20. Twist - T	29. Twist - MD
	21. Slice - MD	30. Flat - T
	22. Slice - T	31. Flat - MD
Triceps	23. Slice - MD	32. Twist - T
	24. Flat - T	33. Twist - MD
	25. Twist - MD	34. Flat - T
	26. Slice - T	35. Twist - T
	27. Flat - MD	36. Flat - MD

SUBJECT 7

Anterior Deltoid	1. Twist - AD	10. Slice - PD
	2. Twist - PD	11. Twist - AD
	3. Slice - AD	12. Flat - PD
	4. Slice - PD	13. Flat - AD
Posterior Deltoid	5. Flat - AD	14. Twist - PD
	6. Slice - PD	15. Flat - PD
	7. Twist - AD	16. Twist - PD
	8. Flat - PD	17. Slice - AD
	9. Flat - AD	18. Slice - AD

Middle Deltoid	19. Flat - MD	28. Flat - T
	20. Flat - T	29. Flat - MD
	21. Slice - MD	30. Slice - T
	22. Twist - T	31. Slice - MD
Triceps	23. Twist - MD	32. Flat - T
	24. Slice - T	33. Twist - MD
	25. Twist - MD	34. Slice - MD
	26. Slice - T	35. Twist - T
	27. Flat - MD	36. Twist - T

SUBJECT 8

Anterior Deltoid	1. Twist - AD	10. Flat - PD
	2. Twist - PD	11. Flat - AD
	3. Flat - AD	12. Twist - PD
	4. Twist - PD	13. Twist - AD
Posterior Deltoid	5. Slice - AD	14. Twist - AD
	6. Slice - PD	15. Flat - AD
	7. Slice - AD	16. Flat - PD
	8. Slice - PD	17. Slice - PD
	9. Slice - AD	18. Flat - PD

Middle Deltoid	19. Flat - MD	28. Twist - T
	20. Twist - T	29. Flat - MD
	21. Twist - MD	30. Slice - MD
	22. Slice - T	31. Slice - T
Triceps	23. Slice - MD	32. Flat - T
	24. Twist - T	33. Flat - MD
	25. Twist - MD	34. Flat - T
	26. Slice - T	35. Flat - T
	27. Slice - MD	36. Twist - MD

SUBJECT 9

Anterior Deltoid	1. Flat - AD	10. Twist - PD
	2. Slice - PD	11. Twist - AD
	3. Flat - AD	12. Flat - PD
	4. Twist - PD	13. Slice - AD
Posterior Deltoid	5. Twist - AD	14. Slice - PD
	6. Twist - PD	15. Flat - PD
	7. Flat - AD	16. Slice - AD
	8. Slice - PD	17. Flat - PD
	9. Twist - AD	18. Slice - AD

Middle Deltoid	19. Twist - MD	28. Twist - T
	20. Flat - T	29. Twist - T
	21. Twist - MD	30. Flat - T
	22. Twist - T	31. Slice - MD
Triceps	23. Flat - MD	32. Slice - T
	24. Slice - T	33. Slice - MD
	25. Flat - MD	34. Slice - T
	26. Flat - MD	35. Slice - MD
	27. Twist - MD	36. Flat - T

SUBJECT 10

Anterior Deltoid	1. Slice - AD	10. Twist - PD
	2. Slice - PD	11. Twist - AD
	3. Flat - AD	12. Slice - PD
	4. Twist - PD	13. Twist - AD
Posterior Deltoid	5. Twist - AD	14. Slice - PD
	6. Twist - PD	15. Slice - AD
	7. Slice - AD	16. Flat - PD
	8. Flat - PD	17. Flat - AD
	9. Flat - AD	18. Flat - PD

Middle Deltoid	19. Slice - MD	28. Slice - T
	20. Flat - T	29. Twist - MD
	21. Flat - MD	30. Twist - T
	22. Twist - T	31. Slice - T
Triceps	23. Slice - MD	32. Slice - T
	24. Flat - T	33. Flat - MD
	25. Twist - MD	34. Flat - MD
	26. Flat - T	35. Twist - MD
	27. Slice - MD	36. Twist - T

Appendix C

Illustration 9

Data and Statistical Analyses

SUBJECT 1

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
1	AD	Twist	.94	.03332	100.65	68.63	.035455
3	AD	Twist	1.09	.21658	101.42	69.15	.198697
5	AD	Twist	.82	.17493	96.42	65.74	.213329
6	PD	Twist	.99	.04165	103.60	70.64	.042071
9	PD	Twist	.84	.03332	109.48	74.65	.039666
10	PD	Twist	.80	.02449	82.91	56.53	.030613
22	T	Twist	.76	.06664	79.59	54.26	.087684
23	MD	Twist	.96	.04165	104.86	71.50	.043385
26	T	Twist	.89	.05831	85.11	58.03	.065517
30	T	Twist	.78	.09996	89.86	61.27	.128159
31	MD	Twist	1.14	.04998	111.36	75.92	.043842
32	MD	Twist	.78	.04165	98.70	67.29	.053397
2	AD	Slice	.98	.0198	98.47	67.14	.020204
7	AD	Slice	.84	.14161	88.91	60.62	.168583
8	PD	Slice	.89	.04165	77.96	53.15	.046797
12	PD	Slice	.74	.04998	101.26	69.04	.067541
14	PD	Slice	.73	.04998	94.75	64.60	.068465
16	AD	Slice	1.06	.17493	87.23	59.47	.165028
19	MD	Slice	.79	.07497	109.95	74.97	.094898
20	T	Slice	.95	.06664	97.55	66.52	.070147
28	T	Slice	.77	.04165	92.97	63.39	.054090

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
33	MD	Slice	.79	.09996	75.93	51.77	.126532
35	MD	Slice	.92	.04998	96.05	65.49	.054326
36	T	Slice	1.08	.14161	109.87	74.91	.131121
4	PD	Flat	.84	.05831	129.23	88.11	.069416
11	AD	Flat	.87	.10829	95.69	65.24	.124471
13	AD	Flat	1.03	.11662	97.37	66.39	.113223
15	AD	Flat	1.09	.06664	97.51	66.48	.061137
17	PD	Flat	.79	.05831	97.28	66.33	.073810
18	PD	Flat	1.06	.04998	89.17	60.79	.047151
21	MD	Flat	.87	.02499	76.36	52.06	.028724
24	T	Flat	.86	.04998	91.51	62.39	.058116
25	MD	Flat	1.19	.05831	95.31	64.98	.049
27	MD	Flat	.87	.05831	86.98	59.30	.067023
29	T	Flat	1.22	.13328	94.60	64.50	.109245
34	T	Flat	.76	.06664	95.35	65.01	.087684

SUBJECT 2

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
2	PD	Twist	1.14	.07497	76.25	51.99	.065763
11	AD	Twist	.85	.11662	70.23	47.88	.1372
12	PD	Twist	.85	.07497	81.02	55.24	.0882
13	AD	Twist	.94	.17493	68.02	46.38	.188096
17	AD	Twist	.93	.16666	86.32	58.85	.179204
18	PD	Twist	1.02	.19992	68.81	46.92	.196
19	MD	Twist	.99	.19159	77.87	53.09	.193525
22	T	Twist	1.12	.18326	75.14	51.23	.163625
24	T	Twist	.75	.11662	76.00	51.82	.155493
25	MD	Twist	.87	.19992	76.86	52.40	.229793
26	T	Twist	1.32	.15827	86.11	58.71	.119901
29	MD	Twist	.89	.95831	86.61	59.05	1.076752
1	AD	Slice	1.09	.19159	87.59	59.72	.175770
7	AD	Slice	1.38	.14994	72.17	49.20	.108652
10	PD	Slice	1.45	.23324	75.07	51.18	.160855
14	PD	Slice	1.05	.0833	75.19	51.27	.079333
15	AD	Slice	.85	.10829	87.60	59.73	.1274
16	PD	Slice	.89	.06664	82.75	56.42	.074876
21	MD	Slice	1.15	.17493	69.89	47.65	.152113
28	T	Slice	.76	.05831	65.76	44.84	.076723
30	T	Slice	1.38	.05831	88.78	60.53	.042253
34	T	Slice	.98	.06664	84.72	57.76	.068
35	MD	Slice	1.20	.06664	74.35	50.69	.055533
36	MD	Slice	.92	.04998	81.00	55.23	.054326

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
3	AD	Flat	1.22	.19159	97.10	66.20	.157041
4	PD	Flat	.91	.13328	87.23	59.47	.146462
5	AD	Flat	.84	.14994	71.73	48.91	.1785
6	PD	Flat	.89	.07497	73.76	50.28	.084235
8	PD	Flat	1.06	.07497	65.62	44.74	.070726
9	AD	Flat	.92	.09996	75.37	51.39	.108652
20	T	Flat	1.16	.14994	78.18	53.30	.129258
23	MD	Flat	.91	.18326	74.23	50.61	.201385
27	MD	Flat	1.07	.19159	72.05	49.12	.179056
31	MD	Flat	1.14	.07497	85.54	58.32	.065762
32	T	Flat	.89	.06664	79.53	54.23	.074876
33	T	Flat	1.11	.04998	74.97	51.12	.045027

SUBJECT 3

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
3	AD	Twist	.77	.59143	58.48	39.87	.768091
4	PD	Twist	.94	.49147	47.75	32.56	.522841
7	AD	Twist	1.09	.56644	30.84	21.03	.519669
9	AD	Twist	1.22	.02499	44.37	30.25	.020483
13	PD	Twist	.98	.73304	58.40	39.82	.748
15	PD	Twist	1.08	.49147	52.41	35.74	.455065
19	MD	Twist	.96	.64141	49.88	34.01	.668135
20	T	Twist	1.26	.01666	47.00	32.04	.013222
23	MD	Twist	1.05	.44483	67.83	46.25	.423648
29	MD	Twist	.95	.44149	64.50	43.98	.464726
30	T	Twist	.80	.00833	50.70	34.56	.010413
31	T	Twist	1.05	.29155	56.98	38.85	.277667
1	AD	Slice	1.28	.34153	64.29	43.83	.266820
2	PD	Slice	1.24	.5831	68.12	46.44	.470242
5	AD	Slice	.78	.02499	67.50	46.02	.032038
8	PD	Slice	1.22	.53312	25.31	17.26	.436983
12	PD	Slice	.86	.01666	49.62	33.83	.019372
14	AD	Slice	1.20	.01666	47.67	32.50	.013833
21	MD	Slice	1.18	.25823	60.94	41.55	.218838
22	T	Slice	.87	.02499	51.46	35.09	.028724
24	T	Slice	1.07	.00833	67.37	44.57	.007785
26	T	Slice	.84	.00834	62.30	42.48	.009928
27	MD	Slice	1.22	.44149	44.12	30.08	.361877
28	MD	Slice	.89	.00833	43.98	29.99	.009359

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
6	PD	Flat	1.05	.00833	36.76	25.07	.007933
10	PD	Flat	1.09	.02499	45.80	31.23	.022926
11	AD	Flat	.92	.01666	73.94	50.42	.018109
16	PD	Flat	.95	.01666	64.07	43.69	.017537
17	AD	Flat	1.40	.51646	63.14	43.05	.3689
18	AD	Flat	1.04	.02499	65.03	44.34	.024028
25	MD	Flat	1.06	.36652	58.32	39.76	.345774
32	T	Flat	.76	.00833	67.23	45.84	.010960
33	MD	Flat	.88	.24157	41.38	28.21	.274511
34	T	Flat	.89	.00833	65.45	44.63	.009359
35	MD	Flat	.97	.22491	69.71	47.53	.231866
36	T	Flat	.89	.00833	63.33	43.18	.009359

SUBJECT 4

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
2	PD	Twist	1.12	.12495	90.00	61.36	.111562
5	AD	Twist	.79	.34153	100.13	68.26	.432316
11	AD	Twist	1.01	.39151	91.07	62.09	.387633
13	AD	Twist	.77	.32487	85.92	58.58	.421909
14	PD	Twist	.82	.02499	90.87	61.96	.030476
18	PD	Twist	1.18	.03332	94.22	64.24	.028237
21	MD	Twist	1.08	.60809	95.43	65.06	.563046
22	T	Twist	.84	.01666	92.79	63.26	.019833
24	T	Twist	.81	.02499	86.46	58.95	.030852
26	T	Twist	1.16	.75803	83.80	57.14	.653474
32	MD	Twist	.82	.25823	97.86	66.72	.314915
36	MD	Twist	.75	.03332	97.03	66.16	.044427
1	AD	Slice	.87	.03332	92.32	62.94	.038299
6	PD	Slice	1.02	.02499	94.32	64.30	.0245
9	AD	Slice	1.10	.31654	89.10	60.75	.287764
12	PD	Slice	1.09	.01666	86.87	59.23	.015284
15	AD	Slice	.86	.35819	90.36	61.61	.4165
16	PD	Slice	1.12	.01666	96.49	65.79	.014875
19	MD	Slice	.77	.18326	83.39	56.86	.238
25	MD	Slice	.90	.28322	96.28	65.64	.314688
29	MD	Slice	1.04	.00833	91.26	62.23	.008009
30	T	Slice	1.24	.19992	93.39	63.68	.161226
31	T	Slice	1.27	.00833	88.20	60.14	.006559
33	T	Slice	1.14	.15827	93.54	63.78	.138833

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
3	AD	Flat	1.14	.09163	87.48	59.64	.080377
4	PD	Flat	.93	.03332	94.93	64.72	.035828
7	AD	Flat	1.16	.14994	93.41	63.69	.129259
8	PD	Flat	.84	.02499	93.76	63.93	.029755
10	PD	Flat	.88	.01666	75.45	51.44	.018932
17	AD	Flat	.79	.43316	92.57	63.12	.548304
20	T	Flat	1.36	.02499	98.34	67.05	.018375
23	MD	Flat	.92	.24157	91.28	62.24	.262576
27	MD	Flat	1.18	.02499	87.59	59.72	.021178
28	T	Flat	.95	.29988	82.67	56.37	.315663
34	T	Flat	.98	.03332	85.07	58.01	.034
35	MD	Flat	.79	.12495	73.33	50.00	.158165

SUBJECT 5

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
2	PD	Twist	.63	.01666	79.81	54.41	.026444
4	PD	Twist	.76	.02499	69.66	47.50	.032882
9	AD	Twist	.84	.1666	69.75	47.56	.198333
10	PD	Twist	.94	.02499	68.48	46.69	.026585
12	AD	Twist	.82	.02499	70.55	48.11	.030476
14	AD	Twist	.83	.02499	74.10	50.58	.030108
21	MD	Twist	.79	.04998	73.52	50.13	.063266
24	T	Twist	.87	.02499	72.07	49.14	.028724
26	T	Twist	.74	.02499	69.14	47.14	.033770
27	MD	Twist	.87	.02499	75.15	51.24	.028724
28	T	Twist	.78	.05831	68.22	46.51	.074756
31	MD	Twist	.92	.02499	82.97	56.57	.027163
1	AD	Slice	1.02	.02499	76.57	52.21	.0245
3	AD	Slice	.70	.33320	67.35	45.92	.476
5	AD	Slice	.73	.29988	84.96	57.93	.410795
6	PD	Slice	.82	.01666	78.15	53.28	.020317
7	PD	Slice	.77	.11662	81.17	53.34	.151455
11	PD	Slice	.92	.11662	63.79	43.49	.126761
23	MD	Slice	.91	.04165	72.70	49.57	.045769
25	MD	Slice	.97	.01666	67.45	45.98	.017175
29	MD	Slice	.82	.02499	82.92	56.54	.030476
32	T	Slice	.78	.01666	74.90	51.07	.021359
33	T	Slice	.83	.02499	77.65	52.94	.030108
34	T	Slice	.77	.00833	79.86	54.45	.010818

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
8	PD	Flat	.96	.02499	61.35	41.83	.026031
13	AD	Flat	.84	.07497	77.07	52.55	.08925
15	AD	Flat	.78	.10829	78.29	52.01	.138833
16	PD	Flat	.78	.22491	73.86	50.35	.288346
17	AD	Flat	.86	.01666	72.02	49.10	.019372
18	PD	Flat	1.24	.34153	75.49	51.47	.275427
19	MD	Flat	.86	.04998	77.03	52.52	.058116
20	T	Flat	.79	.02499	75.74	51.64	.031633
22	T	Flat	.80	.02499	48.78	33.26	.031238
30	T	Flat	.89	.03332	79.18	53.98	.037438
35	MD	Flat	.83	.01666	87.37	59.57	.020072
36	MD	Flat	.78	.05831	76.57	52.21	.074756

SUBJECT 6

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
1	AD	Twist	1.26	.24157	69.33	47.27	.191722
4	PD	Twist	1.89	.01666	59.46	40.54	.008815
9	AD	Twist	.71	.02499	58.95	40.19	.035197
13	AD	Twist	1.19	.02499	71.27	48.59	.021
15	PD	Twist	.99	.02499	70.17	47.84	.025243
16	PD	Twist	1.17	.26656	68.89	46.97	.227829
20	T	Twist	1.20	.01666	64.94	44.28	.013883
25	MD	Twist	1.00	.20855	69.18	47.16	.20855
29	MD	Twist	.80	.24157	60.75	41.42	.301963
32	T	Twist	.94	.01666	60.11	40.98	.017723
33	MD	Twist	.76	.23324	61.19	41.72	.306895
35	T	Twist	1.06	.19159	64.02	43.65	.180745
7	AD	Slice	1.40	.15827	75.17	51.26	.11305
10	PD	Slice	1.80	.14161	56.42	38.47	.078672
12	PD	Slice	1.19	.14161	75.73	51.63	.119
14	PD	Slice	1.47	.20825	70.55	48.10	.141666
17	AD	Slice	1.35	.02499	61.02	41.61	.018511
18	AD	Slice	.92	.23324	67.08	45.74	.253522
19	MD	Slice	1.90	.1666	65.36	44.56	.087684
21	MD	Slice	1.79	.17493	57.79	39.40	.097726
22	T	Slice	1.65	.22491	56.95	38.83	.136309
23	MD	Slice	.82	.02499	71.38	48.67	.030476
26	T	Slice	.92	.02499	59.62	40.65	.027163
28	T	Slice	1.06	.01666	65.68	44.78	.015717

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
2	PD	Flat	1.15	.01666	76.59	52.22	.014487
3	AD	Flat	2.02	.22491	55.26	37.68	.111342
5	AD	Flat	1.89	.17493	72.86	49.68	.092555
6	PD	Flat	2.10	.00833	46.77	31.89	.003967
11	AD	Flat	.88	.01666	61.81	42.15	.018931
24	T	Flat	.99	.01666	68.15	46.47	.016828
27	MD	Flat	.93	.19992	71.07	48.46	.214968
30	T	Flat	.88	.02499	68.22	46.51	.028398
31	MD	Flat	1.11	.06664	73.61	50.19	.060004
34	T	Flat	.74	.01666	63.19	43.08	.022514
36	MD	Flat	1.06	.02499	60.41	41.19	.023575

SUBJECT 7

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
1	AD	Twist	1.18	.30821	55.58	37.89	.261195
2	PD	Twist	1.37	.01666	63.73	43.45	.012161
7	AD	Twist	1.76	.29988	75.79	51.68	.170386
11	AD	Twist	1.42	.20825	68.28	46.56	.146655
14	PD	Twist	.82	.02499	71.80	48.95	.030476
16	PD	Twist	1.12	.02499	71.00	48.41	.022313
22	T	Twist	.78	.19992	78.08	53.24	.256308
23	MD	Twist	.80	.01666	71.03	48.43	.020825
25	MD	Twist	.76	.15827	74.07	50.50	.20825
33	MD	Twist	1.34	.12495	73.96	50.42	.093246
35	T	Twist	.82	.01666	67.63	46.11	.020317
36	T	Twist	1.19	.02499	71.90	49.04	.021
3	AD	Slice	1.76	.30821	71.10	48.41	.175119
4	PD	Slice	1.66	.02499	69.79	47.58	.015054
6	PD	Slice	1.16	.02499	71.13	48.50	.021543
10	PD	Slice	.80	.01666	80.33	54.78	.020825
17	AD	Slice	.78	.19992	71.71	48.89	.256308
18	AD	Slice	1.64	.02499	65.91	44.94	.015238
21	MD	Slice	1.26	.11662	77.41	52.78	.092555
24	T	Slice	.84	.02499	73.11	49.85	.02975
26	T	Slice	1.08	.02499	75.58	51.53	.023139
30	T	Slice	1.00	.02499	75.31	51.35	.02499
31	MD	Slice	.89	.09996	70.49	48.06	.112315
34	MD	Slice	1.08	.20825	58.48	39.87	.192824

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
5	AD	Flat	1.67	.28322	78.23	53.34	.169593
8	PD	Flat	.79	.02499	76.65	52.26	.031633
9	AD	Flat	.82	.23324	76.22	51.97	.284440
12	PD	Flat	.82	.02499	71.62	48.83	.030476
13	AD	Flat	.78	.21658	65.66	44.77	.277667
15	PD	Flat	1.57	.23324	67.79	46.22	.148561
19	MD	Flat	.79	.14994	72.10	49.16	.189798
20	T	Flat	.94	.01666	79.33	54.09	.017723
27	MD	Flat	.79	.07497	74.09	50.52	.094899
28	T	Flat	.99	.02499	71.15	48.51	.025242
29	MD	Flat	.85	.19159	75.75	51.65	.2254
32	T	Flat	.90	.19992	73.48	50.10	.222133

SUBJECT 8

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
1	AD	Twist	1.16	.10829	66.29	45.19	.093353
2	PD	Twist	1.31	.01666	55.38	37.76	.012718
4	PD	Twist	1.08	.01666	53.11	36.21	.015426
12	PD	Twist	1.26	.00833	64.02	43.65	.006611
13	AD	Twist	.92	.14994	83.65	57.03	.162978
14	AD	Twist	.77	.00833	94.30	64.30	.010818
20	T	Twist	1.18	.02499	80.77	55.07	.021178
21	MD	Twist	1.05	.12495	80.54	54.92	.119
24	T	Twist	1.12	.02499	76.97	52.48	.022313
25	MD	Twist	.91	.11662	87.80	59.87	.128154
28	T	Twist	1.04	.03332	65.93	44.95	.032038
36	MD	Twist	.84	.02499	91.37	62.30	.02975
5	AD	Slice	1.16	.09996	58.80	40.09	.086172
6	PD	Slice	.82	.02499	47.02	32.06	.030476
7	AD	Slice	.91	.09996	55.02	37.51	.109846
8	PD	Slice	1.24	.01666	55.47	37.82	.013435
9	AD	Slice	.75	.09163	63.20	43.09	.122173
17	PD	Slice	.82	.26656	81.31	55.44	.325073
22	T	Slice	1.08	.01666	73.74	50.28	.015426
23	MD	Slice	1.21	.05831	94.46	64.81	.048190
26	T	Slice	1.16	.02499	84.49	57.60	.021543
27	MD	Slice	1.72	.09163	97.81	66.76	.053273
31	T	Slice	1.25	.12495	88.81	60.55	.09996
30	MD	Slice	1.35	.02499	91.37	62.57	.018511

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
3	AD	Flat	1.10	.10829	63.13	43.05	.098445
10	PD	Flat	.97	.02499	47.82	32.60	.025763
11	AD	Flat	.82	.19992	48.99	33.40	.243805
15	AD	Flat	1.27	.36652	92.63	63.15	.288598
16	PD	Flat	.97	.02499	73.82	50.33	.025763
18	PD	Flat	1.14	.00833	81.07	55.27	.007307
19	MD	Flat	.78	.18326	88.67	60.46	.234949
29	MD	Flat	1.02	.11662	72.76	49.61	.114333
32	T	Flat	.76	.01666	90.09	61.43	.021921
33	MD	Flat	.88	.37485	92.70	63.21	.425966
34	T	Flat	1.48	.01666	89.36	60.82	.011257
35	T	Flat	1.19	.4165	91.25	62.22	.35

SUBJECT 9

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
4	PD	Twist	.80	.03332	59.55	40.60	.04165
5	AD	Twist	.94	.2499	60.62	41.33	.265851
6	PD	Twist	1.02	.03332	77.63	59.93	.032666
9	AD	Twist	1.00	.38318	81.78	55.76	.38318
10	PD	Twist	1.19	.01666	67.23	45.84	.014
11	AD	Twist	.90	.32487	68.71	46.85	.360967
19	MD	Twist	.80	.1666	82.40	56.19	.20825
21	MD	Twist	.89	.19992	77.17	52.61	.224629
22	T	Twist	.90	.03312	77.96	53.16	.0368
27	MD	Twist	1.15	.01666	80.17	54.66	.014487
28	T	Twist	1.43	.1992	71.35	48.65	.139301
29	T	Twist	1.20	.29155	80.91	55.17	.242958
2	PD	Slice	1.08	.02499	52.71	35.94	.023139
8	PD	Slice	1.16	.02499	77.60	52.91	.021543
13	AD	Slice	.96	.29155	80.47	54.86	.303698
14	PD	Slice	.95	.02499	75.03	51.16	.026305
16	AD	Slice	1.21	.03332	63.76	43.47	.027537
18	AD	Slice	1.09	.01666	78.83	53.75	.015284
24	T	Slice	.90	.02499	79.27	54.05	.027766
31	MD	Slice	1.10	.1666	76.54	52.19	.151515
32	T	Slice	1.00	.01666	75.88	51.74	.01666
33	MD	Slice	1.23	.19159	79.56	54.24	.155764
34	T	Slice	1.33	.01666	78.64	53.62	.012526
35	MD	Slice	.90	.01666	81.22	55.38	.018511

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
1	AD	Flat	.89	.28322	80.99	55.22	.318225
3	AD	Flat	.89	.19159	67.28	45.87	.215270
7	AD	Flat	.84	.27489	82.00	55.91	.32725
12	PD	Flat	1.02	.06664	75.33	51.36	.065333
15	PD	Flat	.94	.38322	79.14	53.46	.301298
17	PD	Flat	.78	.11662	77.24	52.66	.149513
20	T	Flat	1.55	.02499	79.07	53.91	.016123
23	MD	Flat	.80	.19992	78.51	53.61	.2499
25	MD	Flat	1.65	.27489	82.13	56.00	.1666
26	MD	Flat	.77	.01666	79.03	53.89	.021636
30	T	Flat	.82	.02499	87.27	59.51	.030476
36	T	Flat	.93	.01666	80.45	54.85	.017914

SUBJECT 10

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
4	PD	Twist	1.48	.02499	81.84	55.80	.016885
5	AD	Twist	1.65	.59143	88.27	60.18	.358442
6	PD	Twist	1.49	.02499	94.37	64.35	.001677
10	PD	Twist	1.33	.01666	96.03	65.48	.012526
11	AD	Twist	1.56	.48314	68.14	46.46	.309805
13	AD	Twist	1.74	.47481	83.90	57.20	.272879
22	T	Twist	1.51	.4998	87.60	59.73	.330993
25	MD	Twist	1.62	.22491	85.94	58.60	.138833
29	MD	Twist	1.62	.02499	86.75	59.15	.015426
30	T	Twist	1.75	.21415	91.12	62.13	.122375
35	MD	Twist	1.26	.30821	83.56	56.97	.244611
36	T	Twist	1.62	.00833	101.13	68.95	.005142
1	AD	Slice	1.45	.36652	86.44	58.93	.252772
2	PD	Slice	1.58	.02499	77.10	52.57	.015816
7	AD	Slice	1.39	.5831	74.66	50.90	.419496
12	PD	Slice	1.36	.02499	97.18	66.26	.018375
14	PD	Slice	1.44	.01666	92.62	63.15	.011569
15	AD	Slice	1.53	.70805	94.96	64.75	.462777
19	MD	Slice	1.47	.38318	94.52	64.45	.260666
23	MD	Slice	1.62	.02499	100.25	68.35	.015426
27	MD	Slice	1.60	.01666	93.39	63.67	.010413
28	T	Slice	1.70	.19159	53.23	36.29	.1127
31	T	Slice	1.41	.02499	90.26	61.54	.017723
32	T	Slice	1.55	.27489	84.19	57.40	.177348

Trial	Muscle	Type	Time	MV	F/S	MPH	EMG
3	AD	Flat	1.50	.69972	92.69	63.20	.46648
8	PD	Flat	1.33	.02499	72.40	49.36	.018789
9	AD	Flat	1.26	.6664	106.41	72.55	.528888
16	PD	Flat	1.53	.4582	93.28	63.60	.299477
17	AD	Flat	1.27	.01666	73.18	49.89	.013118
18	PD	Flat	1.35	.29155	103.30	70.43	.215963
20	T	Flat	1.72	.01666	81.91	55.85	.009686
21	MD	Flat	.93	.49147	90.42	61.65	.528462
24	T	Flat	1.74	.02499	92.73	63.23	.014362
26	T	Flat	1.68	.34153	81.12	55.31	.203292
33	MD	Flat	1.63	.01666	92.08	62.78	.010221
34	MD	Flat	1.70	.46648	90.25	61.53	.2744

Illustration 10

Intraclass Reliability Coefficients

Computational Formula $R = \frac{MS\ (SUBJECTS) - MS\ (ERROR)}{MS\ (SUBJECTS)}$

1. Twist Serve - Anterior Deltoid $R = \frac{.051688 - .0178005}{.051688}$

   $R = .6556163$

2. Slice Serve - Anterior Deltoid $R = \frac{.027961 - .0205090}{.027961}$

   $R = .266514$

3. Flat Serve - Anterior Deltoid $R = \frac{.0252010 - .0220669}{.0252010}$

   $R = .1243641$

4. Twist Serve - Middle Deltoid $R = \frac{.0643979 - .0126127}{.0643979}$

   $R = .8041442$

5. Slice Serve - Middle Deltoid $R = \frac{.0148224 - .0054181}{.0148224}$

   $R = .6344654$

6. Flat Serve - Middle Deltoid $R = \frac{.01302 - .0116403}{.01302}$

   $R = .1059677$

7. Twist Serve - Posterior Deltoid $R = \frac{.0880445 - .0049909}{.0880445}$

   $R = .9433138$

8. Slice Serve - Posterior Deltoid

$$R = \frac{.0236098 - .0113254}{.0236098}$$

$$R = .5203093$$

9. Flat Serve - Posterior Deltoid

$$R = \frac{.0156588 - .0055345}{.0156588}$$

$$R = .6465565$$

10. Twist Serve - Triceps

$$R = \frac{.010972 - .0211274}{.010972}$$

$$R = -.9255741$$

11. Slice Serve - Triceps

$$R = \frac{.005093 - .0017152}{.005093}$$

$$R = .663224$$

12. Flat Serve - Triceps

$$R = \frac{.0054448 - .0090071}{.0054448}$$

$$R = -.6542572$$

APPENDIX D

PILOT STUDY

INTRODUCTION

A pilot study was conducted by the investigator between June 1, 1976 and December 15, 1976 in the muscular function laboratory of the Division of Health, Physical Education, and Recreation on the campus of Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

PURPOSE

The purpose of the pilot study was to determine the feasibility of the proposed study, selection of muscles to be analyzed, confront any instrumentation problems which might occur, determine the method or methods of analysis, and to recognize any problems which might render the study less effective.

SELECTION OF SUBJECTS

Three male subjects selected for the pilot study had been members of varsity tennis teams. The three subjects possessed the knowledge to discuss the variations in performing the three basic types of serves and the physical ability to execute the three basic types of serves.

SELECTION OF MUSCLES

Selected studies (Basmajean and Latif, 1957; Broer and Houtz, 1967; Scott, 1963; Thompson, 1969) of the tennis serve or overarm movement pattern sited muscles in the upper arm and shoulder considered to be the prime movers. (Appendix B, Table 2 presents a frequency distribution showing the most often cited muscles used in a serving motion pattern.) The anterior deltoid, middle deltoid, posterior deltoid, biceps, pectoralis major, triceps, and the serratus anterior were identified as the prime movers. The location of the serratus anterior combined with the inability to acquire accurate electromyographical recordings caused it to be dropped from the study. Biceps muscles were eliminated due to involvement only in preparatory stage of service movement (Broer and Houtz, 1967). The remaining five muscles were studied to determine their role in the tennis serve.

PROCEDURE

In order to determine the percentage of muscle involvement in performing the tennis serve, Clarke's (1970) Cable Tension Strength tests were used to obtain a maximum output of each muscle under investigation. The subjects performed several different tests for each muscle in order to determine the cable tension strength test which would render maximum muscle output. (The testing procedures are outlined and follow in the body of the study.)

For example: shoulder flexion, shoulder horizontal flexion, shoulder abduction, shoulder extension, and elbow extension cable tension strength were administered on the anterior deltoid. The shoulder flexion cable tension strength test produced more muscle action potential than the other tests used. All tests were administered exactly by the stated procedures in Clarke and Clarke (1970). (These five tests are illustrations 11 - 15 incorporated in the study.) Each muscle was monitored by the EMG recorder for three trials when performing the selected tension strength tests and executing the tennis serve movement. A percentage of muscle involvement was determined by comparing the EMG recordings when serving and when performing the selected tests. (Table 27 incorporated within this appendix gives evidence)

TESTING PROCEDURE FOR SUBJECTS

1. Each subject met the previously stated criteria.

2. Each subject volunteered for a minimum of two sessions (two hours in length as a minimum).

Session 1 - determine the Cable Strength Test to be used for each muscle

Session 2 - determine the percentage of muscle involvement when performing the tennis serve

3. All subjects were read a set of standardized instructions, supervised so the test would be precisely administered, and administered in the same order.

4. The motor points of each specific muscle were precisely located by use of an Eigen A-Alpha Nerve Stimulator. The skin was cleansed and a mild erythema produced by rubbing the site with electrode paste. The electrode discs were filled with electrode paste and sealed in place with aeroplast and adhesive tape. The electrodes were secured four centimeters apart in a line parallel to the muscle fiber. The lead wires were looped and taped to the skin a few inches from the electrodes to avoid excessive stress on the electrodes during activity and to assure freedom of movement. The electromyographic recordings were made at the following settings: 2MV/FS - Channel 1, 2MV/FS - Channel 2, Low filter 1.5, High filter 2.5k, paper speed one inch

per second.

5. Order of testing muscles

   a) Pectoralis Major - shoulder horizontal flexion test, three trials

      Anterior Deltoid - shoulder flexion, three trials

      Tennis Serving Motion - three trials

   b) Middle Deltoid - shoulder abduction, three trials

      Triceps - elbow extension, three trials

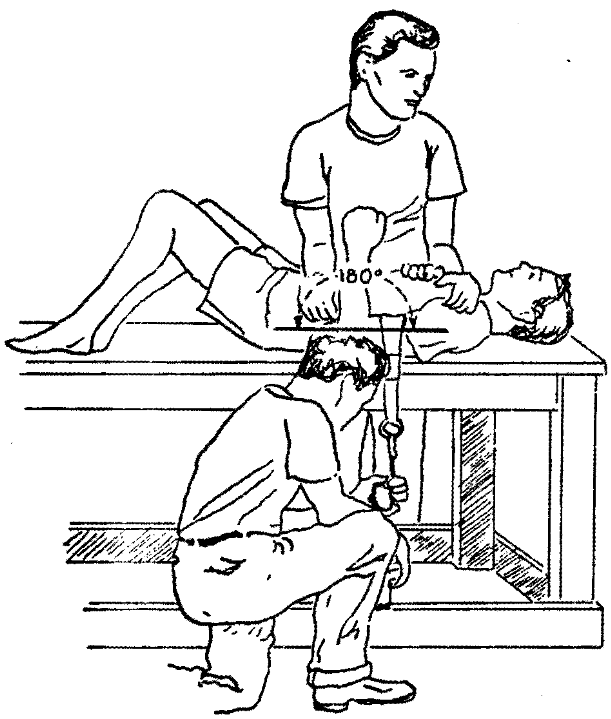
      Tennis Serving Motion - three trials

   c) Posterior Deltoid - shoulder extension, three trials

      Tennis Serving Motion - three trials

Illustration 11

Shoulder Flexion



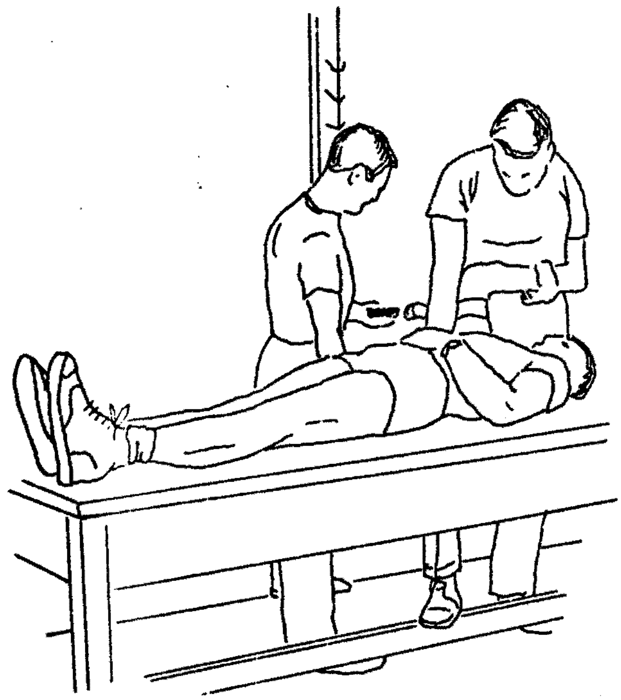
STARTING POSITION. (a) Subject in supine lying position, hips and knees flexed comfortably; free hand resting on chest; (b) Upper arm on side tested close to side; shoulder flexed to 90 degrees; elbow in 90 degrees flexion.

ATTACHMENTS. (a) Regulation strap around upper arm midway between elbow and shoulder joints; (b) Pulling assembly hooked to table runner below subject's arm.

PRECAUTIONS. Prevent shoulder and hip elevation by bracing.

Illustration 12

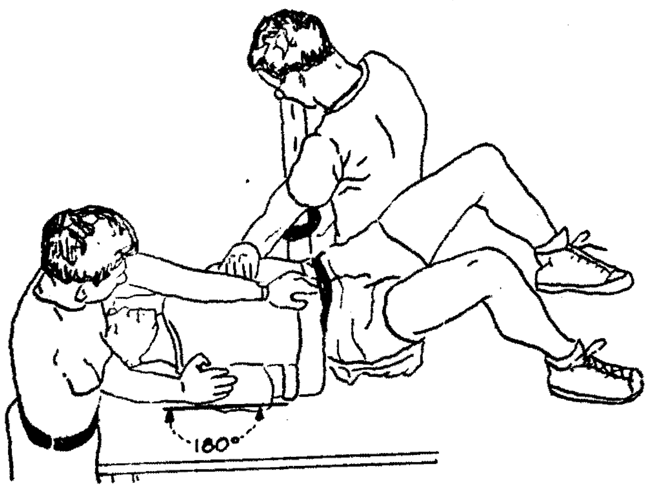
Shoulder Horizontal Flexion



The position for this test is the same as for the Shoulder Extension with the following exceptions: (a) Knees fully extended instead of bent; (b) Pulling assembly attached to wall away from body; (c) Prevent trunk from lateral flexion and shoulders from lifting by bracing at shoulder and hip; require subject to keep head straight; steady subject's arm in testing position by holding wrist.

Illustration 13

Shoulder Abduction



Starting Position. (a) Subject in supine lying position, hips and knwws flexed comfortably, free hand on chest; (b) Upper arm on side tested close to side, elbow at 90 degrees flexion, forearm in mid-prone-supine position; (c) Pad, or folded towel, under buttocks and another across scapula raising body to permit passage of pulling assembly.

Attachments. (a) Regulation strap around distal end of upper arm, just above olecranon process of elbow; (b) Pulling assembly under subject's back and attached to wall opposite side of limb being tested.

Precautions. (a) Prevent shoulder elevation, raising of elbow, and lateral trunk flexion by bracing; (b) Require subject to keep head straight, so as to reduce tendency to flex spine.

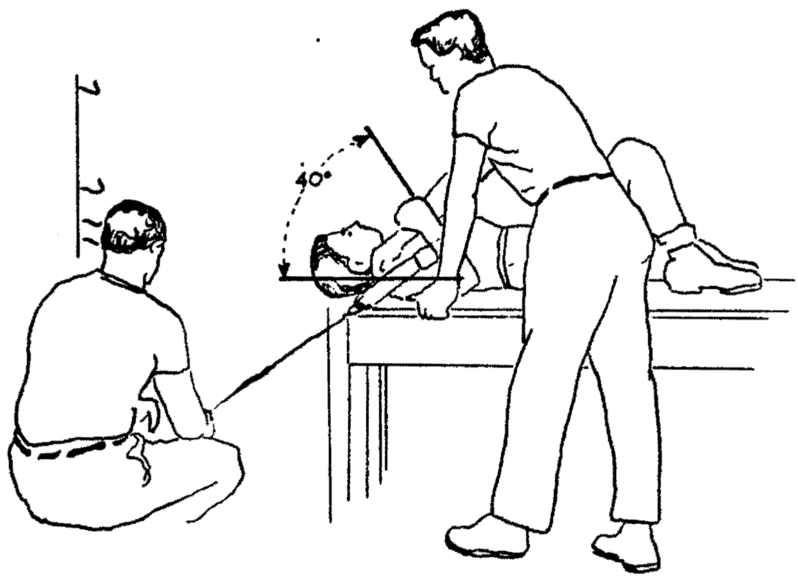
Illustration 14

Shoulder Extension

The position for this test is the same as for Shoulder Flexion with the following exceptions: (a) Shoulder on side being tested flexed to 90 degrees, elbow flexed, forearm directly across body; (b) Pulling assembly attached to wall at subject's head; (c) Prevent shoulder elevation by bracing and prevent shoulder abduction by guiding elbow.

Illustration 15

Elbow Extension



The position for this test is the same as for Elbow Flexion with the following exceptions: (a) Elbow in 40 degrees flexion; (b) Pulling assembly hooked to wall below subject's head; (c) Prevent shoulder elevation by bracing; require subject to keep his head straight so as to reduce tendency to flex spine laterally.

Table 27

Muscle Rank and Composite Rank

Muscles	Rank of Subjects 1	2	3	Average Percentage of All Subjects	Rank
Anterior Deltoid	1	4	2	70	2
Pectoralis Major	5	5	5	22	5
Posterior Deltoid	3	3	3	46	4
Middle Deltoid	4	1	4	56	3
Triceps	2	2	1	100	1

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Page 1 of 2

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Page 2 of 2

AN ELECTROMYOGRAPHIC-CINEMATOGRAPHIC

ANALYSIS OF THE TENNIS SERVE

by

Charles David Taylor

(ABSTRACT)

The tennis serve is considered by tennis specialists to be the most complex and difficult stroke in the game to master. The concept of tennis serving types is accepted; however, research in the area has been greatly neglected. Each of the three basic types of tennis serves requires a specific stroke pattern for the execution of each type of serve.

This investigation was designed to observe systematically the extent of muscular involvement of selected arm and shoulder muscles of ten male varsity tennis players as they performed the twist, slice, and flat tennis serves. The specific muscles analyzed in this study were identified as the prime movers utilized during execution of the tennis serve, specifically, the anterior deltoid, middle deltoid, posterior deltoid, and tricep muscles.

Electromyography was used by the investigator to determine the quantity of muscular involvement as each subject performed a total of thirty-six randomized serving trials. Cinematography synchronized with electromyographic instrumentation was employed to provide the identification of types of serves and the specific racket velocity of each serv-

ing trial.

Analysis of covariance was used to determine significant mean differences of the three serving conditions relative to each muscle under investigation. Duncan's Multiple Range Test was used by the investigator to determine the nature of detected statistical significance.

Analysis of the data revealed no significant difference in the electromyographical responses of the anterior deltoid, middle deltoid, and posterior deltoid muscles related to the performance of the twist, slice, and flat serves. Data analysis also revealed significant differences in electromyographical response of the triceps muscle related to the performance of the twist, slice, and flat serves, specifically, significant differences in muscle action potential were recorded between the twist and slice serves and the twist and flat serves. No significant difference in electromyographical response was found between the slice and flat serves.