AN ANALYSIS OF THE FACTORS WHICH DISTINGUISH
TENNIS PLAYERS OF DIFFERENT
SERVING ABILITIES

THESIS

Presented to the Graduate Council of the
North Texas State University in Partial
Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

By

Margaret Riley-Hagan, B.A.
Denton, Texas
August, 1985

The purpose of this study was to examine selected mechanical factors involved in the tennis serve. Special emphasis was placed on identifying factors which distinguish players of different serving abilities. Ten right-handed female tennis players, five ranked, and five unranked, were evaluated, following filming with a high-speed camera, on the basis of five good and five fault serves.

The ranked players were seen to differ from the unranked players with respect to (a) serving consistency, (b) initial Y-center of gravity values, (c) certain segment angles at the peak of the ball toss and at ball contact, and (d) certain joint angles at the moment of the ball contact.
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</tbody>
</table>
CHAPTER I

INTRODUCTION

Over the last two decades there has been a tremendous growth in the number of individuals participating in the game of tennis (Official United States Tennis Association Yearbook, 1984). An indication of the current popularity of tennis is that in 1980, membership in the United States Tennis Association included 167,624 players, 81,121 of whom were under 19 years of age. In 1981, the total number of members rose to 193,916, including 88,773 members under the age of 19 (Potorski, 1982), while in 1984 there were 242,070 members (Pitsic, 1985). Williams emphasized the popularity of tennis world-wide by stating that tennis is played by 200 million people in 193 countries.

In the game of tennis, a player must master the basic techniques involved in a variety of strokes, which include ground strokes, volleys, overheads, lobs, drop shots, approach shots, and serves. Of all the strokes, the serve is generally considered to be the most difficult to learn (Braden, 1977), and yet serving competency is also considered to be the dominant factor which determines the outcome of a match (Braden, 1977, Fiereck, 1969; Gonzales, 1962; Hopkins, 1976).
The unique characteristics of the serve which distinguish it from all other strokes are the following.

1. The serve is the only stroke executed from a stationary position.
2. The serve is the only means of initiating play.
3. The serve provides the only opportunity to win a point in one stroke.

Although a serve can be executed in a variety of ways, the consistent objective of any serve is to project the ball to a desired area with maximum linear velocity and the appropriate angular velocity. Although the mechanical factors contributing to the attainment of the objectives of a serve have received some scientific scrutiny (Hopkins, 1976; Treadway, 1972), most instructions concerning the way in which a serve is performed have evolved from the opinions of performers and coaches (Braden, 1977; Plagenhoff, 1974; Tennis de France, 1979; World Tennis, 1980).

**Purpose of the Study**

The purpose of this study was to examine selected mechanical factors involved in the tennis serve. Special emphasis was placed on identifying those factors which distinguish players of different serving abilities.

**Delimitations of the Study**

The delimitations in the analysis of the tennis serve included the following.
1. Only young female tennis players with five or less years of experience were used as subjects.
2. All subjects were right-handed servers.
3. The tennis serving ability of each subject was evaluated on the basis of five good and five fault serves.

Limitations of the Study

The limitations in the analysis of the tennis serve included the following.

1. Normal cinematographical analysis limitations were recognized.
2. The anatomical reference points necessary to make various computations were estimates for approximating the actual location.
3. The assumption was made that the subjects' movements occurred in a single plane perpendicular to the optical axis of a single camera.
4. The angles measured were projections of angles and not necessarily true angles.

Definitions of Terms

Service lines.—The lines which are drawn parallel with the net and at a distance of 6.40 m from the net are the service lines.
Right service court.--The right service court is an area between the service lines and the sidelines on each side of the net in which the ball must land when served diagonally from the right of the center mark.

Center service line.--The center service line is drawn half-way between and parallel with the sidelines, dividing the service area into two equal parts.

Center mark.--The center mark is the line which is parallel to the sidelines, perpendicular to the baseline, and divides the baseline in the middle.

Fault serve.--Any service which fails to land in the designated service area is considered a fault serve.

First serve.--The first of two serving attempts for each point played is a first serve.

Flat serve.--A flat serve is a service that is delivered with a minimal amount of spin and a maximal amount of linear velocity.

Good serve.--A good serve is any service landing in the designated service area.

Slice serve.--A slice serve is a service in which sidespin is imparted to the ball, such that when it contacts the court it rebounds to the right of the receiver.
**Topspin serve.**--A topspin serve is a service in which the ball rotates around a horizontal axis such that the top of the ball rotates away from the observer.

**American twist serve.**--An American twist serve is a service which is hit in a manner similar to the topspin serve, containing elements of sidespin and topspin; the spin is more pronounced and the ball toss is further to the left than for the topspin serve.
CHAPTER II

REVIEW OF LITERATURE

A review of related literature revealed that many books and articles have been written on how to perform the tennis serve (Mason, 1974; Tanner, 1976; Ashe, 1976; MacCurdy, 1978; Barnaby, 1969; Tennis, 1979). Several studies have been conducted in which the general purpose was to analyze the service motion. Based on an analysis of the serves of three varsity level players, Holcomb (1962) presented the "basic mechanics" of the serve. Treadway (1972) found that the movement patterns displayed by five varsity level players closely followed the descriptions provided by coaches and professional players. The sequence of joint motion was found to be similar to that used in overhead throwing. Support for this finding is provided by Plagenhoff (1970) and Braden (1977), who likened the motion of the upper limb segments to that used during baseball pitching.

There exists several forms of the service; namely the flat, slice, topspin, and American twist serves. Pasarell (1977) discussed performance differences among service types. Smith (1979) compared the slice and flat serves as performed by five male intercollegiate players. Differences between the serves were recorded for the resultant ball
speed, and both the racquet face position and the horizontal distance between the location of the total body center of gravity and the first toe of the forward foot at the instant of ball contact.

The factors contributing to a successful serve have received some attention. In particular, several investigators have examined aspects of the speed of a serve. Hewitt (1966) developed a service achievement test which incorporated a measure of service speed. Owens (1969) presented relationships among the factors affecting the trajectory of the served ball. Hopkins (1976) attempted to determine the mechanical factors which affect service speed. The results of the study yielded no significant correlations between selected body movements prior to or at the instant of ball contact and the resulting speed of travel of the ball. Beecher (1977), however, reported a significant relationship between ball speed and the speed of hip rotation, and between ball speed and a composite measure of static arm, wrist, and shoulder strength. The relationship between the speed of travel of a served ball and overall playing ability was studied by Sebolt (1970). The speed of ball travel for the forehand and backhand strokes and serves were determined for college-age novice players. Playing ability was determined by performance in a round-robin tournament. Based on the results of the study, it was concluded that the maximum attained service speed was the most stable predictor of overall playing ability.
Another factor affecting the quality of a serve, namely service accuracy, has received some scientific scrutiny. Johnson (1957) found no significant relationship between service accuracy and ball speed. However, it was found that players who achieved the highest combined scores of speed and accuracy also exhibited the greatest amount of trunk rotation, and extension. Colville (1943) examined some of the factors which affect service accuracy for "poor," "fair," and "good" servers. The service ability of the subject was based on a record of the number of defined accurate serves. It was found that the flat serve was the most accurate for all subject groups. Both the good and fair servers contacted the ball at a higher point when they performed an accurate serve. Good servers were also found to extend their upper limb more at ball contact.

Some indication of the mechanical factors distinguishing players of different serving abilities has been provided by Colville (1943), Johnson (1957), and Sebolt (1970). Additional information is available from a study conducted by Huff (1976). In this study the flat serves of two skilled servers were compared with those performed by two unskilled players. The skilled players were found to exhibit greater trunk rotation, lateral flexion, and hyperextension, as well as greater outward rotation of the racquet arm during the backswing phase. The skilled performers also displayed
greater inward rotation of the arm and forearm pronation at the instant of ball contact.

In summary, several authors have attempted to describe the biomechanics of tennis serves and to identify the factors contributing to both service speed and accuracy. However, the research literature would appear to be extremely limited, particularly as it pertains to identifying those factors which distinguish players of different serving abilities.
CHAPTER III

PROCEDURES

The purpose of this study was to examine selected mechanical factors involved in the tennis serves. Special emphasis was placed on identifying those factors which distinguished players of different serving abilities. The methods and procedures that were used for the collection and analysis of data are described in this chapter.

Subjects

The subjects used in this study were ten right-handed female tennis players. All of the subjects were eligible during the interval from October 1, 1981, through September 30, 1982, to compete in tournaments as members of the sixteen and under division as defined by the Official United States Tennis Association Yearbook (1980). In addition, all of the subjects participated in an organized tennis instruction program for at least two years prior to October 1, 1982. The subjects were divided into two groups according to their abilities. Group one consisted of five subjects who at the time of testing had a United States Tennis Association state ranking in the sixteen and under division for the ranking year October 1, 1981 through September 30, 1982. Four of the subjects held a ranking in the state of Texas, while one
subject held a ranking in the state of Oklahoma. The remaining five subjects consisted of tennis players who had no state ranking, but who had received instruction.

**Instrumentation**

A high-speed 16mm motion picture camera (Model DBM-54, Teledyne Camera Systems, Arcadia, CA) was used to obtain film records of each performance. The camera was positioned approximately 1.5 m above ground level and the optical axis directed towards the right lateral side of each subject. Appropriate leveling techniques were used to ensure that the optical axis of the camera was directed along a horizontal line. The camera was aligned so that the entire range of motion of each subject and the racquet was recorded on film. The operating speed of the camera was set at 150 frames per second.

For each trial three sets of number coded cards were included within the field of view of the camera and recorded on film. A known length was positioned horizontally in the anticipated sagittal plane of motion of each subject and filmed. Measurements of the projected length were used in the subsequent determination of a horizontal axis and a linear scale. A timing light and pulse generator used in conjunction with the camera provided a temporal scale.
Racquet and Balls

The racquet used by each subject was the one which each individual preferably used in game situations. All racquets and balls conformed to specifications established by the United States Tennis Association (Official United States Tennis Association Yearbook, 1980, p. 518).

Testing Procedures

All of the testing sessions were conducted on an indoor tennis court at T BAR M Racquet Club (Dallas, Texas). At the beginning of each testing session, each subject was familiarized with the testing procedures and asked to read and sign a consent form for participation (see Appendix A). Measurements of each subject's weight and standing height were also recorded, along with information concerning age, years of tennis played, years of tennis instruction, and years of tournament play.

Prior to the performance of the first trial by each subject, the subject was permitted to perform her preferred "warm-up". At this time each subject was given three new tennis balls which were subsequently used during each of the trials. Each subject was instructed to regard each service as a first service, and to attempt to place the ball within a 900 cm² target area which was marked on the court. During the execution of each serve, the subject was required to remain within an area bounded by the center mark and a mark
30.5 cm to the right of the center mark. The experimental set-up was as illustrated in Figure 1.

At the completion of each trial, the linear coordinates of the point of ball contact on the court with respect to an origin established at the center of the target area were measured and recorded.

**Data Acquisition Procedures**

The motion of the subject, the racquet, and the ball was analyzed for five successful serves (good serves) and five unsuccessful serves (fault serves). Only fault serves which cleared the net were evaluated, so that values for accuracy could be computed. Analysis was done from the initial time, taken to be when the subject's racquet was at the lowest point in the vertical direction upon beginning the service motion, to the final time, when the subject's racquet was at the lowest point in the vertical direction after ball contact. This was done with the aid of a Lafayette 16mm Analyzer (Lafayette Instrument Co., Lafayette, IN) in conjunction with a Numonics Electronic Graphics Digitizer (Model 1200, Numonics Corporation, North Wales, PA), which was interfaced to a Tektronix 4052 Graphics Calculator (Tektronix Inc., Beaverton, OR). The $x$- and $y$- coordinates of the skin overlying the projected image of the following landmarks were digitized and recorded for each film frame:
Fig. 1--Set-Up for Filming of Subjects
1. distal end of the third proximal phalanx of the right and left hand;
2. styloid process of the right and left ulna;
3. lateral epicondyle of the right and left humerus;
4. greater tubercle of the right and left humerus;
5. greater trochanter of the right and left femur;
6. lateral malleolus of the right and left fibula;
7. lateral epicondyle of the right and left femur;
8. distal end of the distal phalanx of the first toe of the right and left foot;
9. crotch;
10. midpoint of the trunk at the level of the suprasternal notch;
11. tragus of the ear;
12. vertex of the head;
13. the four landmarks on the racquet, including the uppermost tip of the frame of the racquet head, each side of the frame of the racquet head, and the end of the racquet handle;
14. the center of the ball.

The body landmark data thus obtained was used in conjunction with a computer program which computed, at each of the instants analyzed, the x- and y- coordinates of the center of gravity of the total body-plus-racquet system, relative to a reference point fixed to the ground. The coordinate center of gravity parameters were smoothed using cubic spline curve fitting
techniques. The magnitudes of each of the component centers of gravity at the instant the thrown ball was at the peak of its trajectory (the so-called ball toss), and the instant the racquet made contact with the ball were identified and recorded.

Instantaneous values at the peak of the ball toss and at ball contact were calculated (as shown in figures 2-5) for the following angles:

1. Segment angle 1, (S1)-orientation of the right arm relative to a right horizontal measured as the counter-clockwise angle;
2. Segment angle 2, (S2)-orientation of the right forearm relative to a right horizontal measured as the counter-clockwise angle;
3. Segment angle 3, (S3)-orientation of the right hand relative to a right horizontal measured as the counter-clockwise angle;
4. Joint angle 1, (J1)-angle of the right elbow joint, with 180 degrees corresponding to full extension;
5. Joint angle 2, (J2)-angle between the right forearm and the racquet, calculated as the counter-clockwise angle from the racquet to the forearm.

A two-way analysis of variance with repeated measures (Nie, 1975) was used to test for main effects and interactions. The level of significance was set at 0.05. Subject groups served as the non-repeating factor and good vs. fault serves
Fig. 2--A Ranked Player at the Peak of the Ball Toss
Fig. 3--An Unranked Player at the Peak of the Ball Toss
Fig. 4--A Ranked Player at Ball Contact
Fig. 5--An Unranked Player at Ball Contact
served as the repeating factor. The instantaneous values of the kinematic parameters, accuracy, time to ball toss, and time to ball contact served as the dependent variables.

When a significant interaction was found, the "studentized range" statistic (Ferguson, 1976) was used to test for significant differences between individual group or treatment means (simple effects). Once again, the level of significance was set at 0.05.

A one-way analysis of variance (Nie, 1975) was conducted to determine whether there was any significant difference between groups with respect to number of attempts to achieve five good serves, various physical characteristics, and tennis history characteristics.
CHAPTER IV

RESULTS

The purpose of this study was to examine selected mechanical factors in serving a tennis ball. Consideration was given to (a) kinematic parameters selected to describe the motion of the performer and (b) an identification of those factors which distinguish players of different serving abilities.

Subjects

Subject characteristics are shown in Table I. There were no statistically significant differences in these physical characteristics between Group 1 and Group 2. A summary of physical characteristics for each subject appears in Appendix B.

TABLE I
Subject Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Age(years)</th>
<th>Height(cm)</th>
<th>Mass(kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (Grp 1)</td>
<td>16.43</td>
<td>162.52</td>
<td>54.65</td>
</tr>
<tr>
<td>SD (Grp 1)</td>
<td>1.16</td>
<td>3.43</td>
<td>2.40</td>
</tr>
<tr>
<td>Mean (Grp 2)</td>
<td>16.32</td>
<td>163.52</td>
<td>53.06</td>
</tr>
<tr>
<td>SD (Grp 2)</td>
<td>1.05</td>
<td>6.89</td>
<td>2.60</td>
</tr>
</tbody>
</table>
Tennis history characteristics were also recorded. With respect to total years of tennis played, a statistically significant difference (p<0.05) was seen between Group 1 ($\bar{X}=6.08$ years, SD=1.30) and Group 2 ($\bar{X}=4.40$ years, SD=1.82). Years of tennis tournament play was also significantly different with the mean of Group 1 equal to 4.80 years (SD=0.76) and the mean of Group 2 equal to 1.60 years (SD=1.14). Years of tennis instruction was not significantly different between Group 1 ($\bar{X}=5.00$ years, SD=1.87) and Group 2 ($\bar{X}=3.20$ years, SD=1.30).

Accuracy

The values for distance from the center of the target and the angle in degrees relative to a x-axis through the center of the target are reported in Table II. No significant differences were seen in the first of these measurements. A statistically significant difference was seen between the mean values for all good serves and all fault serves with respect to the angle of the serve relative to an x-axis through the center of the target. This indicates that the fault serves landed above and to the left of the target, while the good serves landed below and to the left of the target.

X Center of Gravity and Y Center of Gravity Parameters

The X and Y coordinates of the body-plus-racquet system ($X_{CG}$ and $Y_{CG}$) for initial and final values, values at the peak of the ball toss, and values at ball contact are reported in Table III and Table IV, respectively. $X_{CG}$ and
TABLE II

Characteristics of Accuracy of Tennis Serve

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Subject Group</th>
<th>Good Serves</th>
<th>Fault Serves</th>
<th>All Serves</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>107.79</td>
<td>171.59</td>
<td>139.69</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>135.40</td>
<td>160.29</td>
<td>147.84</td>
</tr>
<tr>
<td>A</td>
<td>1+2</td>
<td>121.59</td>
<td>165.93</td>
<td>........</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>217.72</td>
<td>127.20</td>
<td>171.89</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>203.40</td>
<td>138.08</td>
<td>170.74</td>
</tr>
<tr>
<td>B</td>
<td>1+2</td>
<td>210.28**</td>
<td>132.93**</td>
<td>........</td>
</tr>
</tbody>
</table>

*A* = distance in cm from center of target
*B* = angle in degrees relative to x-axis through center of target

**p < .0001** for treatments

YCG initial values were taken to be when the server's racquet reached the lowest point in the vertical direction upon beginning the serve. XCG and YCG final values were taken to be after ball contact when the racquet again reached the lowest point in a vertical direction. While no significant differences were found for any XCG values, a statistically significant interaction was seen with respect to YCG initial values.

An underlining notation is used in Table IV and subsequent tables in the case of significant interactions. A horizontal line is used to illustrate any significant simple effects between serves, while a vertical line was used to indicate any significant simple effects between groups. Group 1 (see Table IV) showed a significantly lower initial
Table III

Characteristics of Selected X-Center of Gravity Measures

<table>
<thead>
<tr>
<th>Characteristic*</th>
<th>Subject Group</th>
<th>Good Serves</th>
<th>Fault Serves</th>
<th>All Serves</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>1</td>
<td>6.64</td>
<td>6.70</td>
<td>6.67</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>6.61</td>
<td>6.58</td>
<td>6.59</td>
</tr>
<tr>
<td>C</td>
<td>1+2</td>
<td>6.63</td>
<td>6.64</td>
<td>...</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>7.31</td>
<td>7.38</td>
<td>7.34</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>7.27</td>
<td>7.23</td>
<td>7.25</td>
</tr>
<tr>
<td>D</td>
<td>1+2</td>
<td>7.29</td>
<td>7.31</td>
<td>...</td>
</tr>
<tr>
<td>E</td>
<td>1</td>
<td>5.90</td>
<td>5.93</td>
<td>5.92</td>
</tr>
<tr>
<td>E</td>
<td>2</td>
<td>6.15</td>
<td>6.13</td>
<td>6.14</td>
</tr>
<tr>
<td>E</td>
<td>1+2</td>
<td>6.03</td>
<td>6.03</td>
<td>...</td>
</tr>
<tr>
<td>F</td>
<td>1</td>
<td>8.59</td>
<td>8.67</td>
<td>8.63</td>
</tr>
<tr>
<td>F</td>
<td>2</td>
<td>7.91</td>
<td>7.84</td>
<td>7.88</td>
</tr>
<tr>
<td>F</td>
<td>1+2</td>
<td>8.25</td>
<td>8.26</td>
<td>...</td>
</tr>
</tbody>
</table>

*C=XCG relative to film reference point at the peak of the ball toss (meters)
D=XCG relative to film reference point at the moment of ball contact (meters)
E=XCG initial relative to film reference point (meters)
F=XCG final relative to film reference point (meters)

A significantly lower initial YCG was also seen in good serves of ranked players compared to unranked players. A similar difference was seen for fault serves. This indicates that a lower initial YCG was beneficial in the performance of a good serve by ranked players, but was not a factor in the performance of good serves by unranked players. None of the other differences were found to be
TABLE IV

Characteristics of Selected Y-Center of Gravity Measures

<table>
<thead>
<tr>
<th>Characteristic*</th>
<th>Subject Group</th>
<th>Good Serves</th>
<th>Fault Serves</th>
<th>All Serves</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>1</td>
<td>2.43</td>
<td>2.46</td>
<td>2.45</td>
</tr>
<tr>
<td>G</td>
<td>2</td>
<td>2.65</td>
<td>2.54</td>
<td>2.59</td>
</tr>
<tr>
<td>G</td>
<td>1+2</td>
<td>2.53</td>
<td>2.50</td>
<td>...</td>
</tr>
<tr>
<td>H</td>
<td>1</td>
<td>2.64</td>
<td>2.71</td>
<td>2.67</td>
</tr>
<tr>
<td>H</td>
<td>2</td>
<td>2.81</td>
<td>2.82</td>
<td>2.82</td>
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<tr>
<td>H</td>
<td>1+2</td>
<td>2.72</td>
<td>2.76</td>
<td>...</td>
</tr>
<tr>
<td>I</td>
<td>1</td>
<td>2.41**</td>
<td>2.46**</td>
<td>2.43</td>
</tr>
<tr>
<td>I</td>
<td>2</td>
<td>2.53**</td>
<td>2.52**</td>
<td>2.52</td>
</tr>
<tr>
<td>I</td>
<td>1+2</td>
<td>2.47</td>
<td>2.49</td>
<td>...</td>
</tr>
<tr>
<td>J</td>
<td>1</td>
<td>2.30</td>
<td>2.35</td>
<td>2.33</td>
</tr>
<tr>
<td>J</td>
<td>2</td>
<td>2.46</td>
<td>2.47</td>
<td>2.47</td>
</tr>
<tr>
<td>J</td>
<td>1+2</td>
<td>2.30</td>
<td>2.41</td>
<td>...</td>
</tr>
</tbody>
</table>

*G=YCG relative to film reference point at the peak of the ball toss (meters)
H=YCG relative to film reference point at the moment of ball contact (meters)
I=YCG initial (meters)
J=YCG final (meters)

**p<0.05 for interaction between groups and serves statistically significant.

Other measurements involving the YCG were analyzed. These included the first and second maximum value for the YCG, the minimum value for YCG, the time to the first and second maximum YCG, the time to the minimum, and the time to the final YCG. The values for these parameters are recorded in Table V. A statistical analysis showed no significant differences for any of these values. Since the important
### TABLE V
Maximum, Minimum, and Temporal Values of Y-Center of Gravity Measures

<table>
<thead>
<tr>
<th>Characteristic*</th>
<th>Subject Group</th>
<th>Good Serves</th>
<th>Fault Serves</th>
<th>All Serves</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>1</td>
<td>2.63</td>
<td>2.67</td>
<td>2.65</td>
</tr>
<tr>
<td>K</td>
<td>2</td>
<td>2.76</td>
<td>2.75</td>
<td>2.76</td>
</tr>
<tr>
<td>K</td>
<td>1+2</td>
<td>2.70</td>
<td>2.72</td>
<td>....</td>
</tr>
<tr>
<td>L</td>
<td>1</td>
<td>2.66</td>
<td>2.72</td>
<td>2.69</td>
</tr>
<tr>
<td>L</td>
<td>2</td>
<td>2.85</td>
<td>2.85</td>
<td>2.85</td>
</tr>
<tr>
<td>L</td>
<td>1+2</td>
<td>2.76</td>
<td>2.79</td>
<td>....</td>
</tr>
<tr>
<td>M</td>
<td>1</td>
<td>2.33</td>
<td>2.36</td>
<td>2.34</td>
</tr>
<tr>
<td>M</td>
<td>2</td>
<td>2.45</td>
<td>2.52</td>
<td>2.49</td>
</tr>
<tr>
<td>M</td>
<td>1+2</td>
<td>2.39</td>
<td>2.44</td>
<td>....</td>
</tr>
<tr>
<td>N</td>
<td>1</td>
<td>0.310</td>
<td>0.316</td>
<td>0.308</td>
</tr>
<tr>
<td>N</td>
<td>2</td>
<td>0.300</td>
<td>0.300</td>
<td>0.300</td>
</tr>
<tr>
<td>N</td>
<td>1+2</td>
<td>0.305</td>
<td>0.303</td>
<td>....</td>
</tr>
<tr>
<td>O</td>
<td>1</td>
<td>0.888</td>
<td>0.942</td>
<td>0.915</td>
</tr>
<tr>
<td>O</td>
<td>2</td>
<td>0.944</td>
<td>0.932</td>
<td>0.938</td>
</tr>
<tr>
<td>O</td>
<td>1+2</td>
<td>0.916</td>
<td>0.937</td>
<td>....</td>
</tr>
<tr>
<td>P</td>
<td>1</td>
<td>0.650</td>
<td>0.690</td>
<td>0.670</td>
</tr>
<tr>
<td>P</td>
<td>2</td>
<td>0.688</td>
<td>0.670</td>
<td>0.679</td>
</tr>
<tr>
<td>P</td>
<td>1+2</td>
<td>0.689</td>
<td>0.670</td>
<td>....</td>
</tr>
<tr>
<td>Q</td>
<td>1</td>
<td>1.374</td>
<td>1.394</td>
<td>1.384</td>
</tr>
<tr>
<td>Q</td>
<td>2</td>
<td>1.314</td>
<td>1.346</td>
<td>1.330</td>
</tr>
<tr>
<td>Q</td>
<td>1+2</td>
<td>1.344</td>
<td>1.370</td>
<td>....</td>
</tr>
</tbody>
</table>

*K=First maximum of YCG relative to film reference point (meters)
L=Second maximum of YCG relative to film reference point (meters)
M=Minimum value of YCG relative to film reference point (meters)
N=Time to first maximum YCG (seconds)
O=Time to second maximum YCG (seconds)
P=Time to minimum YCG (seconds)
Q=Time to final YCG (seconds)
movements involved in the tennis serve were assumed to take place in the Y direction, maximum, minimum, and temporal characteristics were not evaluated for the XCG.

**Segment Angles**

The angle of the arm (S1), forearm (S2), and hand (S3), relative to a right horizontal were each seen to be significantly different between Group 1 and Group 2 at the moment of the peak of the ball toss (see Table VI). The arm of players in Group 1 was seen to drop below the horizontal, creating a segment angle (S1) of 201.03°, while the arm of Group 2 remained above a horizontal, forming an angle of 163.34°. The forearm of Group 1 created an angle (S2) somewhat greater than a line perpendicular to the horizontal (109.47°), contrasted with the forearm of Group 2 which formed a much smaller angle (59.75°) relative to a horizontal. The hand of Group 2 dropped below a horizontal, forming an angle of -8.35°, and with the racquet behind the head, while the hand of Group 2 formed an angle of 51.04° relative to the horizontal. Figure 2 and Figure 3 illustrate subjects whose upper limbs were representative of Group 1 and Group 2, respectively, at the moment of the peak of the ball toss. Also illustrated are the location of the segment and joint angles.

No significant differences were seen in the angle of the arm (S1) nor the angle of the forearm (S2) relative to a right horizontal at the moment of ball contact (see Table VII).
TABLE VI

Segment Angles (Degrees) at the Peak of the Ball Toss

<table>
<thead>
<tr>
<th>Segment Angle Relative to a Right Horizontal</th>
<th>Subject Group</th>
<th>Mean Good Serves</th>
<th>Mean Fault Serves</th>
<th>Mean All Serves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arm (S1) 1</td>
<td>202.19</td>
<td>199.86</td>
<td>201.03*</td>
<td></td>
</tr>
<tr>
<td>Arm (S1) 2</td>
<td>164.27</td>
<td>162.42</td>
<td>163.34*</td>
<td></td>
</tr>
<tr>
<td>Arm (S1) 1+2</td>
<td>183.25</td>
<td>181.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forearm (S2) 1</td>
<td>110.39</td>
<td>108.55</td>
<td>109.47**</td>
<td></td>
</tr>
<tr>
<td>Forearm (S2) 2</td>
<td>60.52</td>
<td>58.97</td>
<td>59.75**</td>
<td></td>
</tr>
<tr>
<td>Forearm (S2) 1+2</td>
<td>85.45</td>
<td>83.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand (S3) 1</td>
<td>52.53</td>
<td>49.55</td>
<td>51.04*</td>
<td></td>
</tr>
<tr>
<td>Hand (S3) 2</td>
<td>-8.30</td>
<td>-8.40</td>
<td>-8.35*</td>
<td></td>
</tr>
<tr>
<td>Hand (S3) 1+2</td>
<td>22.11</td>
<td>20.58</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p<0.05 for between groups
**p<0.01 for between groups

TABLE VII

Segment Angles (Degrees) at Ball Contact

<table>
<thead>
<tr>
<th>Segment Angle Relative to a Right Horizontal</th>
<th>Subject Group</th>
<th>Good Serves</th>
<th>Fault Serves</th>
<th>All Serves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arm (S1) 1</td>
<td>66.91</td>
<td>67.45</td>
<td>67.18</td>
<td></td>
</tr>
<tr>
<td>Arm (S1) 2</td>
<td>45.11</td>
<td>46.16</td>
<td>45.63</td>
<td></td>
</tr>
<tr>
<td>Arm (S1) 1+2</td>
<td>56.01</td>
<td>56.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forearm (S2) 1</td>
<td>81.31</td>
<td>82.06</td>
<td>81.69</td>
<td></td>
</tr>
<tr>
<td>Forearm (S2) 2</td>
<td>71.71</td>
<td>72.48</td>
<td>72.09</td>
<td></td>
</tr>
<tr>
<td>Forearm (S2) 1+2</td>
<td>76.51</td>
<td>77.27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand (S3) 1</td>
<td>91.15*</td>
<td>93.04**</td>
<td>92.10*</td>
<td></td>
</tr>
<tr>
<td>Hand (S3) 2</td>
<td>99.32**</td>
<td>97.04**</td>
<td>98.63*</td>
<td></td>
</tr>
<tr>
<td>Hand (S3) 1+2</td>
<td>95.24</td>
<td>95.49</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p<0.005 for between groups
**p<0.05 for interaction between groups and serves
The hand (S3) relative to a right horizontal was seen to have a statistically larger angle at the moment of ball contact in Group 2 (98.63°) than Group 1 (92.10°). Also a significant interaction was seen with respect to this parameter, although no significant differences were observed between fault and good serves within either group. Group 1 demonstrated a smaller angle when serving a good serve, while Group 2 demonstrated a smaller angle when serving a fault serve. The position of the hand for Group 1 when executing a good serve (91.15° relative to a right horizontal) was significantly different than the position of the hand for Group 2 when executing a good serve (99.32° relative to a right horizontal). A significantly larger angle was also seen when comparing fault serves for Group 2 (R=97.94°) and Group 1 (R=93.04°). Figures 4 and 5 demonstrate the position of segment and joint angles at ball contact by subjects representative of Group 1 and Group 2, respectively. This trend indicates that placement of the hand nearly perpendicular to a right horizontal contributes to the performance of a successful serve by a ranked players and is a characteristic which distinguishes ranked players from unranked players. Unranked players tend to hold the racquet at a slightly greater angle (98.63° vs. 92.10°).

**Joint Angles**

The results concerning the angle at the right elbow (J1), and the angle between the forearm and the racquet
(J2), at the moment of the ball toss are reported in Table VIII. No significant main effects or interactions were found. Figures 2 and 3 illustrate the position of players of Groups 1 and 2, respectively, at the moment of the ball toss.

**TABLE VIII**

Projected Joint Angles (Degrees)

at the Peak of the Ball Toss

<table>
<thead>
<tr>
<th>Projected Joint Angle</th>
<th>Subject Group</th>
<th>Good Serves</th>
<th>Fault Serves</th>
<th>All Serves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow (J1)</td>
<td>1</td>
<td>88.19</td>
<td>88.69</td>
<td>88.43</td>
</tr>
<tr>
<td>Elbow (J1)</td>
<td>2</td>
<td>77.67</td>
<td>76.66</td>
<td>78.66</td>
</tr>
<tr>
<td>Elbow (J1)</td>
<td>1+2</td>
<td>82.93</td>
<td>84.17</td>
<td>....</td>
</tr>
<tr>
<td>(J2)*</td>
<td>1</td>
<td>239.45</td>
<td>239.01</td>
<td>239.23</td>
</tr>
<tr>
<td>(J2)</td>
<td>2</td>
<td>248.80</td>
<td>247.40</td>
<td>248.10</td>
</tr>
<tr>
<td>(J2)</td>
<td>1+2</td>
<td>244.12</td>
<td>243.20</td>
<td>....</td>
</tr>
</tbody>
</table>

*J2=Angle between the right forearm and the racquet

Table IX presents the results for angles J1 and J2 at the moment of ball contact. No significant differences for the elbow angle (J1) were observed at ball contact. The angle between the right forearm and racquet (J2) however, was found to be significantly larger when comparing means of all serves of Group 1 (169.59°) with the means of all serves of Group 2 (153.45°). Also a significant interaction was seen between groups (ranked and unranked) and serves (good vs. fault) for J2. A further evaluation of the interaction revealed that neither group showed any significantly different
values between good and fault serves. However, the mean angle for Group 1's good serves (170.16°) and the mean angle for Group 2's good serves (152.39°) were found to be significantly different. Group 1 also demonstrated a significantly larger angle for J2 upon serving fault serves (169.02°) than did Group 2 (154.52°) in performing fault serves. These results indicated that the ranked players were observed to have a consistently larger angle (J2) at the time of ball contact than did the unranked players. As illustrated in Figures 4 and 5, the racquet of the players in Group 1 was more aligned with the forearm, indicating a neutral position of the wrist, while that of Group 2 indicated a position of wrist hyper-extension.

### TABLE IX
Projected Joint Angles (Degrees) at Ball Contact

<table>
<thead>
<tr>
<th>Projected Joint Angle</th>
<th>Subject Group</th>
<th>Good Serves</th>
<th>Fault Serves</th>
<th>All Serves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elbow (J1)</td>
<td>1</td>
<td>165.62</td>
<td>165.28</td>
<td>165.45</td>
</tr>
<tr>
<td>Elbow (J1)</td>
<td>2</td>
<td>153.44</td>
<td>153.70</td>
<td>153.51</td>
</tr>
<tr>
<td>Elbow (J1)</td>
<td>1+2</td>
<td>159.53</td>
<td>159.49</td>
<td>...</td>
</tr>
<tr>
<td>(J2)</td>
<td>1</td>
<td>170.16**</td>
<td>169.02**</td>
<td>169.59*</td>
</tr>
<tr>
<td>(J2)</td>
<td>2</td>
<td>152.39**</td>
<td>154.52**</td>
<td>153.45*</td>
</tr>
<tr>
<td>(J2)</td>
<td>1+2</td>
<td>161.27</td>
<td>161.77</td>
<td>...</td>
</tr>
</tbody>
</table>

*p<0.05 for between groups
**p<0.05 for interaction between groups and serves
Time to Ball Toss and Time to Ball Contact

A statistical analysis was also done on the time to ball toss and the time to ball contact (see Table X). Initial time (t=0) was taken to be when the server's racquet reached the lowest point in the vertical direction upon beginning the serve. These results demonstrate that differences observed in serving characteristics were not due to temporal differences in the ball toss or in ball contact.

TABLE X

<table>
<thead>
<tr>
<th>Parameter (Seconds)</th>
<th>Subject Group</th>
<th>Good Serves</th>
<th>Fault Serves</th>
<th>All Serves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball toss time</td>
<td>1</td>
<td>0.571</td>
<td>0.621</td>
<td>0.596</td>
</tr>
<tr>
<td>Ball toss time</td>
<td>2</td>
<td>0.586</td>
<td>0.587</td>
<td>0.586</td>
</tr>
<tr>
<td>Ball toss time</td>
<td>1+2</td>
<td>0.579</td>
<td>0.603</td>
<td></td>
</tr>
<tr>
<td>Ball contact time</td>
<td>1</td>
<td>0.928</td>
<td>0.975</td>
<td>0.951</td>
</tr>
<tr>
<td>Ball contact time</td>
<td>2</td>
<td>0.959</td>
<td>0.957</td>
<td>0.958</td>
</tr>
<tr>
<td>Ball contact time</td>
<td>1+2</td>
<td>0.943</td>
<td>0.966</td>
<td></td>
</tr>
</tbody>
</table>

Consistency

The number of attempts necessary to achieve five good serves was also analyzed (see Table XI). It was observed that Group 1 needed a mean of 7.60 tries to execute five good serves, while Group 2 needed a mean of 12.40 tries. These differences were statistically significant and demonstrate as expected that ranked players perform a successful serve more consistently than do unranked players.
TABLE XI
Number of Attempts to Achieve Five Successful Serves

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Group</th>
<th>Number of Attempts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>1</td>
<td>7.60*</td>
</tr>
<tr>
<td>SD</td>
<td>1</td>
<td>1.14</td>
</tr>
<tr>
<td>Mean</td>
<td>2</td>
<td>12.40*</td>
</tr>
<tr>
<td>SD</td>
<td>2</td>
<td>2.07</td>
</tr>
</tbody>
</table>

*p<0.005 for difference in number of attempts

Discussion

Ranked (Group 1) and unranked (Group 2) players were observed to have similar physical characteristics. These two groups were also similar with respect to years of tennis instruction, but ranked players had played significantly more years of tennis and significantly more tournaments. Therefore, while instruction is important in learning to become a good server, practice and tournament play appear to contribute greatly to this ability.

Accuracy was not significantly different between ranked and unranked players, but ranked players were more consistent in their performance of a good serve. This indicates that good servers do not necessarily have the ability to hit closer to a target, but that they are less likely to serve a fault serve when aiming for a certain area of the service court.

No differences were observed in the time to the peak of
the ball toss or the time to ball contact. Ranked and unranked players apparently take the same amount of time to perform these movements in their serves.

Many of the XCG and YCG characteristics were seen to be similar for both groups. These include the XCG and YCG at the peak of the ball toss and at ball contact, the final XCG and YCG, the initial XCG, and all maximal, minimal, and temporal YCG values.

A significantly lower YCG was seen in ranked players compared to unranked players for good serves and fault serves. These results indicate that ranked players begin their serves in a crouched position, although this position apparently does not contribute to the attainment of a greater height of the person-plus-racquet system at ball contact.

Several of the segment and joint angles were different at the peak of the ball toss between groups. As illustrated in Figure 2, the ranked players tended (a) to hold the upper limb such that the arm was below a horizontal, (b) to hold the forearm approximately perpendicular to a horizontal, forming an angle at the elbow joint of approximately 90°, and (c) to hold the hand pointing away from the head. The unranked players, by contrast, (see Figure 3) tended to hold the arm above a horizontal with the forearm pointing toward them. This formed a similar angle at the elbow joint as the ranked players, but with the hand and racquet pointing down below the head. It is interesting to note that the position
of the unranked players, the "back-scratch" position advocated by some instructors (Seaton, 1965, p. 298) was not that adopted by the ranked players at the peak of the ball toss.

Since most players pause at the peak of the ball toss, the following advantages for the position of the upper limb of the ranked players is proposed: the ranked players are able, following the peak of the ball toss, to have a continuous motion as the racquet drops down behind the head and rises to meet the ball. The unranked players on the other hand, having paused in the back scratch position, have in essence stopped the momentum of the racquet head prior to ball contact. The smoother motion demonstrated by the ranked players following the peak of the ball toss may well contribute to their more consistent execution of a good serve.

At the moment of ball contact ranked and unranked players differed significantly in the position of the hands and of the racquet-forearm angle (see Figures 4 and 5). The hand of the ranked players was nearly perpendicular to a horizontal with the angle of the forearm and racquet approaching 180°. The unranked players, by contrast, appeared to "push" the ball by laying back the wrist and by placing the racquet beneath the ball. This position contributed to the significantly larger angle of the hand relative to a horizontal and the significantly smaller angle between the forearm and racquet at ball contact.
The differences seen at ball contact between the ranked and unranked players might be partially explained by the different grips that each player chose to grasp the racquet. It was observed that the unranked players often served with an Eastern grip, which contributed to the hyperextended wrist position seen at ball contact. The Continental grip employed by the ranked players allowed them to contact the ball with the racquet and forearm approximately parallel to each other. This grip also permitted the placing of more spin on the ball, again contributing to the more consistent performance of a good serve by the ranked players.
CHAPTER V

SUMMARY AND CONCLUSIONS

Introduction

The purpose of this study was to examine selected mechanical factors involved in the tennis serve, with special emphasis placed on identification of those factors which distinguish players of different serving abilities.

Review of Literature

A review of literature revealed that very few scientific studies existed which analyzed the mechanical differences between the serves of players of different abilities. However, several authors have discussed the mechanical factors relating to serving a tennis ball. Holcomb (1962) and Treadway (1972) described the movement patterns of the serve, and Plagenhoff (1970) and Braden (1977) discussed the similarities between serving and baseball pitching. Other authors such as Pasarell (1977) and Smith (1979) have discussed spin and the importance it plays in tennis performance. The speed of a serve and its contribution to serving success was evaluated by Hewitt (1966), and Owens (1969), Hopkins (1976), Beecher (1977), and Sebolt (1970). Sebolt found that maximum attained service speed was the most stable predictor of overall playing ability. Service
accuracy was examined by Johnson (1957) and Colville (1943). Huff (1976) compared some selected mechanical factors between two skilled and two unskilled players, and found that the skilled players differed from the unskilled players in their trunk rotation and arm rotation during the backswing phase, and in their arm and forearm rotation at the instant of ball contact.

**Procedures**

Ten right-handed female subjects were used, five ranked and five unranked players. Each subject served until she had performed five good and five fault serves. These serves were subsequently analyzed and used to obtain selected XCG and YCG values, certain segment angles relative to a right horizontal, and specific joint angles.

A two-way analysis of variance with repeated measure was used to test for main effects and interactions with the level of significance set at 0.05. Subject groups served as the non-repeating factor, and good vs. fault serves served as repeating factor. The subsequent statistical analysis consisted of an analysis of the simple effects in the case of a significant interaction. A one-way analysis of variance was conducted to determine whether there was any significant difference between groups with respect to number of attempts to achieve five good serves, various physical characteristics, and tennis history characteristics.
Results and Discussion

The physical characteristics of the ranked and unranked players were observed to be similar. The two groups were also found to be similar in their tennis playing history, although the ranked players had participated in significantly more tournaments, and had played tennis for a significantly greater number of years. Instruction, therefore, while contributing to the development of a good server, needs to be accompanied by practice and tournament play.

Ranked players were significantly more consistent than the unranked players in their achievement of a good serve, but did not place their serves significantly closer to a specific target area. Good servers are less likely to deliver a fault serve when aiming for a certain area of the service court, but do not appear to hit closer to a target than intermediate-level servers. No temporal differences were seen in the time to ball toss or the time to ball contact between groups. Apparently, during the performance of a serve, ranked and unranked players take the same amount of time to accomplish these movements.

At the peak of the ball toss and at ball contact, XCG and YCG values were observed to be the same for the two groups. Also similar values were seen for XCG and YCG final values, and maximum, minimum, and temporal YCG values. While initial XCG was seen to be similar for both groups, initial YCG was significantly lower for ranked compared
to unranked players during good and during fault serves. These findings indicate that ranked players begin their serves in a crouched position, but that this position contributes little to the development, at the time of ball contact, to a greater person-plus-racquet system height.

One of the most striking differences observed between groups was that of the segment and joint angles. As illustrated in Figures 2 and 3, at the peak of the ball toss the ranked players held the arm below a horizontal, while the unranked players held it above a horizontal. The forearm of Group 1 was observed to form a segment angle greater than 90° relative to a horizontal, while that of the unranked players formed an angle substantially less than 90° relative to a horizontal. The angle at the elbow joint was similar for both groups, as was the angle between the racquet and forearm. Although these angles were similar, the ranked players pointed the elbow downward with the hand pointing away from the body. This is contrasted with the ranked players who had the elbow pointing upward with the hand and racquet positioned below the head.

At the moment of ball contact ranked and unranked players had significantly different positions for the hand segments and for the angles of the racquet and forearm (see Figures 4 and 5). While the hand of the ranked players was nearly perpendicular to a horizontal with the angle between the forearm and racquet approaching 180°, the unranked players
tended to hyperextend the wrist, placing the hand beneath the ball, to form a significantly smaller angle between the forearm and racquet.

**Conclusions**

It was seen from the results of this study that players of different serving abilities are distinguished by the following factors.

1. Ranked players are more consistent in the execution of a good serve than unranked players.

2. Different positions of the arm, forearm, and hand are adopted at the peak of the ball toss for ranked and unranked players. Ranked players hold the upper limb away from the body while unranked players adopt the "back scratch" position with the racquet pointing down behind the head.

3. Different positions of the hand are demonstrated by ranked players than for unranked players at ball contact. Unranked players tend to hyperextend the wrist at ball contact more than do ranked players.

4. Ranked players begin good serves and fault serves in a more crouched position than do unranked players.

**Recommendations**

Based on the findings of this study the following recommendations are made for further study.
1. An examination of the differences between servers of different abilities while serving flat, slice, and topspin serves.

2. An analysis, using three-dimensional cinematographical techniques, of the mechanical factors distinguishing players of different serving abilities.

3. An analysis of the influence of grip preference on the mechanical factors involved in a tennis serve.

4. An examination of the velocity of a served tennis ball and the importance it plays in distinguishing players of different serving abilities.
APPENDIX A

INFORMED CONSENT

I.D. # ____________________________ DATE: ________

NAME: ____________________________

AGE: ____________________________

BIRTHDATE: ______________________

HEIGHT: __________________________

WEIGHT: __________________________

AGE YOU STARTED LEARNING AND PLAYING TENNIS: ______________________

NUMBER OF YEARS HAVE PLAYED TENNIS: ______________________

TOURNAMENT PARTICIPANT: Circle YES or NO

IF YES, HOW MANY YEARS: ______________________

RACQUET: ______________________

SIZE GRIP: ______________________

RACQUET WEIGHT: ______________________

YEARS OF INSTRUCTION: ______________________

I, ____________________________, fully understand the nature of this study and the risks involved and agree to participate.

__________________________________
(SIGNATURE OF PARTICIPANT)

ADDRESS: ______________________ PHONE NUMBER: ________
## APPENDIX B

### PHYSICAL CHARACTERISTICS FOR EACH SUBJECT

<table>
<thead>
<tr>
<th>Subject (I.D. #)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Age (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1*</td>
<td>162.7</td>
<td>55.57</td>
<td>18.25</td>
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<tr>
<td>1-2</td>
<td>161.6</td>
<td>55.00</td>
<td>15.33</td>
</tr>
<tr>
<td>1-3</td>
<td>167.5</td>
<td>58.18</td>
<td>16.58</td>
</tr>
<tr>
<td>1-4</td>
<td>162.9</td>
<td>52.95</td>
<td>16.50</td>
</tr>
<tr>
<td>1-5</td>
<td>157.9</td>
<td>52.05</td>
<td>15.50</td>
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<td>163.3</td>
<td>53.18</td>
<td>16.17</td>
</tr>
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</table>

*=Group 1, Subject 1*
BIBLIOGRAPHY


Mason, E., Tennis, Boston: Allyn and Bacon, 1974.


Pirsic, N., Membership Committee, United States Tennis Association, personal communication, June, 1985.


Potorski, J., Membership Committee, United States Tennis Association, personal communication, January 13, 1982.


Smith, S.L., Comparison of Selected Kinematic and Kinetic Parameters Associated with the Flat and Slice Serves of Male Intercollegiate Tennis Players, (Ph.D. dissertation, Indiana University, 1979).

Tanner, R., Roscoe Tanner's Serving Secrets, Tennis, April, 1980, 45-47.

Tennis, Keys to the Serve, February, 1979, 75-81.

Tennis de France, September, 1978, 75.

Williams, O., Texas Professional Tennis Association Meeting, personal communication, January 16, 1982.