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ENERGY COST OF RACQUETBALL  
THESIS FOR THE DEGREE OF M. A.  
MICHIGAN STATE UNIVERSITY

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THOMAS DORAN McKIE

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## ABSTRACT

### ENERGY COST OF RACQUETBALL

By

Thomas Doran McKie

The purpose of this study was to determine the energy cost of playing racquetball each of the three different ways: singles, cut-throat, and doubles.

Four male undergraduate students of Oklahoma State University who were skilled racquetball players volunteered as subjects for this study.  $O_2$  intake was measured as the subjects exercised on a treadmill at two different work loads while their heart rate was monitored through telemetry. Oxygen intake was plotted on a graph with heart rate establishing an oxygen consumption prediction line in relation to heart rate.

The subjects played all three types of racquetball against all possible combinations of opponents. Heart rates were monitored and oxygen intakes predicted for each subject for each type of play and for the group for each type of play. Calorie cost was figured for each type of play.

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Oxygen intake per kilogram of body weight per minute was calculated for each type of play and a 't' ratio used to check for a significant difference. Using Cooper's aerobic point chart for singles as a base, point value guides were figured for cut-throat and doubles.

Major findings included:

1. Mean heart rate response was highest when playing singles (171.5) and substantially lower in the other two (cut-throat, 148.7 and doubles, 144.8).
2. Mean predicted oxygen was 2.40 liters per minute during singles, 1.75 during cut-throat, and 1.63 during doubles.
3. Calorie Cost when playing singles was 12 calories per minute and 720 calories per hour, 8.75 and 525 when playing cut-throat, and 8.15 and 489 when playing doubles.
4. There was a significant difference in energy cost between singles and cut-throat and singles and doubles but no significant difference between cut-throat and doubles.
5. Guidelines for using Cooper's aerobic point chart for handball and applying it to racquetball are: singles, as is; cut-throat, 3/4 of singles; and doubles, 2/3 of singles.

in

Department

ENERGY COST OF RACQUETBALL

By

Thomas Doran McKie

A THESIS

Submitted to  
Michigan State University  
in partial fulfillment of the requirements  
for the degree of

MASTER OF ARTS

Department of Health, Physical Education, and Recreation

1972

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## ACKNOWLEDGEMENTS

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Special acknowledge goes to Dr. A. B. Harrison, Director of Graduate Studies in HPER at Oklahoma State University, for his guidance, untiring assistance, and many helpful suggestions.

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## CHAPTER I

### INTRODUCTION

In recent years much has been written about the state of health of the citizens of our country. Research<sup>6</sup> indicates that a conscientiously followed program of physical activity is likely to increase the physical fitness of an individual or, if he is already at a desirable level, allows him to remain at that level.

Physical fitness is important to everyone. While it is not a cure-all it has been shown to lessen the chances of heart trouble, reduce the amount of medication needed for diabetes, improve cardiovascular efficiency, improve muscle tone, and lessen the chance or severity of stomach ulcer. In general, then, improved physical fitness can help a person feel better, allow his body to function more efficiently, reduce the possibilities or severities of illness, and consequently function more efficiently both on the job and at home.<sup>6</sup>

Racquetball is a relatively new sport that is being used by many as their program of physical activity. The game is a derivation of handball and is played on the same court with basically the same set of rules. A racquet resembling a short-handled tennis racquet and

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a ball made of black molded rubber that is softer and less lively than a handball and slightly smaller than a tennis ball are the only pieces of equipment needed. However participation is limited by the facilities required -- a four wall 40' x 20' x 20' court -- and thus is played mainly at colleges and universities, YMCAs, and health clubs where these courts are found.

Three different types of racquetball are played with the number of players being the determining factor. Singles involving two players competing against each other and doubles where two players form a team and compete against another team of two players are officially recognized forms of the game. A third, three-man which is commonly called cut-throat, is not an official game but is commonly played. In it the three players rotate with the server always competing against the other two players.

### Statement of the Problem

It was the intent of this study to compare the energy cost of racquetball while playing singles, cut-throat, and doubles.

After obtaining a comparison of the energy cost of these types of racquetball play, the results were related to the "aerobics" point chart.<sup>1</sup>

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### Assumption of the Problem

Heart rate and oxygen intake were assumed to have a linear relationship. The oxygen intake from work on the treadmill was assumed to be equivalent to that obtained in actually playing the game.

The subjects were experienced players and therefore it was assumed there was no learning or conditioning that took place during the study.

The prior physical condition and age of the subjects were assumed to have no effect on results since their performances in the court were comparable.

The subjects were all tested near the noon hour and therefore the time of day was not considered as affecting one's performance differently than another.

Finally it was assumed that the pulse rate and energy cost of the subjects were not affected through emotional response to the telemetry equipment.

### Delimitation of the Problem

Four skilled male racquetball players volunteered to be the subjects in this study. They were all under graduate students at Oklahoma State University and ranged in age from 20 - 26 years.

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### Limitation of the Problem

The number of subjects had to be held down to four due to the number of interactions involved in using the three different types of play.

The subjects were all volunteers and were not randomly selected due to an attempt to equalize proficiencies.

### Significance of the Study

Dr. Kenneth H. Cooper, M.D., M.P.H., Major, V.S.A.F. Medical Corps, has made extensive studies of the energy costs of various forms of physical activities. He has then translated these energy costs into "aerobic" points on the basis of the oxygen required by the activity. The reason behind these "aerobic" points was a desire to provide a quantitative field measure of physical activity. By attaining a minimum of thirty (30) points per week and exercising at least four times per week or every other day, an individual would maintain himself in or above Dr. Cooper's "good" physical fitness category.

Among the activities that were incorporated into the point system, running, swimming, and cycling gave the most reliable measures. In these, both intensity and duration could be easily measured. However, because of their competitive qualities, other sports such as racquetball have drawn the interests of many who desire to use the

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"aerobic" point system. In this manner they achieved their desirable physical fitness level by participation in an activity they enjoyed.

Dr. Cooper has a point chart for playing singles handball. He has allotted six points for forty minutes of continued activity. (The author felt that due to the similarities in the games of handball and racquetball those points could also apply to racquetball. In both games the same court and rules are used and while a racquetball player has a longer reach his opponent can place the ball more accurately). However, many players desired to play doubles or cut-throat in contrast to singles. Some facilities would not allow singles play due to the great demand for court usage. Other players simply preferred a less strenuous activity. By comparing the energy cost of all three types of play it was possible to expand the point chart to the other two types of racquetball (cut-throat and doubles). This provided a guide enabling those who did not play singles to still accurately follow the "aerobics" system to evaluate their physical activity.

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## CHAPTER II

### REVIEW OF LITERATURE

This review of the related literature is presented in three different phases: (1) Literature showing the validity of a linear relationship between heart rate and oxygen consumption, (2) Studies in which telemetry has been used to obtain exercise heart rates in athletic events, and (3) Studies showing that handball, paddleball and racquetball are considered physically active sports.

#### Heart Rate and Oxygen Consumption Relationships

In looking for a practical method of estimating an individual's maximal oxygen intake Maritz, Morrison, Peter, Strydom, and Wyndham<sup>18</sup> conducted a study at Johannesburg, South Africa. They tested thirty-two subjects over different work loads measuring heart rate, work and oxygen intake. Their conclusions were that heart rate is a linear function of oxygen intake over most of the range of work up to the individual's maximum. However, the linear line differs from individual to individual and therefore several heart rates should be measured before plotting the line.

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At the University of Milano, Italy, Margaria, Aghemo, and Rovelli<sup>17</sup> also looked for an indirect determination of maximal oxygen consumption. They found that the heart rate is a linear function of the oxygen consumption and that the maximal heart rate is a constant in a class of individuals. Therefore the maximal oxygen consumption can be determined from heart rate measurements at sub-maximal work rates. They found this reliable within  $\pm 7\%$ .

Astrand and Ryhming<sup>2</sup> at Stockholm, Sweden, found that for a submaximal work level -- heart rates at a steady state between 125 and 170 -- there is a linear relationship between metabolism and heart rate.

In a study comparing maximal oxygen uptake values determined by predicted and actual methods Glassford, Baycroft, Sedgwick, and Macnab<sup>10</sup> tested twenty-four subjects between the ages of seventeen and thirty-three. They randomly administered three direct tests and one indirect -- the Astrand-Ryhming nomogram. Correlation coefficients between all four were found to be significant. They concluded that the Astrand-Ryhming nomogram appears to produce a good estimation of maximal oxygen intake.

Bradford, Huntzicker, and Fruehan<sup>4</sup> at the University of California (Berkeley) conducted a study simultaneously comparing respirometer and heart rate telemetry techniques as measures of human energy expenditure. Heart rate was found to be a good predictor of energy

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expenditure in each of six activity levels in twenty-four young adult males. They found a coefficient of regression greater than 0.95 with the standard error of estimate less than 0.64 kilocalories per minute in twenty-one of the twenty-four subjects.

Malhorta, Gupta, and Rai<sup>16</sup> ran a study on seven subjects at the Defence Institute of Physiology in Delhi, India. While examining pulse count as a measure of energy expenditure they found a linear correlation between the two. Two components of each curve were found -- one for less than ninety-five beats per minute and one for greater than ninety-five beats per minute. Percentages of error ranged from 0.3 to 7.0%. Also significant differences were found in the coefficient of variations for different subjects showing that separate regression lines are required for each of them.

#### Activities Monitored by Telemetry

Since its inception in 1960 at the University of Michigan, the wireless transistorized telemetry transmitter has been used in a number of studies dealing with monitoring heart rates during physical activity.

Kozar<sup>13</sup> at the University of Michigan telemetered heart rates during gymnastics routines. The subject's heart rate was recorded during work on the parallel bars, high bar, still rings and side horse. Kozar had the subject go through a routine that included stunts of average difficulty and a routine including complex stunts. Peak heart

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rates were 169 beats per minute for the difficult routine on the parallel bars and 150 for the average routine. Peaks of 140 and 165 were obtained on the high bar. Still rings performances were 165 and 150 and only the difficult routine was performed on the side horse yielding a peak of 160 beats per minute. Kozar concluded that there was a strong correlation between work load and heart rate.

Also at the University of Michigan, Kozar and Hunsicker<sup>14</sup> conducted a study to determine the relative strenuousness of six selected sports. Using twenty-three adult men, tests were conducted in handball, paddleball, tennis, badminton, volleyball, and bowling. Using the mean heart rate as the criterion for determining severity the means included: handball, 166; paddleball, 164; tennis, 159; badminton, 150; volleyball, 136; and bowling, 99. The results indicated that handball, paddleball, tennis, and badminton do not differ significant from each other but are significantly greater than volleyball and bowling. Volleyball was also significantly greater than bowling. All of the top four sports reached peak heart rates that were similar (180). All reached their peak by eight minutes except handball which didn't reach its peak until twenty-four minutes. Also there was much variability throughout activity.

In a masters thesis at Penn State, Donatelli<sup>8</sup>, tested ten middle aged men by a telemetric assessment of their cardiovascular work in paddleball, running, and calisthenics. She found running was more strenuous than either of the other two activities. Paddleball and

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calisthenics were not significantly different.

Skiers were tested at Middleburg College, Vermont by Hanson.<sup>12</sup> Four members of the college ski team had their heart rate telemetered in downhill racing, cross country racing and jumping from a 50 meter jump. Results found were that heart rates increased from a resting rate to a pre-start rate by between 100% to 219%. During the events heart rates increased only 5% to 21% above pre-start figures to a high of 200 beats per minute for cross country in one subject. Two minutes after the finish in jumping the heart rate was down to between -2 and 23 beats per minute above the pre-start rates.

Bowles and Sigerseth<sup>3</sup> used telemetry to gain responses to pace patterns in the one mile run. Sixteen varsity track athletes at the University of Oregon were tested during running a mile under 4:30. Three different paces were used: a steady pace, a fast-slow pace and a slow-fast pace. Heart rates changes were found to be significant after the first 220 yards (twenty-five seconds). Values found were a mean of 125 after warm-up and 177 after 220 yards. A range of 174 - 208 occurred at the end of the run with a mean of 193. The testers commented that heart rate responses were chosen because of their close relationship to cardiac output and oxygen consumption and, as a single factor, they quite accurately depict the adjustment of the subject to exercise.

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McArdle and others<sup>19</sup> at Queens College also telemetered responses to track events. Their subjects included eighteen varsity trackmen and four untrained subjects all of whom were tested in the 60, 220, 440, 880, one mile and two mile. They found: One, that the heart rate immediately preceding the start of the race was greatest in the 60 and successively lower in events of longer distance. In the 60 it reached 74% of the actual adjustment while at the other end, in the two mile, it only reached 33% of the actual adjustment. Second, the heart rate increased rapidly during the initial stages of each race reaching approximately 180 in twenty-eight seconds in the one mile and two mile. One hundred eighty beats per minute was reached in ten seconds in the 220. Third, significantly higher peak heart rates were elicited in the longer events. Fourth, recovery was faster from the 60 but there was no significant difference in the others. Finally the trained athletes and the untrained subjects showed no difference in their recovery patterns.

Magel, McArdle, and Glaser<sup>15</sup> telemetered heart rate response to selected competitive swimming events. Seven members of the Queens College, New York, varsity swim team served as subjects and were tested during the 50, 100, 200, 500, and 1000 yard swims. The investigators found that the heart rate increased rapidly during the initial stages of the race. This occurred most rapidly in the 50. Heart rate then climbed progressively to peak at the race's end. During the longer races several plateaus were reached in the course of the event. Higher

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peaks were found in the longer events -- these getting up to from 173 to 181 beats per minute. All subjects also ran distances comparable to the swimming events and essentially the same pattern was found except that the magnitude was greater in the running events.

Telemetry was used to test little league baseball players by Hanson<sup>11</sup> of Macalester College in Minnesota. Ten little league players between the ages of nine and twelve were tested during a variety of different baseball situations. The highest mean was for "at bat", a rate of 163. The average heart rate for "in the field" was 127. A rate of 95 beats per minute was found for pre game sitting and 112 for standing prior to the start of the game. Values for the corresponding post game situations were 100 to 121. Hanson concluded that, except for the pitcher and catcher, one and one-half to two hours of baseball does not provide for attainment of much physical fitness.

Five girls highly trained in track were tested by Skubic and Hiltgendorf<sup>23</sup> using telemetry. Anticipatory, exercise, and recovery rates were collected for the 220, 440, 880, and one mile. They found the anticipatory (taken thirty seconds prior to "on your mark") was 59% of the adjusted to exercise amount. Heart rates during exercise were two and a half times that of resting values. Also heart rates at the end of all four events were similar. Mean values found were: resting, 72; anticipatory, 138; exercise, 184; and at the conclusion, 194.

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Skubic and Hodgkins<sup>24</sup> at the University of California conducted a study collecting cardiac responses to participation in tennis, badminton, golf, archery, and bowling as determined by telemetry. Two subjects, neither of varsity caliber were tested. Rates from the end of twenty minutes of playing time and the end of a match were compared with no significant differences found except in golf. It was concluded that tennis and badminton are the most strenuous, then golf and archery, and finally bowling.

The same investigators, Skubic and Hodgkins<sup>25</sup>, studied the relative strenuousness of a number of selected sports as performed by women. These included archery, badminton singles, bowling, golf, tennis singles, basketball, field hockey, softball, and volleyball. Energy cost levels were determined through laboratory testing at heart rates of 100, 120, 145, and 185. The results indicated energy cost highest in field hockey and as a rover in basketball.

Rozenblat<sup>21</sup> in Russia tested a variety of different subjects in skating, skiing and gymnastics. He found the resting rate doesn't have much correlation with peak heart rate values. Peak rates were similar between both untrained and trained subjects. Rozenblat concluded that the mean heart rate is a valid indication of the intensity of the training effect. He found means of 150 in runners and 110-120 for middle-aged men in gymnastics.

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At Oklahoma State University, Crowell,<sup>7</sup> used telemetry on seven subjects to study the energy cost of participation in golf. Subjects heart rates were monitored while carrying their clubs, using a pull cart, and while riding a motorized cart during rounds of golf. He found mean heart rate response and mean predicted oxygen to be highest when carrying clubs (113.1 beats per minute and 1.5 liters of oxygen per minute) and lowest when riding (89.1 and 1.05). Heart rates were higher when putting than while teeing off or playing from tee to green. Crowell concluded that when expecting to improve physical fitness to any great extent, golf is not a suitable activity.

#### Handball, Paddleball, and Racquetball Studies

Racquetball is a relatively new sport and because of this not much has of yet been written on it. However, it is a derivative of paddleball which in turn is a derivative of handball. The only basic differences between the three sports are in the pieces of equipment used. The same sized court and the same rules are used by all three sports. Therefore, for this study literature concerning any one of the three was considered as representing all of three. Since handball is the oldest sport many more articles and books have been written on it.

Wickstrom and Larson in Racquetball and Paddleball Fundamentals<sup>27</sup> stated that "racquetball and paddleball are essentially the same game." The game was also described by them as being "vigorous enough to

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provide a significant amount of physical exercise. "

Allsen and Witbeck in Paddleball,<sup>1</sup> stated "Paddleball is a fast game requiring endurance, skill, and body control. Because of its demands on the cardio-respiratory system, it ranks as an excellent conditioning activity. "

In Beginning Handball, Roberson and Olson<sup>20</sup> described the sport, "Handball, an excellent sport for developing and maintaining physical fitness, presents a real challenge to its participants. It provides them with a wonderful opportunity to develop strength, endurance, agility, coordination, and other physiological benefits that help to balance the inactivity of sedentary living. " They concluded by stating "Handball has been considered a better overall conditioner than almost any other sport. "

Yessis, in Handball<sup>28</sup> also supported this view. He stated that "participation in handball helps to develop the lungs, heart, blood vessels, and probably even more important, the ability of the body to re-create and/or strengthen its restorative processes and metabolic functions. One can achieve or maintain a high level of physical fitness merely by playing handball several times a week. "

Handball was described by Shaw<sup>22</sup> as "one of the most strenuous of games and has been recommended highly as a conditioner. "

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## Summary

Numerous researchers have found a high validity between predicted energy cost values using heart rates and those actually obtained in the laboratory. The literature supports the assumption that there is a linear relationship between heart rate and oxygen consumption although this linear relationship varies from individual to individual and, thus, must be calculated for each subject.

The popularity of using telemetry to obtain heart rates from exercising subjects has spread rapidly. Data has been collected from subjects performing a wide variety of activities and sports. Without the hinderance of limiting external equipment subjects have been able to perform these sports as they would in competition and thus accurate indications of the work load have been and can be obtained outside the laboratory.

Racquetball, paddleball, and handball are vigorous physical activities and are considered as excellent means of improving physical condition.

## CHAPTER III

### RESEARCH PROCEDURES

In this study four subjects were tested in the laboratory to obtain a graph representing the relationship between heart rate and oxygen consumption for each subject. These same subjects then played racquetball singles, cut-throat, and doubles in all combinations with each other while their heart rate was being monitored through telemetry. From the heart rate means found during play, oxygen consumptions were predicted for the three types of racquetball using the previously established heart rate-oxygen consumption relationship for each subject.

#### Subjects

The four male subjects who volunteered for this study were undergraduate students of Oklahoma State University. They were all skilled players and ranged in age from 20 - 26 years. All played racquetball about five times a week and all were familiar with the three types of play. All were non-smokers.

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## Laboratory Testing and Measuring Devices

Laboratory procedure was similar to that followed by Malhorta, Gupta, and Rai<sup>16</sup> and by Crowell.<sup>7</sup> Initial testing was done in the physiology of exercise laboratory to determine resting heart rate and to establish a valid oxygen consumption prediction line. The tests consisted of obtaining heart rates and oxygen consumptions at rest and at two different work loads on the Quinton Treadmill, Model 642.

Heart rate measurements were taken with the aid of a Narco Bio-Systems Telemetry System consisting of a transmitter, Model FM-1100-E2, and a Bio-Telemetry Receiver, Model FM-1100-7. The receiver was connected to an E and M Instrument Company Physiograph, Model Type PMP-4A, for recording purposes.

Oxygen consumption measurements were taken using a Warren E. Collins 100 liter Tissot Tank to collect the expired air for volume readings and an Instrumentation Associates Godart Pulmo-analyzer to analyze the expired air for oxygen and carbon dioxide content. The Godart Pulmo-analyzer utilizes the thermal-conductivity principle and uses room air as a reference gas.

## Laboratory Procedure

Telemetry electrodes were attached to the subject, one on the sternum near the manubrosternal junction, the other approximately two inches below the left nipple. Attachment was made by first

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cleansing the area with gauze using an alcohol solution. Electrode washers with a sticky surface on both sides were placed on the electrode and the center contact area filled with an electrolyte-Redux creme -- to reduce the resistance between the skin and the electrodes. The electrodes were then attached by the washer to the cleansed area. An area on the upper back on the left-hand side of the body was cleansed in the same manner and the transmitter was attached using an electrode washer. Preliminary tests indicated this area would not restrict the swing of a right-handed player, be minimally affected by muscle movement, and be less likely to accumulate perspiration than an area lower on the body. The telemetry receiver and the physiograph were adjusted so that a clear reading was recorded at a paper speed of 0.5 cm per second.

The subject was asked to assume a comfortable sitting position and a nose-clip was put on his nose. A Collins plastic two-way J valve was connected by a plastic hose to the tissot tank. A rubber mouthpiece was placed on the J valve and the subject put the mouthpiece in his mouth and began breathing through the system. After a few minutes of acclimation to using the apparatus and flushing out old air from the tank the test was begun.

Temperature and barometric pressure in the room were recorded and then heart rate and volume of expired air were collected for a three minute interval. A sample of the collected expired air was taken

from the tissot tank in a one liter rubber anesthesia bag. The sample was analyzed for oxygen and carbon dioxide content in the Godart Pulmo-analyzer.

Liters of oxygen were figured according to the procedure used in Consolazio, Johnson, and Pecora.<sup>5</sup> The Johnson and Darling nomogram was used. All volumes were corrected to STPD.

Work loads on the treadmill were adjusted to elicit heart rates from the subjects approximate to their minimum and maximum heart rates found in racquetball. Thus the work loads varied somewhat from subject to subject. Both subjects one and two were tested at work loads of 6 mph, 0% elevation (jogging speed) and 7 mph, 5% elevation. Subject three had too high a heart rate at the 6 mph, 0% elevation work load in comparison to his minimum heart rate during racquetball. He was tested at a speed of 3.5 mph (walking) and elevations of 0%, 5%, 10%, and 15%. Subject four jogged at a work load of 5 mph, 0% elevation and 6 mph, 5% elevation.

At each work load the subject worked for a time sufficient to allow his heart rate to stabilize. This was generally two to three minutes. Then heart rate and volume of expired air were collected for a thirty second interval. A sample of the expired air was once again analyzed for oxygen and carbon dioxide content and liters of oxygen consumed per minute figured.

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The two exercise heart rate-oxygen consumption readings were then plotted on a graph to establish an oxygen consumption prediction line in relation to heart rate for each subject.

### Racquetball Participation

Before each testing situation the subjects reported to the court observation area to have the telemetry equipment attached and adjusted for a clear recording. They then played every other subject in singles, as a cut-throat participant with all combinations of the other two cut-throat players, and as the partner of every other subject against all combinations in doubles. Each subject played only one match per day. Heart rates were monitored for a minimum of fifteen minutes in all game situations. Multiple monitoring was used to collect data on more than one subject during a match. A second telemetry system consisting of another Narco Bio-Systems transmitter, Model FM-1100-E2, and a Narco Bio-Systems Bio-Telemetry Receiver, Model FM-1100-6, was used along with the set that was used in the laboratory.

Heart rate recordings were examined for maximum and minimum peaks and for means. Means were calculated by scanning a subject's heart rate recording and taking a ten second count in the last fifteen seconds of every minute. This count was then multiplied by six to equate to heart rate per minute. The first five minutes were dropped

to allow sufficient time for the subject's heart rate to plateau at or near a playing rate and then the remaining minute heart rates were averaged to get a mean rate for that subject that day. Daily means were averaged to obtain a mean for that subject for that type of play.

### Analysis of the Results

Oxygen consumption values were predicted from the mean exercise heart rates for each subject for each type of play. Mean predicted oxygen intake values per kilogram of body weight were then figured for each of the three types of play. These values were then tested for significance of difference with a 't' ratio using Dwyers Single Computational Formula.<sup>26</sup> Using Cooper's aerobics point chart as a base,<sup>6</sup> suggested point values were derived for cut-throat and doubles play. Oxygen consumption and calorie cost for each type of play were compared with resting measures for each subject and for the group.

## CHAPTER IV

### PRESENTATION AND ANALYSIS OF DATA

This chapter includes a summary and description of data collected in the three types of racquetball play and analysis of data for the four subjects who participated in these three types of play. All of the heart rates were computed from the heart rate scores obtained by telemetry.

The writer was satisfied that oxygen intakes during laboratory testing on the treadmill showed a linear relationship to heart rate. The oxygen consumption prediction line in relation to heart rate obtained in the laboratory was then used to predict oxygen consumptions in relation to monitored heart rates during play.

#### Subject No. 1

##### Relationship of Heart Rate to Oxygen Intake During Treadmill Exercise

Subject No. 1, who was 20 years old, 5'7" tall, and weighed 123 pounds, had a resting heart rate of 60 and a resting oxygen intake of .24 liters per minute. Pulmonary ventilation was 6.75 liters per minute. At a workload on the treadmill of 6 mph and 0% elevation his heart rate increased to 142 and his oxygen intake was 1.70 liters per

minute. Pulmonary ventilation increased to 37.78 liters per minute. At his second exercise workload of 7 mph and 5% elevation, Subject No. 1 had an oxygen intake of 2.31 liters per minute and a heart rate of 172. Pulmonary ventilation at this workload was 61.19 liters per minute. (See Table 1 and Figure 1).

#### Heart Rate and Predicted Oxygen Intake During Racquetball

Singles: While playing racquetball singles, Subject No. 1 had a mean heart rate of 178.3 and a mean predicted oxygen intake of 2.43 liters per minute. Mean predicted oxygen intake per kilogram of body weight was 43.6 per minute. Mean oxygen intake at rest was .24 liters per minute and the multiple of resting oxygen intake was 10.12. (See Table 2 and Figure 1).

Cut-throat: While playing cut-throat, the subject had a mean heart rate of 164.2 and a mean predicted oxygen intake of 2.15 liters per minute. Mean predicted oxygen intake per kilogram of body weight was 38.5 per minute. The multiple of resting oxygen intake was 8.96. (See Table 2 and Figure 1).

Doubles: While playing doubles, the subject had a mean heart rate of 161.2 and a mean predicted oxygen intake of 2.10 liters per minute. Mean predicted oxygen intake per kilogram of body weight was 38.0 per minute. The multiple of resting oxygen intake was 8.75. (See Table 2 and Figure 1).

Analysis of the results for Subject No. 1 indicated his highest mean heart rate (178.3) and highest mean predicted oxygen intake per kilogram of body weight per minute (43.6) occurred while playing singles and lowest (161.2 and 38.0) while playing doubles.

TABLE 1

SUBJECT NO. 1 - RELATIONSHIP OF HEART RATE  
TO OXYGEN INTAKE DURING TREADMILL EXERCISE

|                                   | Resting | Treadmill<br>6 mph 0%<br>grade | Treadmill<br>7 mph 5%<br>grade |
|-----------------------------------|---------|--------------------------------|--------------------------------|
| Heart Rate<br>per minute          | 60      | 142                            | 172                            |
| Oxygen Intake<br>L/min.           | .24     | 1.70                           | 2.31                           |
| Pulmonary Ven-<br>tilation L/min. | 6.75    | 37.78                          | 61.19                          |

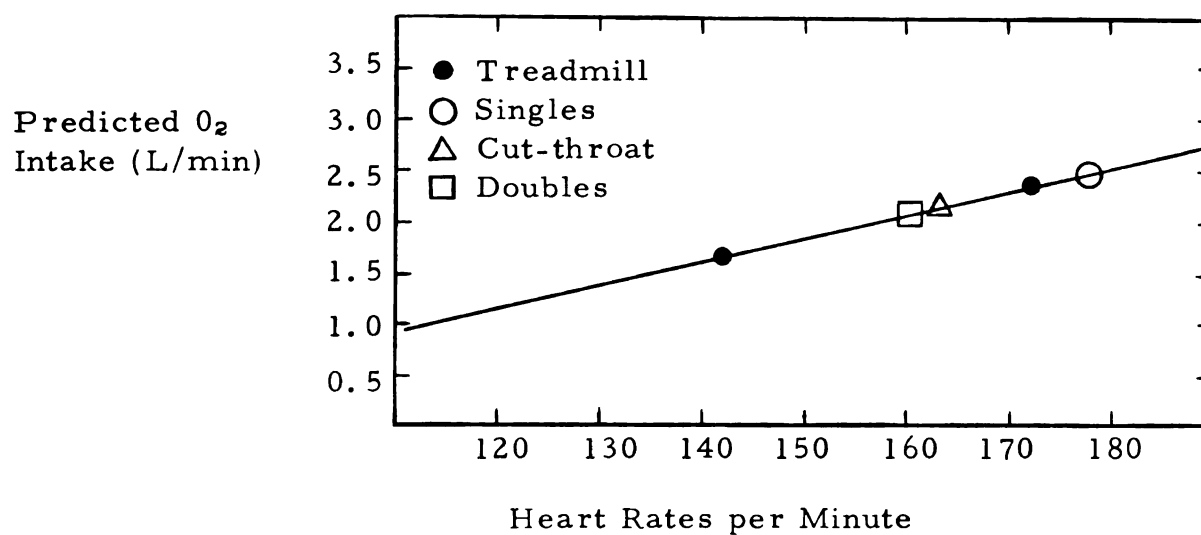


FIGURE 1. Subject No. 1 - Predicted Oxygen Intakes

TABLE 2

HEART RATE AND OXYGEN INTAKE -- SUBJECT NO. 1

|                                                                   | <u>Singles</u> | <u>Cut-throat</u> | <u>Doubles</u> |
|-------------------------------------------------------------------|----------------|-------------------|----------------|
| Heart Rate Mean - 1st Match                                       | 178.4          | 162.0             | 149.8          |
| Heart Rate Mean - 2nd Match                                       | 178.2          | 170.4             | 163.6          |
| Heart Rate Mean - 3rd Match                                       | 178.4          | 160.2             | 170.3          |
| Heart Rate Mean - All Matches                                     | 178.3          | 164.2             | 161.2          |
| Mean Predicted Oxygen Intake (L/min)                              | 2.43           | 2.15              | 2.10           |
| Mean Predicted Oxygen Intake per Kilogram of Body Weight (ml/min) | 43.6           | 38.5              | 38.0           |
| Multiple of Resting Oxygen Intake                                 | 10.12          | 8.96              | 8.75           |

## Subject No. 2

Relationship of Heart Rate to Oxygen Intake During Treadmill Exercise

Subject No. 2, who was 20 years old, 5'9" tall, and weighed 144 pounds, had a resting heart rate of 58 and his resting oxygen intake was .23 liters per minute. Pulmonary ventilation was 6.52 liters per minute. At a workload on the treadmill of 6 mph and 0% elevation his heart rate increased to 150 and his oxygen intake was 2.12 liters per minute. Pulmonary ventilation increased to 56.55 liters per minute. At his second exercise workload of 7 mph and 5% elevation the subject had a heart rate of 180 and an oxygen intake of 2.63 liters per minute. Pulmonary ventilation at this workload was 107.08 liters per minute. (See Table 3 and Figure 2).

Heart Rate and Predicted Oxygen Intake During Racquetball

Singles: While playing racquetball singles, Subject No. 2 had a mean heart rate of 182.6 and a mean predicted oxygen intake of 2.71 liters per minute. Mean predicted oxygen intake per kilogram of body weight was 41.8 milliliters per minute. Mean oxygen intake at rest was .23 liters per minute and the multiple of resting oxygen intake was 11.78 (See Table 4 and Figure 2).

Cut-throat: Subject No. 2's mean heart rate while playing cut-throat was 161.1 and he had a mean predicted oxygen intake of 2.32

liters per minute. Mean predicted oxygen intake per kilogram of body weight was 35.3 milliliters per minute. The multiple of resting oxygen intake was 10.09. (See Table 4 and Figure 2).

Doubles: While playing doubles, the subject's mean heart rate was 158.8 and his mean predicted oxygen intake was 2.28 liters per minute. The mean predicted oxygen intake per kilogram of body weight was 34.7 milliliters per minute. The multiple of resting oxygen intake was 9.91. (See Table 4 and Figure 2).

Analysis of the results for Subject No. 2 indicated his highest mean heart rate (182.6) and highest mean predicted oxygen intake per kilogram of body weight per minute (41.8) occurred while playing singles. Lowest was while playing doubles (158.8 and 34.7).

TABLE 3

SUBJECT NO. 2 - RELATIONSHIP OF HEART RATE  
TO OXYGEN INTAKE DURING TREADMILL EXERCISE

|                                   | Resting | Treadmill<br>6 mph 0%<br>grade | Treadmill<br>7 mph 5%<br>grade |
|-----------------------------------|---------|--------------------------------|--------------------------------|
| Heart Rate<br>per minute          | 58      | 150                            | 180                            |
| Oxygen Intake<br>L/min.           | .23     | 2.12                           | 2.63                           |
| Pulmonary Ven-<br>tilation L/min. | 6.52    | 56.55                          | 107.08                         |

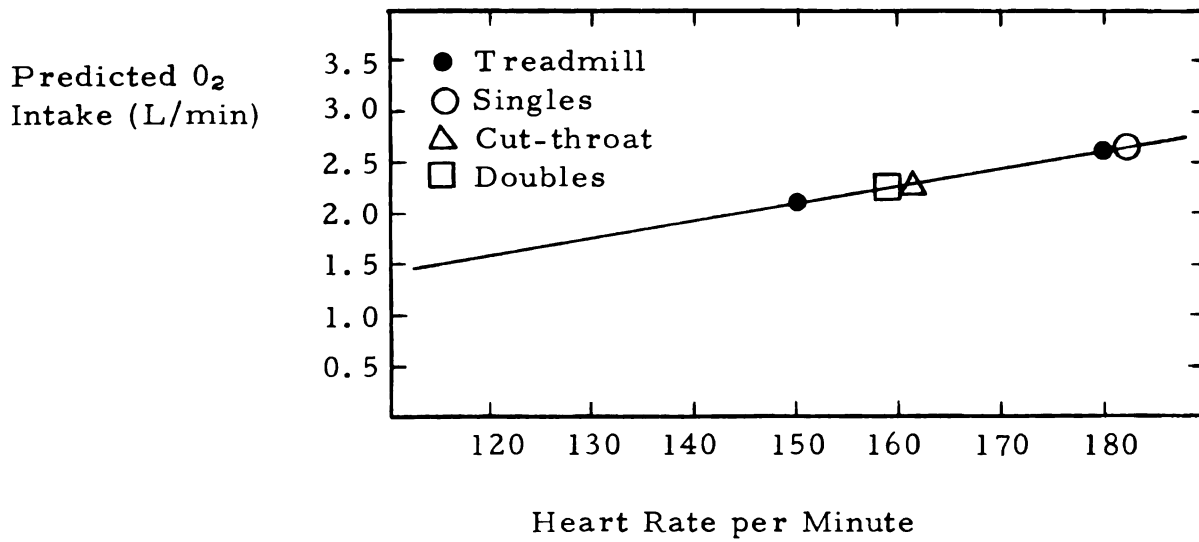


FIGURE 2. Subject No. 2 - Predicted Oxygen Intakes

TABLE 4

## HEART RATE AND OXYGEN INTAKE -- SUBJECT NO. 2

|                                                                   | <u>Singles</u> | <u>Cut-throat</u> | <u>Doubles</u> |
|-------------------------------------------------------------------|----------------|-------------------|----------------|
| Heart Rate Mean - 1st Match                                       | 188.5          | 161.8             | 165.5          |
| Heart Rate Mean - 2nd Match                                       | 178.1          | 151.8             | 154.8          |
| Heart Rate Mean - 3rd Match                                       | 181.3          | 169.8             | 156.0          |
| Heart Rate Mean - All Matches                                     | 182.6          | 161.1             | 158.8          |
| Mean Predicted Oxygen Intake (L/min)                              | 2.71           | 2.32              | 2.28           |
| Mean Predicted Oxygen Intake per Kilogram of Body Weight (ml/min) | 41.8           | 35.3              | 34.7           |
| Multiple of Resting Oxygen Intake                                 | 11.78          | 10.09             | 9.91           |

## Subject No. 3

Relationship of Heart Rate to Oxygen Intake During Treadmill Exercise

Subject No. 3, who was 26 years old, 5'5" tall, and weighed 157 pounds, had a resting heart rate of 84 and a resting oxygen intake of .25 liters per minute. Pulmonary ventilation was 7.54 liters per minute. At a workload on the treadmill of 3.5 mph and 0% elevation his heart rate was 108 and his oxygen intake was .73 liters per minute. Pulmonary ventilation was 19.44 liters per minute. At a second exercise workload of 3.5 mph and 5% elevation his heart rate increased to 128 and his oxygen intake increased to 1.28 liters per minute. Pulmonary ventilation was 29.16 liters per minute.

At a third exercise workload of 3.5 mph and 10% elevation Subject No. 3's heart rate increased to 152 and his oxygen intake was 2.21 liters per minute. Pulmonary ventilation increased to 42.44 liters per minute. At a fourth exercise workload of 3.5 mph and 15% elevation his heart rate leveled at 172 and his oxygen intake was 3.09 liters per minute. Pulmonary ventilation was 71.84 liters per minute. (See Table 5 and Figure 3).

Heart Rate and Predicted Oxygen Intake During Racquetball

Singles: While playing racquetball singles, Subject No. 3 had a mean heart rate of 153.1 and a mean predicted oxygen intake of 2.33 liters per minute. Mean predicted oxygen intake per kilogram

of body weight was 32.7 milliliters per minute. Oxygen intake at rest was .25 liters per minute and the multiple of resting oxygen intake was 9.32. (See Table 6 and Figure 3).

Cut-throat: While playing cut-throat, the subject had a mean heart rate of 120.4 and a mean predicted oxygen intake of 1.12 liters per minute. Mean predicted oxygen intake per kilogram of body weight was 15.8 milliliters per minute. The multiple of resting oxygen intake was 4.48. (See Table 6 and Figure 3).

Doubles: While playing doubles, Subject No. 3 had a mean heart rate of 105.7 and a mean predicted oxygen intake of .57 liters per minute. Mean predicted oxygen intake per kilogram of body weight was 8.0 milliliters per minute. The multiple of resting oxygen intake was 2.28. (See Table 6 and Figure 3).

Analysis of the results for Subject No. 3 indicated his highest mean heart rate (153.1) and highest mean predicted oxygen intake per kilogram of body weight per minute (32.7) occurred during singles play and lowest (105.7 and 8.0) while playing doubles.

TABLE 5

SUBJECT NO. 3 - RELATIONSHIP OF HEART RATE  
TO OXYGEN INTAKE DURING TREADMILL EXERCISE

|                                    | Resting | Treadmill<br>3.5 mph<br>0% grade | Treadmill<br>3.5 mph<br>5% grade | Treadmill<br>3.5 mph<br>10% grade | Treadmill<br>3.5 mph<br>15% grade |
|------------------------------------|---------|----------------------------------|----------------------------------|-----------------------------------|-----------------------------------|
| Heart<br>Rate                      | 84      | 108                              | 128                              | 152                               | 172                               |
| Oxygen<br>Intake<br>L/min.         | .25     | .73                              | 1.38                             | 2.21                              | 3.09                              |
| Pulmonary<br>Ventilation<br>L/min. | 7.54    | 19.44                            | 29.16                            | 42.44                             | 71.84                             |

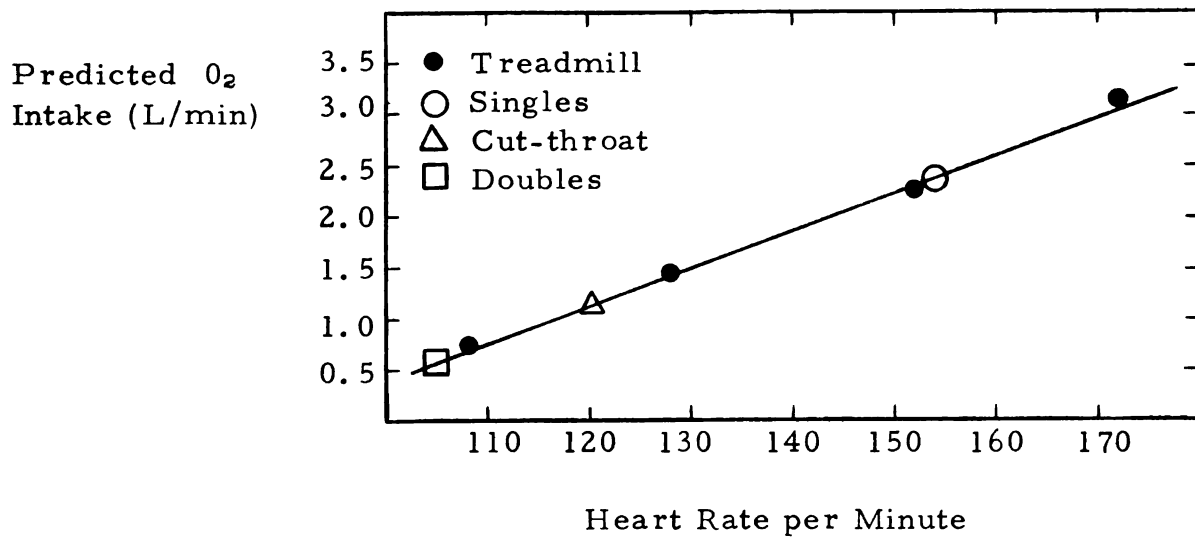


FIGURE 3. Subject No. 3 - Predicted Oxygen Intakes

TABLE 6

HEART RATE AND OXYGEN INTAKE -- SUBJECT NO. 3

|                                                                         | <u>Singles</u> | <u>Cut-throat</u> | <u>Doubles</u> |
|-------------------------------------------------------------------------|----------------|-------------------|----------------|
| Heart Rate Mean - 1st Match                                             | 166.4          | 124.9             | 107.3          |
| Heart Rate Mean - 2nd Match                                             | 160.2          | 109.8             | 103.4          |
| Heart Rate Mean - 3rd Match                                             | 132.9          | 126.5             | 106.2          |
| Heart Rate Mean - All Matches                                           | 153.1          | 120.4             | 105.7          |
| Mean Predicted Oxygen<br>Intake (L/min)                                 | 2.33           | 1.12              | .57            |
| Mean Predicted Oxygen Intake<br>per Kilogram of Body Weight<br>(ml/min) | 32.7           | 15.8              | 8.0            |
| Multiple of Resting Oxygen Intake                                       | 9.32           | 4.48              | 2.28           |

## Subject No. 4

Relationship of Heart Rate to Oxygen Intake During Treadmill Exercise

Subject No. 4, who was 20 years old, 5'7" tall, and weighed 129 pounds, had a resting heart rate of 62 and a resting oxygen intake of .27 liters per minute. Pulmonary ventilation was 8.67 liters per minute. At a workload on the treadmill of 5 mph and 0% elevation his heart rate was 154 and his oxygen intake was 1.57 liters per minute. Pulmonary ventilation increased to 40.76 liters per minute. At a second exercise workload of 6 mph and 5% elevation his heart rate leveled at 182 and his oxygen intake increased to 2.41 liters per minute. Pulmonary ventilation at this workload was 59.46 liters per minute. (See Table 7 and Figure 4).

Heart Rate and Predicted Oxygen Intake During Racquetball

Singles: While playing racquetball singles, Subject No. 4 had a mean heart rate of 172.0 and a mean predicted oxygen intake of 2.12 liters per minute. Mean predicted oxygen intake per kilogram of body weight was 36.3 milliliters per minute. Oxygen intake at rest was .27 liters per minute and the multiple of resting oxygen intake was 7.85. (See Table 8 and Figure 4).

Cut-throat: While playing cut-throat, the subject had a mean heart rate of 149.0 and a mean predicted oxygen intake of 1.41 liters per minute. Mean predicted oxygen intake per kilogram of body

weight was 23.7 milliliters per minute. The multiple of resting oxygen intake was 5.22. (See Table 8 and Figure 4).

Doubles: While playing doubles, Subject No. 4 had a mean heart rate of 153.4 and a mean predicted oxygen intake of 1.55 liters per minute. Mean predicted oxygen intake per kilogram of body weight was 26.5. The multiple of resting oxygen intake was 5.74. (See Table 8 and Figure 4).

Analysis of the results for Subject No. 4 indicated his highest mean heart rate (172.0) and highest mean predicted oxygen intake per kilogram of body weight per minute (36.3) while playing singles. Lowest (49.0 and 23.7) was during cut-throat play.

TABLE 7

SUBJECT NO. 4 - RELATIONSHIP OF HEART RATE  
TO OXYGEN INTAKE DURING TREADMILL EXERCISE

|                                   | Resting | Treadmill<br>5 mph<br>0% grade | Treadmill<br>6 mph<br>5% grade |
|-----------------------------------|---------|--------------------------------|--------------------------------|
| Heart Rate                        | 62      | 154                            | 182                            |
| Oxygen Intake<br>L/min.           | .27     | 1.57                           | 2.41                           |
| Pulmonary Ven-<br>tilation L/min. | 8.67    | 40.76                          | 59.46                          |

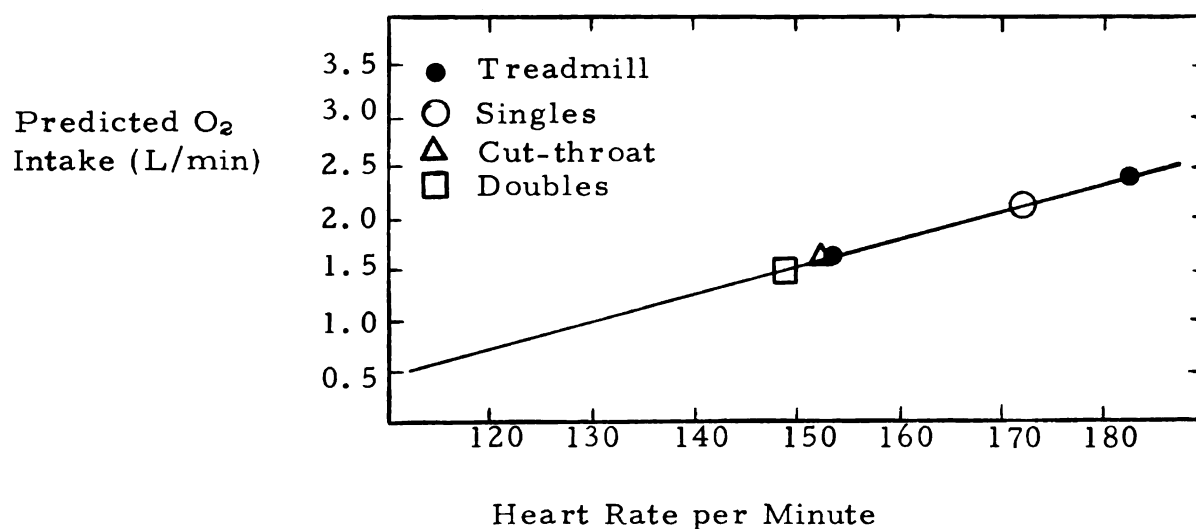


FIGURE 4. Subject No. 4 - Predicted Oxygen Intakes

TABLE 8

## HEART RATE AND OXYGEN INTAKE -- SUBJECT NO. 4

|                                                                   | <u>Singles</u> | <u>Cut-throat</u> | <u>Doubles</u> |
|-------------------------------------------------------------------|----------------|-------------------|----------------|
| Heart Rate Mean - 1st Match                                       | 187.6          | 148.8             | 167.1          |
| Heart Rate Mean - 2nd Match                                       | 162.0          | 156.7             | 151.1          |
| Heart Rate Mean - 3rd Match                                       | 166.4          | 141.6             | 141.9          |
| Heart Rate Mean - All Matches                                     | 172.0          | 149.0             | 153.4          |
| Mean Predicted Oxygen Intake (L/min)                              | 2.12           | 1.41              | 1.55           |
| Mean Predicted Oxygen Intake per Kilogram of Body Weight (ml/min) | 36.3           | 23.7              | 26.5           |
| Multiple of Resting Oxygen Intake                                 | 7.85           | 5.22              | 5.74           |

## Group Relationships of Heart Rates and Oxygen Consumption

Analysis of group data when at rest indicated a mean heart rate of 66 and a mean oxygen intake of .25 liters per minute.

During singles play the heart rate mean was 171.5 and mean predicted oxygen intake was 2.40 liters per minute. Mean predicted oxygen intake per kilogram of body weight was 38.6 milliliters per minute. The multiple of resting oxygen intake was 9.77. Calorie cost was 12 calories per minute and 720 per hour.

Group data during cut-throat play showed a mean heart rate of 148.7 and a mean predicted oxygen intake of 1.75 liters per minute. Mean predicted oxygen intake per kilogram of body weight was 28.3. The multiple of resting oxygen intake was 7.19. Calorie cost was 8.75 calories per minute and 525 per hour.

A mean heart rate of 144.8 and a mean predicted oxygen intake of 1.63 liters per minute were indicated by analysis of group data during doubles play. Mean predicted oxygen intake per kilogram of body weight was 26.8 milliliters per minute. The multiple of resting oxygen consumption was 6.67. Calorie cost was 8.15 calories per minute and 489 per hour. (See Table 9).

Mean predicted oxygen intakes per kilogram of body weight per minute were compared between each type of play using a "t" ratio.<sup>9</sup> A one-tailed test was used to compare singles and the other two under the assumption the singles would always be the higher value.

A "t" of 2.353 was needed to show significance at the 5% level of confidence. Singles play when compared to cut-throat play yielded a significant "t" ratio difference of 3.74. A significant "t" ratio difference of 2.69 was found between singles play and doubles play. a Two-tailed test was used to compare cut-throat and doubles under the assumption either could be the higher value. A "t" ratio of 3.182 was needed to show significance at the 5% level of confidence between cut-throat and doubles. Cut-throat and doubles play showed only a "t" ratio of .68 and was not significant. (See Table 10).

Energy cost of playing cut-throat racquetball was 73.3% of the energy cost of playing singles. Energy cost of playing doubles was 69.4% of that playing singles.

TABLE 9  
GROUP DATA

|                                                | <u>Rest</u> | <u>Singles</u> | <u>Cut-throat</u> | <u>Doubles</u> |
|------------------------------------------------|-------------|----------------|-------------------|----------------|
| Heart Rate Mean                                | 66          | 171.5          | 148.7             | 144.8          |
| Mean Predicted<br>Oxygen Intake (L/min)        | .25         | 2.40           | 1.75              | 1.63           |
| Mean Predicted Oxygen<br>Intake ml/kg per min. |             | 38.6           | 28.3              | 26.8           |
| Multiple of Resting<br>Oxygen Intake           |             | 9.77           | 7.19              | 6.67           |
| Calorie Cost per min.                          |             | 12             | 8.75              | 8.15           |
| Calorie Cost per hour                          |             | 720            | 525               | 489            |

TABLE 10

"t" RATIOS

|            | Oxygen Intake<br>ml/kg/minute | Difference | "t" ratio | Sig  |
|------------|-------------------------------|------------|-----------|------|
| Ratio 1    |                               |            |           |      |
| Singles    | 38.6                          | 10.3       | 3.74*     | >.05 |
| Cut-throat | 28.3                          |            |           |      |
| Ratio 2    |                               |            |           |      |
| Singles    | 38.6                          | 11.8       | 2.69*     | >.05 |
| Doubles    | 26.8                          |            |           |      |
| Ratio 3    |                               |            |           |      |
| Cut-throat | 28.3                          | 1.5        | .68       | N.S. |
| Doubles    | 26.8                          |            |           |      |

\* For Ratio 1 and 2 2.353 needed for significance for N = 4 at the 5% level of confidence (single tail)

\*\* For Ratio 3 3.182 needed for significance for N = 4 at the 5% level of confidence (two-tailed)

### Discussion

It appeared from the results of this study that singles racquetball, when played by two experienced opponents of relatively equal playing ability, was a very strenuous activity. Mean heart rates averaged 171.5 beats per minute which was near the 180 beat aerobic peak load. During singles play subjects averaged using 38.6 ml of oxygen per minute per kilogram of body weight. This equated favorably with running a mile in seven to seven and a half minutes.<sup>6</sup>

Using the same caliber of opponents and partners, both cut-throat and doubles had close to the same amount of energy cost. Both were significantly less than singles but not significantly different from each other. However, in both events three of the four subjects maintained mean heart rates of over 150. According to Cooper "if the exercise is vigorous enough to produce a sustained heart rate of 150 beats per minute or more, the training-effect benefits begin about 5 minutes after the exercise starts and continue as long as the exercise is performed."<sup>6</sup>

Assuming that Cooper's aerobic point chart<sup>6</sup> for playing handball is for singles and that racquetball singles is comparable in energy cost to handball singles, a guide was devised for applying aerobic points to cut-throat and doubles racquetball. Percentages of the energy cost of playing singles racquetball were figured for cut-throat and doubles. These percentages were then translated into common fractions to allow the player to make the calculations quickly in his head by multiplying the fraction times the singles value. Otherwise it was felt the point chart would become too complicated to follow easily. Finally point values were rounded off to the nearest one quarter point as Cooper had done on his charts. (See Table 11).

The author observed by watching play and by analyzing the monitored recordings that heart rate (and therefore energy cost) varied

according to the difference in the score of the match. Lower mean heart rates were observed in both players as the point spread got farther apart. Therefore if the match is not close or the players are of unequal ability point totals may have to be modified for that session.

TABLE 11  
AEROBIC POINTS GUIDE FOR  
CUT-THROAT AND DOUBLES RACQUETBALL

| Minutes of<br>Continuous<br>Activity | Aerobic<br>Points<br>Singles<br>(Cooper) | Cut-<br>Throat<br>Points | Doubles<br>Points |
|--------------------------------------|------------------------------------------|--------------------------|-------------------|
| 10                                   | 1 1/2                                    | 1                        | 1                 |
| 15                                   | 2 1/4                                    | 1 3/4                    | 1 1/2             |
| 20                                   | 3                                        | 2 1/4                    | 2                 |
| 25                                   | 3 3/4                                    | 2 3/4                    | 2 1/2             |
| 30                                   | 4 1/2                                    | 3 1/2                    | 3                 |
| 35                                   | 5 1/4                                    | 4                        | 3 1/2             |
| 40                                   | 6                                        | 4 1/2                    | 4                 |
| 45                                   | 6 3/4                                    | 5                        | 4 1/2             |
| 50                                   | 7 1/2                                    | 5 1/2                    | 5                 |
| 55                                   | 8 1/4                                    | 6 1/4                    | 5 1/2             |
| 60                                   | 9                                        | 6 3/4                    | 6                 |
| 65                                   | 9 3/4                                    | 7 1/4                    | 6 1/2             |
| 70                                   | 10 1/2                                   | 8                        | 7                 |
| 75                                   | 11 1/4                                   | 8 1/2                    | 7 1/2             |
| 80                                   | 12                                       | 9                        | 8                 |
| 85                                   | 12 3/4                                   | 9 1/2                    | 8 1/2             |
| 90                                   | 13 1/2                                   | 10                       | 9                 |

Cut-throat = 73.3% of singles = 3/4

Doubles = 69.4% of singles = 2/3

## CHAPTER V

### SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to determine the energy cost of playing racquetball singles, cut-throat, and doubles. To determine the energy cost of playing racquetball, heart rates were monitored during play through the use of bio-telemetry equipment and oxygen intake values were predicted from the heart rate means.

Preliminary testing was done in the physiology laboratory to obtain a graph representing the relationship between heart rate and oxygen intake for each subject. This was done by having the subject perform at two different workloads on the treadmill while his heart rate was monitored and his expired air was collected. Pulmonary ventilation was measured and from a sample of his expired air, oxygen and carbon dioxide percentages were determined. From these values oxygen intakes were calculated and paired with the heart rates for each workload. A linear relationship was found and was used as an oxygen consumption prediction line in relation to heart rate.

The subjects for this study were four undergraduate students of Oklahoma State University. They were all skilled racquetball players

familiar with the three types of play. All played an average of five times per week.

Predicted oxygen intake means were established for each player for each type of play. Group predicted oxygen intake means were also established and analyzed for significance of difference with a 't' ratio. Suggested aerobic point values were figured for cut-throat and doubles in relation to already established values for singles.

### Conclusions

Racquetball is a sport which will stimulate vigorous cardiovascular response when playing singles and moderate response when playing cut-throat and doubles.

On the basis of the analysis of data presented in this study, the following conclusions were reached.

1. Mean heart rate response to the three types of play was highest when playing singles (171.5 beats per minute) and substantially lower in the other two (cut-throat, 148.7 and doubles, 144.8).
2. Mean predicted oxygen intake was 2.40 liters per minute when playing singles, 1.75 liters per minute when playing cut-throat, and 1.65 liters per minute when playing doubles.
3. Calorie cost when playing singles was 12 calories per minute and 720 calories per hour, 8.75 calories per minute

and 525 calories per hour when playing cut-throat, and 8.15 calories per minute and 489 calories per hour when playing doubles.

4. There was a significant difference ( $p > .05$ ) in energy cost between playing singles and cut-throat and between singles and doubles but no significant difference between cut-throat and doubles.
5. When using the "Cooper's" aerobic point chart for handball and applying it to racquetball:

singles - use as is

cut-throat -  $3/4$  of singles

doubles -  $2/3$  of singles

#### Recommendations

1. Study other combinations of subjects to see whether changes in heart rates and oxygen intakes do follow the same percentages between the different types of play. These other combinations could include the middle-aged, the inexperienced, and women.
2. Compare the energy cost of racquetball participation between smokers and non-smokers.
3. Study the changes in heart rates and oxygen intakes of racquetball players during tournament play -- particularly during the week-end tournament where the player plays numerous matches in a

short period of time.

4. Compare the energy cost of racquetball participation in air-conditioned courts with that in non air-conditioned courts.



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## APPENDIX

TABLE 12

## Singles Play - Minute Heart Rates

| Minute     | Matches | Subject 1 |     |     | Subject 2 |     |     | Subject 3 |     |     | Subject 4 |     |     |
|------------|---------|-----------|-----|-----|-----------|-----|-----|-----------|-----|-----|-----------|-----|-----|
|            |         | 1         | 2   | 3   | 1         | 2   | 3   | 1         | 2   | 3   | 1         | 2   | 3   |
| 1          |         | 180       | 132 | 168 | 180       | 174 | 174 | 138       | 132 | 138 | 156       | 138 | 150 |
| 2          |         | 180       | 180 | 168 | 186       | 180 | 186 | 156       | 132 | 132 | 168       | 144 | 168 |
| 3          |         | 180       |     | 174 | 192       | 180 | 180 | 150       | 132 | 138 | 174       | 156 | 162 |
| 4          |         | 180       | 180 | 180 | 192       | 180 | 174 | 168       | 132 | 120 | 186       | 156 | 168 |
| 5          |         | 180       | 180 | 180 | 192       | 180 | 168 | 168       | 132 | 120 | 186       | 168 | 162 |
| 6          |         | 174       | 180 | 180 | 180       | 180 | 186 | 168       | 138 | 132 | 180       | 144 | 174 |
| 7          |         | 180       | 180 | 180 | 186       | 180 | 186 | 180       | 156 | 120 | 192       | 168 | 174 |
| 8          |         | 180       | 174 | 180 | 192       | 180 | 186 | 174       | 144 | 132 | 192       | 144 | 174 |
| 9          |         | 180       | 168 | 180 | 192       | 180 | 180 | 174       | 168 | 132 | 180       | 150 | 168 |
| 10         |         | 174       | 180 | 180 | 192       | 180 | 180 | 174       | 162 | 120 | 180       | 168 | 162 |
| 11         |         | 180       | 180 | 180 | 192       | 168 | 180 | 168       | 162 | 132 | 192       | 144 | 162 |
| 12         |         | 180       | 180 | 174 | 192       | 174 | 180 | 162       | 168 | 144 | 192       | 144 | 150 |
| 13         |         | 180       | 180 | 180 | 192       | 180 | 174 | 168       | 156 | 132 | 186       | 168 | 162 |
| 14         |         | 180       | 180 | 180 | 186       | 180 | 180 | 162       | 174 | 144 | 192       | 180 | 162 |
| 15         |         | 174       | 180 | 174 | 186       | 180 | 180 | 150       | 174 | 126 | 192       | 174 | 168 |
| 16         |         | 180       |     | 174 | 186       | 180 | 180 | 150       |     | 132 | 186       | 156 | 174 |
| 17         |         |           |     |     | 186       | 180 | 180 |           |     | 126 |           | 180 |     |
| 18         |         |           |     |     |           | 180 | 180 |           |     | 144 |           | 168 |     |
| 19         |         |           |     |     |           | 180 | 186 |           |     | 144 |           | 162 |     |
| 20         |         |           |     |     |           | 180 |     |           |     |     |           | 174 |     |
| 21         |         |           |     |     |           | 168 |     |           |     |     |           | 168 |     |
| Mean       |         | 178       | 178 | 178 | 189       | 178 | 181 | 166       | 160 | 133 | 188       | 162 | 166 |
| Mean/Event |         | 178       |     |     |           | 183 |     |           | 153 |     |           | 172 |     |

Mean - Singles play - 171.5

TABLE 13

## Cut-throat Play - Minute Heart Rates

| Minute     | Matches | Subject 1 |     |     | Subject 2 |     |     | Subject 3 |     |     | Subject 4 |     |     |
|------------|---------|-----------|-----|-----|-----------|-----|-----|-----------|-----|-----|-----------|-----|-----|
|            |         | 1         | 2   | 3   | 1         | 2   | 3   | 1         | 2   | 3   | 1         | 2   | 3   |
| 1          |         | 156       | 126 | 150 | 174       | 144 |     | 108       |     | 108 |           | 102 | 84  |
| 2          |         | 150       | 144 | 138 | 174       | 132 |     | 138       |     | 108 |           | 126 | 90  |
| 3          |         | 162       | 138 | 150 | 150       | 132 |     | 120       |     | 114 |           | 126 | 96  |
| 4          |         | 156       | 144 | 132 | 150       | 120 |     | 114       |     | 114 |           | 102 | 108 |
| 5          |         | 156       | 156 | 144 | 150       | 132 |     | 144       |     | 102 |           | 114 | 102 |
| 6          |         | 150       | 168 | 156 | 144       | 144 |     | 138       |     | 108 |           | 138 | 144 |
| 7          |         | 162       | 174 | 162 | 138       | 138 |     | 120       |     | 102 |           | 126 | 168 |
| 8          |         | 156       | 168 | 156 | 156       | 156 |     | 132       |     | 120 |           | 174 | 132 |
| 9          |         | 150       | 168 | 162 | 162       | 144 |     | 114       |     | 114 |           | 168 | 156 |
| 10         |         | 174       | 174 | 162 | 156       | 132 |     | 138       |     | 114 |           | 144 | 120 |
| 11         |         | 168       | 174 | 156 | 168       | 168 |     | 132       |     | 120 |           | 156 | 132 |
| 12         |         | 180       | 174 | 156 | 186       | 156 |     | 114       |     | 120 |           | 156 | 144 |
| 13         |         | 168       | 168 | 162 | 168       | 150 |     | 114       |     | 144 |           | 156 | 144 |
| 14         |         | 144       | 162 | 174 | 144       | 162 |     | 114       |     | 144 |           | 144 | 126 |
| 15         |         | 168       | 174 | 156 | 162       | 168 |     | 114       |     | 126 |           | 132 | 150 |
| 16         |         |           |     |     | 120       |     | 126 | 126       | 108 | 102 | 96        | 156 |     |
| 17         |         |           |     |     | 168       |     | 162 | 144       | 102 | 114 | 156       | 150 |     |
| 18         |         |           |     |     | 156       |     | 156 | 126       | 108 | 114 | 162       | 180 |     |
| 19         |         |           |     |     | 168       |     | 150 | 114       | 102 | 114 | 150       | 174 |     |
| 20         |         |           |     |     | 132       |     | 156 | 138       | 108 | 126 | 138       | 180 |     |
| 21         |         |           |     |     | 162       |     | 150 | 114       | 108 | 138 | 132       | 162 |     |
| 22         |         |           |     |     | 168       |     | 180 | 132       | 114 | 150 | 168       | 168 |     |
| 23         |         |           |     |     | 162       |     | 162 |           | 120 | 132 | 162       |     |     |
| 24         |         |           |     |     | 174       |     | 174 |           | 114 | 120 | 162       |     |     |
| 25         |         |           |     |     | 186       |     | 174 |           | 102 | 132 | 144       |     |     |
| 26         |         |           |     |     | 174       |     | 174 |           | 102 | 132 | 150       |     |     |
| 27         |         |           |     |     | 168       |     | 174 |           | 114 | 138 | 144       |     |     |
| 28         |         |           |     |     | 174       |     | 168 |           | 120 | 156 | 132       |     |     |
| 29         |         |           |     |     | 168       |     | 168 |           | 102 | 156 | 150       |     |     |
| 30         |         |           |     |     | 180       |     | 174 |           | 102 |     | 144       |     |     |
| Mean       |         | 162       | 170 | 160 | 162       | 152 | 170 | 125       | 110 | 127 | 149       | 157 | 142 |
| Mean/Event |         | 164       |     |     |           | 161 |     |           | 120 |     |           | 149 |     |

Mean - Cut-throat play - 148.7

TABLE 14

## Doubles Play - Minute Heart Rates

| Minute     | Matches | Subject 1 |     |     | Subject 2 |     |     | Subject 3 |     |     | Subject 4 |     |     |
|------------|---------|-----------|-----|-----|-----------|-----|-----|-----------|-----|-----|-----------|-----|-----|
|            |         | 1         | 2   | 3   | 1         | 2   | 3   | 1         | 2   | 3   | 1         | 2   | 3   |
| 1          |         | 144       | 150 | 168 | 168       | 138 | 162 | 90        | 120 | 114 | 162       | 138 | 126 |
| 2          |         | 150       | 144 | 162 | 168       | 132 | 150 | 108       | 114 | 108 | 162       | 144 | 102 |
| 3          |         | 150       | 150 | 162 | 138       | 126 | 150 | 108       | 102 | 102 | 156       | 150 | 138 |
| 4          |         | 132       | 150 | 162 | 156       | 150 | 156 | 108       | 108 | 108 | 156       | 162 | 132 |
| 5          |         | 144       | 150 | 174 | 168       | 150 | 174 | 96        | 102 | 108 | 150       | 138 | 150 |
| 6          |         | 162       | 156 | 162 | 168       | 156 | 162 | 102       | 108 | 96  | 162       | 144 | 132 |
| 7          |         | 144       | 156 | 168 | 180       | 156 | 150 | 96        | 114 | 114 | 156       | 156 | 138 |
| 8          |         | 138       | 162 | 168 | 168       | 168 | 162 | 108       | 108 | 108 | 150       | 168 | 138 |
| 9          |         | 156       | 168 | 180 | 174       | 156 | 168 | 90        | 102 | 102 | 174       | 168 | 138 |
| 10         |         | 150       | 156 | 186 | 162       | 162 | 150 | 102       | 108 | 102 | 168       | 162 | 150 |
| 11         |         | 150       | 168 | 168 | 162       | 162 | 144 | 102       | 96  | 114 | 162       | 162 | 150 |
| 12         |         | 144       | 168 | 168 | 168       | 162 | 150 | 108       | 108 | 108 | 162       | 162 | 156 |
| 13         |         | 144       | 168 | 168 | 168       | 168 | 144 | 108       | 96  | 102 | 162       | 156 | 156 |
| 14         |         | 144       | 174 | 168 | 162       | 150 | 162 | 96        | 96  | 108 | 150       | 156 | 162 |
| 15         |         | 144       | 174 | 168 | 162       | 150 | 156 | 102       | 102 | 102 | 168       | 150 | 144 |
| 16         |         | 144       | 162 | 162 | 180       | 162 | 138 | 108       | 90  | 96  | 168       | 126 | 138 |
| 17         |         | 132       | 168 | 180 | 162       | 138 | 162 | 120       | 114 | 108 | 168       | 138 | 144 |
| 18         |         | 138       | 156 | 162 | 168       | 150 | 174 | 114       | 90  | 102 | 174       | 150 | 120 |
| 19         |         | 144       | 162 | 168 | 162       | 138 | 150 | 108       | 96  | 114 | 168       | 150 | 120 |
| 20         |         | 156       | 156 | 180 | 156       | 144 |     | 108       | 108 | 114 | 174       | 126 |     |
| 21         |         | 144       |     | 168 | 156       |     |     | 120       | 102 | 108 | 174       | 132 |     |
| 22         |         | 156       |     |     | 156       |     |     | 132       | 114 | 108 | 168       | 144 |     |
| 23         |         | 150       |     |     |           |     |     |           | 120 |     | 180       | 156 |     |
| 24         |         | 162       |     |     |           |     |     |           | 102 |     | 186       | 156 |     |
| 25         |         |           |     |     |           |     |     |           | 102 |     |           | 150 |     |
| 26         |         |           |     |     |           |     |     |           | 96  |     |           | 162 |     |
| Mean       |         | 150       | 164 | 170 | 166       | 155 | 156 | 107       | 103 | 106 | 167       | 151 | 142 |
| Mean/Event |         | 161       |     |     |           | 159 |     |           | 106 |     |           | 153 |     |

Mean - Doubles play - 144.8

TABLE 15

## Sample Laboratory Oxygen Intake Calculation Sheet

Subject No. 1 Date July 18, 1972 Age 20 Ht. 5'7" Wt. 123

Temp. 21°C. Barometric Pressure 725 mm Hg. Corr. Factor .87

Resting Heart Rate 60

1. O<sub>2</sub>% 17.39 CO<sub>2</sub>% 3.32 True O<sub>2</sub> 3.6 R.Q. .91

$$2. \text{Vent. /min} = \frac{58.3 \text{ Kym mm}}{10} = \underline{5.83} \times 1.332 = \underline{7.7655 \text{ L/min.}}$$
$$3. \text{ Corr. Vent.} = \text{Vent.} \times \text{Corr. Factor} = 7.7655 \times .87 = 6.75 \text{ L/min.}$$
$$4. \text{ O}_2 \text{ Intake} = \frac{\text{Corr. Vent.} \times \text{True O}_2}{100} = \frac{6.75 \times 3.6}{100} = .24 \text{ L/min.}$$

TABLE 16  
 "t" Ratio Calculations<sup>26</sup>

Singles vs. Doubles

| Subject   | Singles | Doubles | X                 | X <sup>2</sup>       |
|-----------|---------|---------|-------------------|----------------------|
| 1         | 43.6    | 38.0    | 5.6               | 31.4                 |
| 2         | 41.8    | 34.7    | 7.1               | 50.4                 |
| 3         | 32.7    | 8.0     | 24.7              | 610.1                |
| 4         | 36.3    | 26.5    | <u>9.8</u>        | <u>96.0</u>          |
| ml/kg/min |         |         | $\Sigma X = 47.2$ | $\Sigma X^2 = 787.9$ |

$$t^2 = \frac{(\Sigma X)^2 (N-1)}{N \Sigma X^2 - (\Sigma X)^2} = \frac{(47.2)^2 (4-1)}{4(787.9) - (47.2)^2}$$

$$t = 2.69$$

Singles vs. Cut-throat

| Subject   | Singles | Cut-throat | X                  | X <sup>2</sup>       |
|-----------|---------|------------|--------------------|----------------------|
| 1         | 43.6    | 38.5       | 5.1                | 26.0                 |
| 2         | 41.8    | 35.3       | 6.5                | 42.3                 |
| 3         | 32.7    | 15.8       | 16.9               | 285.6                |
| 4         | 36.3    | 23.7       | <u>12.6</u>        | <u>158.8</u>         |
| ml/kg/min |         |            | $\Sigma X = 41.10$ | $\Sigma X^2 = 512.7$ |

For N = 4 at the 5% level of confidence  
 2.353 needed to show significance

$$t^2 = \frac{(\Sigma X)^2 (N-1)}{N \Sigma X^2 - (\Sigma X)^2} = \frac{(41.1)^2 (4-1)}{4(512.7) - (41.1)^2}$$

$$t = 3.74$$

TABLE 16 (cont'd)

Cut-throat vs. Doubles

| Subject | Cut-throat | Doubles | X                | X <sup>2</sup>      |
|---------|------------|---------|------------------|---------------------|
| 1       | 38.5       | 38.0    | .5               | .25                 |
| 2       | 35.3       | 34.7    | .6               | .36                 |
| 3       | 15.8       | 8.0     | 7.8              | 60.84               |
| 4       | 23.7       | 26.5    | <u>-2.8</u>      | <u>7.84</u>         |
|         |            |         | $\Sigma X = 6.1$ | $\Sigma X^2 = 69.3$ |

$$t^2 = \frac{(\Sigma X)^2 (N-1)}{N(\Sigma X^2) - (\Sigma X)^2} = \frac{(6.1)^2 (4-1)}{4(69.3) - (6.1)^2}$$

$$t = .68$$

For N = 4 at the 5% level of confidence  
3.182 needed to show significance

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