THE EFFECTS OF AN EXTENDED CARBOHYDRATE RESTRICTED DIET ON CONTINUED TREADMILL RUNNING PERFORMANCE

by

JOHN S. CARLSON

B.P.E. University of Alberta, 1975

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Health, Physical Education and Recreation

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1976

Approved by:

William B. Zuti
Major Professor

THIS BOOK CONTAINS NUMEROUS PAGES WITH THE ORIGINAL PRINTING BEING SKEWED DIFFERENTLY FROM THE TOP OF THE PAGE TO THE BOTTOM.

THIS IS AS RECEIVED FROM THE CUSTOMER.

306

DEDICATION

I would like to dedicate this work to my Mother and Father, for it was they who provided me with the initial academic opportunity.

ACKNOWLEDGEMENTS

The writer wishes to extend sincere appreciation to Dr. William B. Zuti, my advisor, for the excellent teaching and guidence I received during this study and throughout the academic year. Many thanks are also extended to my good friends Robert Albright and Tim Strathman for their invaluable assistance in collection of the text data. Special appreciation is extended to Chris Arheart for his patient and excellent work in assisting greatly with the statistical analysis of the study. To my friends who acted as subjects, many thanks, without you the study would have been impossible. John Graves is acknowledged for the help he gave in the construction of the graphs that appear in the text. Finally I would like to recognize and thank my typist Karen Zuti for her excellent work.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Figure | page

Chapter 1

INTRODUCTION

Many factors are present that influence the athlete's performance, achievement and ability to run. The one factor that stands out over which the athlete himself has direct control is his diet. The dietary requirements and composition can effect, either beneficially or detrimentally, the performance of both the recreational jogger and the competitive athlete. No matter how well-trained or gifted a runner is, without the fuel for energy production provided through the diet, success and accomplishment will evade him. Still, today a great deal of misunderstanding, ignorance and superstition exists regarding diet and exercise (19).

There are three types of fuel substances that man consumes in his diet, fat, carbohydrate and protein. Historically for many years it was believed that high protein diets were essential for energy production for strenuous work (3). Research since then has shown that this is not the case (36, 67). Simonson (62) stated definitely that protein intake and work performance were not related. The major fuels then that contribute to muscular energy production have been established from metabolic measurements and determination of the respiratory quotient (10). Krogh and Lindhard (52) have found fat to be 10% less economical as a fuel than carbohydrate. It requires more oxygen to metabolize it and hence a limitation is placed on performance in that the amount of usable oxygen for energy production is reduced (49). This also accounts for the differing respiratory quotients (RQ's) obtained when differing amounts of carbohydrate and fats are being metabolized. Carbohydrate metabolism produces an RQ of 1.0, whereas the value for fat combustion is 0.7. Research has shown that both carbohydrate and fat contribute to energy production in varying proportions dependent on the diet (25).

Studies (14, 31) have shown the effects of diet on fat metabolism. Fat is seen as an inferior form of energy production (53), but it is also very capable of supplying energy for muscular activity (3).

Carbohydrate diet modifications have demonstrated the body requires carbohydrate and is the preferred fuel by the body especially in athletic pursuits (48).

Few attempts have been made to observe the accumulative effects of endurance exercise performed on successive days. Costill et al. (22) in 1971 conducted a study with subjects running on three consecutive days on a mixed diet. A need therefore exists for a study that will examine the effects of a carbohydrate restricted diet for extended periods with continued endurance exercise performed daily. This will allow it to be established if an adaptation will occur to a specific level of energy production from fat metabolism as reflected by RQ, heart rate and VO_2 parameters. This carbohydrate restricted diet on the athlete and continued endurance exercise would allow observation of energy metabolism from fat stores and its limitations on running performance.

PURPOSE

It was the purpose of this study to determine the effects of an extended carbohydrate restricted diet on changes in the parameters of respiratory quotient, work-end heart rate amd volume of oxygen uptake during continued treadmill running. More specifically, the parameters were observed while the subjects ran for 45 minutes a day for three total days on a normal mixed diet and three consecutive days on a carbohydrate restricted diet.

LIMITATIONS OF THE STUDY

The results of this study may have been affected by several variables which this author may have failed to exercise control over or had no actual control over.

1. Subject selection was not completely random. Five subjects were chosen who were known to be physically active and capable of running for six consecutive days on the treadmill for 45 minutes a day.
2. No strict control was placed on the subjects to ensure that in actual fact the carbohydrate diet restriction was stringently followed.
3. The personal daily routines of the subjects prior to testing differed greatly and could possibly have affected their running performance in some way; however, the subjects followed closely their normal personal daily routines.
4. Subject #1 was unable to finish the last day of the testing sequence due to a leg injury sustained while running. This limited the amount of data available for statistical analyzation.

DELIMITATIONS

The subjects were five well-trained recreational runners at Kansas

State University. Each subject ran for six consecutive days for 45 minutes a day on the treadmill. Open circuit metabolism measures were conducted throughout rest, exercise and recovery during each testing session. The study and collection of data were commenced on February 17, 1976 and concluded February 29, 1976. Physiological performance parameters only were observed. The physical performance parameters were kept constant; i.e., running time on the treadmill, treadmill speed and grade all remained constant.

DEFINITIONS OF TERMS

Several terms that are used throughout this study are defined to present more clarity to the reader.

Glucose

Glucose is the form of carbohydrate most readily used in the body and is the principal source of energy for living organisms. It is a monosaccharide with the chemical formula $C_6H_{12}O_2$.

Free Fatty Acids - FFA

These are acids in the blood formed from the breakdown of fat by hydrolysis.

Glycogen

This is a carbohydrate in the form of a polysaccharide - $C_6H_{10}O_2$. It is stored in the liver and skeletal muscle and is readily converted into energy.

Respiratory Quotient - RQ

When carbohydrate is oxidized the volume of O_2 used and carbon dioxide produced are equal. When fat is oxidized more O_2 is used than carbon dioxide produced. A ratio of carbon dioxide production to oxygen consumption, $\frac{CO_2}{O_2}$, gives the respiratory quotient, RQ. The chemical structures of carbohydrate and fat differ and as a consequence have different RQ's. From this knowledge, the amount of these substances supplying the energy for muscular activity can be determined from RQ's calculated from expired air (20, 21).

Chapter 2

REVIEW OF LITERATURE

INTRODUCTION

The human machine like any other machine in this world requires energy in the form of fuel to function (19). The fuels consumed in the diet determine the amount, rate and efficiency of energy production (32). These fuels contained in the human diet for muscular energy production have been identified as carbohydrate, fat and protein. The effects of diet, both beneficial and detrimental, on physical performance have long been of interest to researchers. Tuttle et al. (65) showed the importance of diet fuels on performance by just altering breakfast habits.

The following review of literature attempted to examine the relevant research conducted into the role and effects of the constituents of diet on physical exercise.

FAT AS A FUEL FOR MUSCULAR ENERGY METABOLISM

Carlson (16) noted that for a long time it was believed that carbohydrates were the major fuel if not the one fuel for the production of energy in muscle tissue.

Furusawa (31) in 1925 studied the effects of short and long continuous exercise performed following a normal diet and following a high fat diet. The subjects completed an hour of slow bench stepping and achieved very low RQ's and it was concluded "...fat or protein is presumably used to replenish the carbohydrate store which has disappeared." This was one of the earliest studies to establish the role of fat in energy production.

Andres *et al*. (1) in a 1956 study found that in the resting muscles of the forearm, that only 7% of the oxygen uptake was due to oxidation of glucose. The mean RQ's obtained were 0.8 which indicated that fat served as the major substrate for oxidation.

Fritz *et al*. (30) further cited evidence of muscle use of free fatty acids in rest and activity. Electrical stimulation of muscle of normally fed rats resulted in a 60% increase in oxygen consumption and a 100% use in free fatty acid oxidation.

Carlson and Pernow (14) had subjects ride with one leg on a bicycle ergometer till exhaustion to establish the role of blood lipids during exercise. Catheters were placed in the brachial artery and femoral vein and at moderate exercise an increased flow of free fatty acids from the blood plasma to the exercising muscle was noted. From the RQ's recorded it was established that carbohydrate metabolism could not account for the total oxygen consumption of the subjects.

Freidberg *et al*. (29) found in subjects who had consumed a normal mixed diet, that after pacing themselves for 15 minutes on a bicycle ergometer, plasma free fatty acids were promptly lowered. This suggested an increased flow of free fatty acids into the muscle during exercise. In a further study Freidberg *et al*. (28) obtained more direct evidence that the forearm during alternate sqeezing and relaxation extracted free fatty acids from the blood and oxidized this to form carbon dioxide.

The main sources of fat ultilization have been identified by Havel *et al*. (35) as free fatty acids supplied through the blood and intracelular muscle lipids. Masoro *et al*. (54) similarly identified two sources of fat for energy metabolism. In further pursuit to identify the sources of fat for fuel Carlson (14) inhibited the mobilization of free fatty acids by injection of nicotinic acid. The exercising subjects still obtained very low RQ's which indicated that the major fuel was still lipid. He suggested then that free fatty acids have "two pools - intra and extracellular".

Hultman (41) on the other hand, by methods of muscle biopsy, attempted to study the role of free fatty acids during exercise. He noted no significant decrease before or after exercise in fat content of the exercising muscle.

The following were advanced by Carlson (15) as a summary of the research findings that fat can be adapted for use and is a fuel in muscular energy production. The findings were : (1) low RQ values that signify that fat is being oxidized, (2) muscle cells contain enzymes that oxidize fat to carbon dioxide and water, (3) A-V difference studies of glucose and glycogen found that their metabolism did not account for the total VO_2, (4) lipids can be transported in the blood plasms and (5) intracellular fatty acids are contained in the muscle and are consumed in exercise.

CARBOHYDRATE VERSUS FAT UTILIZATION IN PHYSICAL ACTIVITY

Research has shown that carbohydrate if in adequate supply, would be the preferred fuel for physical activity (2, 13). However research has presented many factors that effect the contribution of fat and carbohydrates to varying degrees during periods of physical activity.

Intensity and Duration of Exercise

The actual intensity and duration of exercise has been found to be a major determinate as to which energy source is preferred for energy metabolism. Krogh and Lindhard (52) in 1926 found that subjects using a bicycle ergometer were more efficient when exercise followed the intake of a high carbohydrate diet rather than following a high fat diet. They found that when the workload was most severe the greatest difficulty was experienced when exercise followed a diet consisting predominantly of fat. Best et al. (9) and Furusawa (31) recognized that following extremely strenuous work, high RQ's of unity revealed that carbohydrate was the primary fuel being metabolized in exercise.

Marsh and Murlin (53) established the muscular efficiency of subjects working on the bicycle ergometer having previously followed diets that were normal, high carbohydrate and high fat. They found that exercise following the high carbohydrate diet was 11-12% more efficient.

Christensen and Hansen (20) in their classic 1939 study utilized the RQ to determine the participation of fat and carbohydrate during exercise with subjects following different diet regimes. The subjects performed a standard workload of 1080 Kgm/min on a bicycle ergometer. Following a normal diet they established that fat contributed 50-60% of the energy production. After the subjects had consumed a high fat diet for several days an exercise RQ indicated that fat combustion accounted for between 70-99% of the energy output. Finally a high carbohydrate diet in which 90% of the calories supplied were from carbohydrate, was consumed prior to exercise. Increased RQ's were obtained which indicated a much less contribution from fat. It was found that after the carbohydrate diet that one subject could work on the bicycle ergometer for 240 minutes, whereas following a high fat diet could only exercise for 80 minutes. They concluded that in activity that is aerobic in nature that fat supplies between 50 and 70 percent of the energy production. Long heavy endurance work saw a gradual decrease in carbohydrate utilization and an increased fat usage. In anaerobic work of very short duration carbohydrates were the major fuel.

Courtice and Douglas (25) worked untrained subjects for 10 miles at 4.5 miles per hour on the treadmill. Exercise RQ's were observed to increase from resting levels. Even higher RQ's were obtained after ingestion of a high carbohydrate diet; this induced greater carbohydrate participation. The treadmill speed was slowed and exercise RQ's were obtained that differed little from those obtained at rest. They concluded that this indicated less dependence on carbohydrate participation.

The detrimental effects of a high fat diet were shown by Henschell (37). He found that workers fatigued more rapidly and were less efficient after following a high fat diet regime.

Carlson and Pernow (14) studied subjects exercising on a bicycle ergometer with one leg to exhaustion. They found that carbohydrate metabolism can't account for the total amount of oxygen consumed by the subjects during exercise. During moderate exercise they found that fat contributes a great deal to the energy production, but during maximum work because of insufficient oxygen supply to aid in fat oxidation, carbohydrate is predominantly metabolized.

Issekutz, Birkhead and Rodahl (43) had subjects exercise at a very light load of 300 KPM on a bicycle ergometer. An exercise RQ of 0.73 was obtained following a high fat diet in which 247 grams of carbohydrate, 231 grams of fat and 89 grams of protein were consumed. They calculated from the RQ's that between 75 and 81 percent of the energy supplied was from fat metabolism.

Havel et al. (35) found that subjects exercising at 50% of their maximum volume of oxygen uptake (MVO_2) that fat metabolism supplied 50% of energy production. After fasting for 48 hours between 41 and 49% of energy metabolism was obtained by fat oxidation. However, after ingestion of a carbohydrate meal, fat only contributed to between 7 and 10% of the energy metabolism.

The workload intensity and relative fuel participation has been demonstrated to be dependent upon the individual's state of fitness (45). An individual with a greater aerobic capacity can work at higher workloads and not produce lactic acid and still be able to metabolize fat, oxygen availability being a limiting factor in fat utilization for energy production (43). Issekutz, Miller and Rohahl (44) in a further study with "fit" and "unfit" dogs showed that the "unfit" dogs called upon anaerobic metabolism for fuel (carbohydrates) earlier than the "fit" dogs.

The critical point of choice of fuel for metabolism depends upon the relative severity of the work in relation ship to the aerobic capacity possessed (47, 58, 61). Astrand (3) observed that by increasing the workload from 29% of maximum aerobic power to 79% was associated with an increase in the combustion of fat from 2.5 Kcal to 3.6 Kcal whereas carbohydrate combustion increased from 3.4 Kcal to 12.3 Kcal. He concluded that workloads of 75% or more of max VO_2 depended on the carbohydrate store in the form of glycogen and would determine the amount of time exercise could be performed. Hermansen, Hultman and Saltin (38) further substantiated this when they exercised subjects at their 77% of MVO_2 and found glycogen levels to be the limiting factor. Pruett (57) worked subjects at 70% MVO_2 and combined a high fat diet, standard diet and a high carbohydrate diet. The work times to exhaustion following the diets were 164, 187 and 193 minutes respectively. With subjects working at 50% of their MVO_2, carbohydrate contribution to energy metabolism was 40% when the standard diet was consumed, 35% on the fat diet and 50% on the carbohydrate diet. At 70% of their MVO_2 the percentage contribution of carbohydrates were 53%, 50% and 60% respectivly. He concluded from the study that glycogen stores can be depleted at workloads that elicit between 65 to 75% MVO_2 depending on diet conditions.

Taylor et al. (63) obtained a progressive increase in blood lactate and a decrease in free fatty acids with workloads that progressed from 25% to 50% MVO_2 and finally 75% MVO_2. With the increasing levels of work, the source of energy changed from free fatty acid oxidation to carbohydrate. However, it was established that the point of transfer was unclear. Williams et al. (66) indicated that at 50% MVO_2 fat accounts for 69% of energy metabolism. Astrand (2) in a 1967 study found that athletes exercising aerobically on a normal diet obtain between 50 and 60% of their energy from fat metabolism. With increased aerobic activity for three hours fat accounted for 66% of the energy produced as reflected by low exercise RQ's. Subjects were then placed on a high fat diet and it was found that they could only perform half as long. Very low exercise RQ's were obtained and energy was indicated as coming from between 70 to 90% fat metabolism.

Karlsson and Saltin (48) had 10 subjects run a 30 Km race on two separate occasions. All subjects ran their best times after they had consumed a carbohydrate enriched diet prior to the event. Costill et al. (22)

ran five subjects 16.1 Km at 80% of their MVO_2 for three successive days. Muscle biopsies were performed to determine the amount of fat and carbohydrate participation. The RQ's were seen to decrease throughout the runs and over the three days. A mixed diet was consumed which was composed of the following. Forty to 60% was carbohydrate, 30-40% was fat and 10-15% was protein. On day one carbohydrate was estimated to contribute 87% of the energy metabolism, 66% on day two and 57% on day three. Fat utilization, determined from the biopsies, was 15.2 grams on day one, 38.4 grams on day two and 46.4 grams on day three. They felt that the body shifts in its choice of fuels from necessity and availability.

Costill (24) saw that in the early stages of a marathon carbohydrates contribute 90% of the energy and fat 10%, but near the end of the gruelling 26 miles 95-98% of energy was supplied by fat oxidation.

Brooke and Green (12) observed the effects of diet immediately consumed following exercise on a bicycle ergometer for two and one-half hours. During a 40 minute rest period carbohydrate only, carbohydrate and fat and a low energy content meals were consumed. Riding was then resumed till exhaustion or an RQ value of 0.73 was reached. The pure carbohydrate meals permitted the most work to be done by all subjects.

Edwards et al. (27) performed a specific study on the fuel contributions of four college football players with a calorie need of 5,600 calories. It was established that 12% of the energy came from protien, 44% from fat and 46% from carbohydrate.

Glycogen, Glucose and Free Fatty Acids and Exercise

The levels of glycogen, blood glucose amd free fatty acids (FFA) have all been found to vary with exercise and diet (7, 10, 15). The initial level of glycogen has been seen as a major limiting factor in exercise as well as a major contribution to performance (3, 8).

Saltin and Hermansen (61) used muscle biopsy techniques to determine the amount of glycogen contained in the quadriceps femoris muscles of subjects prior to riding a bicycle ergometer at 75% of their MVO_2 to exhaustion. They found that on a mixed diet that the resting level of glycogen ranged from 1.5 - 2.3 grams/100 grams of wet muscle (g%) and that subjects were able to work on the ergometer for times that ranged from 85-114 minutes. A high fat and protein diet was imposed on the subjects and further resting biopsies were performed. Glycogen levels ranged from 0.3 - 1.3 grams percent and the mean performance time on the bicycle ergometer dropped to 54 minutes. A high carbohydrate diet was next followed by the subjects and resting muscle biopsies performed. Values of 3-4.7 grams percent were obtained and the mean performance time on the bicycle was increased to 189 minutes. Bergstrom et al (8) in a further expansion of this study observed that three days of fat diet following exhaustion did not resynthesize muscle glycogen to more than 50% of the normal resting range.

Bergstrom and Hultman (7) further utilized muscle biopsies and noted that glycogen levels decrease and approached zero in the working muscles. They stressed the fact that glycogen stored in the exercised muscles only can be used. Glycogen stored in other muscle groups cannot be recruited for use.

Hultman and Bergstrom (41) in an excellent study combined differing diets with depletion of glycogen stores in order to see what effects this would have on subsequent glycogen stores. The subjects exercised with one leg to exhaustion. After depletion of the muscle glycogen and consuming a fat and protein diet, there was a very slow resynthesis of glycogen. The subsequent effect of a high carbohydrate diet was a rapid and elevated glycogen resynthesis in the working muscles well above normal levels. Karlsson and Saltin (48) in 1971 found an increase in muscle glycogen and improved performance times of runners in a 30 Km race following the ingestion of a high carbohydrate diet. They also warned that increasing glycogen stores too much could be disadvantageous in that glycogen is stored with water in the skeletal muscle and liver. There would be an increase in body weight greater than the increase in the weight of the glycogen stored. This increased weight would reduce the MVO_2 in ml/Kg/min.

The water loss of athletes must be considered. When one gram of glycogen was broken down more than 2.5 - 3 grams of water were released (5, 41). The initial water loss of a carbohydrate diet is an excellent example of the water storage of glycogen.

The amount of lactate which is produced at relative workloads is higher than on a low carbohydrate diet indicating a greater tendency toward carbohydrate usage in exercise (50).

Blood sugar drops with exercise and is dependent on the diet (62). Bergstrom et al. (8) found that following a fat and protein diet regime blood glucose levels dropped to very low levels. They also found that glucose production by the liver increases toward the end of work, but was in actual fact small compared to the total carbohydrate demand. The most important role of blood glucose was described by Guyton (34). Blood glucose is the fuel for the central nervous system (CNS). A fall in blood sugar interferes with the functioning of the CNS and is termed hypoglycemia. Astrand (5) has observed hypoglycemic conditions in cross country skiers after distances of 20-25 Km or after approximately one and one-half hours of exercise. Christensen and Hansen (20) and Hedman (36) also observed low blood glucose levels with approached hypoglycemic conditions in their previously mentioned studies.

Boje (11) studied the effects of the ingestion of large amounts of dextrose prior to muscular work. He found that this ingestion of sugar immediately prior to exercise produced post exercise hypoglymeia down to levels of clinical symptoms. This was due to an abnormal glucose tolerance effect (34).

Following complete exhaustion and the ingestion of cabohydrate subjects have recovered and continued exercising, thus suggesting a high neural involvement via the depressed CNS. Christensen and Hansen (20) further established this CNS involvement could be a limiting factor in exercise. After ingestion of sugar to exhausted subjects, work was able to be resumed but low RQ's indicated that the sugar ingested was not associated with an increased oxidation of carbohydrates.

The liver during exercise has been seen to increase the release of glucose, but the increased demand for glucose during exercise limited the effectiveness of this output (7, 62). Thus the CNS is put under stress for fuel.

Pruett (57) in 1970 conducted a study into the effects of different diets on work stress. Blood glucose levels were found to drop during exercise at 50-70% MVO_2. Drops in the blood glucose levels of 62% were found to produce CNS symptoms of hypoglycemia. Subjects exercised on diets that were high in carbohydrate, high fat and a mixed diet. Blood glucose levels were the lowest on the high fat diet and subjects fatigued earlier when following this fat diet regime. During prolonged work blood glucose was seen to fall along with blood insulin. This suggests to Pruett that a possible mechanism for the preservation of liver glycogen stores for the CNS metabolism exists, otherwise the working muscle would too quickly utilize it and hypoglycemia would be inevitable.

Bergstrom and Hultman (7) studied subjects riding a bicycle ergometer at 950 KPM with direct glucose infusion. The glucose was given intervenously; 170-210 grams during one hour of work. They showed that infusion only replaced glycogen to a very limited amount. It was concluded that glycogen is the major muscular fuel but when depleted blood glucose is used to a greater extent. Simonson (62) saw two limitations of hard physical work, First, the level of blood glucose effects the CNS and second, the exhaustion of muscle glycogen adds further limitation to physical activity.

The supply and utilization of free fatty acids (FFA) has been established by previously mentioned research (44). Simonson (62) advocated that once readily accessible fuel stores in the muscle have been depleted FFA were available for absolute use for continuous work. Rennie et al. (58) observed that by altering the diet athletes could improve performance by sparing fat stores initially by using carbohydrates and then fats later. Rodahl et al. (60) advocated that the combined effects of insulin and norepinephrine could account for the differing effects of FFA levels during exercise. Norepinephrine was found to increase the FFA level during activity. Insulin however delayed and depressed the release of FFA but facilitated glucose uptake. Dole (26) found that lactic acid interfered with the release of FFA and hence relative workloads that elicit anaerobic responses determined the role FFA played in energy metabolism. Johnson et al. (47) concluded with subjects that were trained and untrained that after one and one-half hours of exercise that trained athletes can more effectively oxidize fats for energy. The trained subjects also had lower lactate levels.

Oxygen Consumption and Diet

The amount of literature that reported oxygen consumption and the influence of diet on this parameter was limited. A 1926 study by Cathcart and Burnett (18) had one subject exercise on a hand ergometer while on different diets. They reported that oxygen consumption remained constant when the subject was on a mixed diet and a high fat diet. When a high carbohydrate diet was followed a lower oxygen demand was noted. Goldsmith et al. (33) found the effects of three separate 500 calorie meals on separate occasions. The three diet meals consisted of protein, carbohydrate and fat and pure carbohydrate. Mean oxygen uptakes were found to increase by 15% after the protein meal, 9% after the fat meal and no change in oxygen uptake after the carbohydrate meal. The authors suggested that there was a decreased efficiency of work performance following the fat and protein meals.

Diet-Protein and Energy Production

The role of protein in providing energy for muscular activity was, and in many cases still is, shrouded in a cloud of ignorance, old fads and habits (39, 46). Astrand (3) stated that for at least 2,500 years it was believed that a high protein diet was essential for physical work. Keys (51) illustrated that it wasn't until 1866 that the theory of protein being the fuel for exercise to any appreciable extent was finally refuted.

Wilson (67) in 1931 studied subjects who worked on a bicycle ergometer for periods of 10 minutes to an hour following a high protein diet. Only slight increases in Nitrogen and Sulfur excretions were observed in the urine. He saw these slight increases were small and in terms of extra protein metabolized, were completely inadequate to account for the work done. Studies (2, 23, 56) all confirmed the fact that there was no real correlation between protein intake and work performance above the level needed for bodily maintenance. Hedman (36) studied cross country skiers after two and one-half hours of skiing and found glycogen stores were depleted completely, yet continued exercise did not significantly raise the nitrogen excretion. Mayer and Bullen (55), Nelson (56) and Itallie et al. (46) alluded to the idea that protein had a very high psychological influence on the athlete and his performance despite the scientific evidence that illustrated that the role of protein in energy metabolism is limited.

SUMMARY

The literature demonstrated that the major sources of fuel for energy production are fats and carbohydrates. The predominant participation by one particular fuel source is determined by such factors as the intensity and duration of the particular physical activity. Specificity again being of an essential nature to the task. Dietary adjustments are also another factor in deciding which fuel contributes most in energy metabolism.

The relative workload with respect to each individual's maximal aerobic power determines from which fuel, fat or carbohydrate, energy production originates. Very low workloads use fat as the primary fuel. Moderate exercise utilizes both carbohydrate and fat equally. Carbohydrates are found to be the major fuel preferred for muscular work of heavy, short duration. As exercise increases in duration fats play a more major role in energy production. The availability of carbohydrate however permits endurance activity to be performed at a higher intensity. Adaptation to exercising on pure fat is established but is considred inefficient.

The role of protein in the diet for energy supply in physical activity is found to be minimal.

Chapter 3

PROCEDURES

This study investigated the effects of a three-day carbohydrate restricted diet on energy metabolism of trained subjects performing endurance treadmill running. The study was conducted during the Spring semester of the 1975-76 school year at Kansas State University, Manhattan, Kansas. The following discussion in this chapter describes the procedures utilized in this study.

Subjects

Five subjects volunteered to participate in this diet and exercise study. Three Ph.D's who were on the faculty at Kansas State University and two physical education graduate students consented to act as subjects. All five subjects were identified as well-trained, as they all participated in regular jogging of five to six miles on five or six days per week. Their jogging participation was purely for recreational purposes and personal fitness attainment.

The subjects were not competitive runners but all had run in long distance races on a recreational basis.

The age of each subject was recorded and appears in Table 1. The five subjects ranged in age from twenty-five to forty-two years. The mean and standard deviation of their ages were 32.6 and 7.12 respectively. The initial subject data was assembled and appears in Table 1.

Table 1

Subject Data

Subject	Age (yrs)	Height (cm)	Initial Weight (Kg)
1	25	176.4	80.8
2	26	172.72	72.12
3	42	175.26	78.75
4	36	185.42	85.19
5	34	181.34	87.27

Informed Consent Form

A form which explained the requirements of treadmill running and diet in the study, medical release and the choice to cease participation in the study at any time was presented to and acknowledged by the signature of each subject. A sample form appears in Appendix A.

Treadmill Experience and Running Speed Determination

Each subject had had previous experience at running on the treadmill. However, to ensure adequate skill was possessed for the required prolonged treadmill run, all subjects were given a practice run for forty-five minutes on the day immediately preceeding the study sequence. This fulfilled a three-fold purpose. First, practice was gained on the treadmill apparatus, second, it provided for the normal exercise program of the subjects to be followed, and third, it ensured uniformity and consistency amongst all the subjects.

The maximum volume of oxygen uptake (MVO_2) of each subject had previously been established in volitional maximal performance tests conducted in the exercise physiology lab of the H.P.E.R. Department at Kansas State University. With this information available concerning each subject, the workload of approximately 75 percent MVO_2 was established and the necessary treadmill running speeds required to elicit this cardiovascular response for the study were determined. Table 2 was constructed from the treadmill running speeds data.

Table 2

Treadmill Running Speeds

Subject	Speed in MPH	Grade %
1	8.00	0
2	8.25	0
3	7.75	0
4	8.00	0
5	7.75	0

Dietary and Running Requirements

The main purpose was to study the effects of a carbohydrate restricted diet and treadmill running. The subjects were required to run on the treadmill for six consecutive days for a forty-five minute duration per day at the previously discussed and determined speeds.

Three consecutive days of carbohydrate restricted diet were to be observed by the subjects. The carbohydrate restriction diet limited the intake of carbohydrate to no more than 50 grams per day. Following the carbohydrate diet a normal diet was resumed and running continued for two further days.

The running and diet response is presented in Table 3.

Table 3

Diet and Treadmill Running Sequence

Day	Diet and Running
0	Diet normal, practice run for 45 minutes (no data collected)
1	Breakfast normal - run for 45 minutes
2	Diet all day - run for 45 minutes
3	Diet all day - run for 45 minutes
4	Diet breakfast - resume normal diet following run
5	Normal diet - run for 45 minutes
6	Normal diet - run for 45 minutes

Diet Guidelines and Recommendations

A diet outline was given to each subject and they were asked to follow it closely. The diet was constructed to eliminate carbohydrate but care was taken to ensure that basic nutritional requirements within the restricted capacity of the low carbohydrate diet were met. No caloric intake limitations was established. These diet guidelines and recommendations appear in Appendix B.

Testing Procedures

The testing procedures adopted in this study were most beneficially discussed in the following areas of testing time, equipment and preparation and data collection.

Testing Time

It was decided that testing would be between 11:00 a.m. and 1:00 p.m. each day, as this time best suited the availability of all subjects and the test administrators. Time and personnel limited to two the number of subjects who could be tested daily. Consequently only two subjects were able to follow the running and diet regime for the six days concurrently. This resulted in the study taking three weeks to complete.

Equipment and Preparation

Each day prior to testing the wet and dry bulb temperatures along with the barometric pressure in the exercise physiology laboratory were recorded. This facilitated the determination of the partial pressure of water in the air (17) and the standard temperature pressure dry (STPD) correction factor of the inspired air to be recorded for the subject.

Expired air was analyzed for oxygen and carbon dioxide content using a Beckman Model E2 oxygen analyzer and a Beckman Model LB1 carbon dioxide analyzer.

Calibration of the oxygen analyzer was performed prior to each daily testing with Helium gas for a Zero percent reading and room air at the 20.93 percent reading. The carbon dioxide analyzer was also calibrated and regularly checked during each testing using a gas of known quantity of carbon dioxide (5%). The calibration for room air was 0.03%. Both gas analyzers were also checked for calibration accuracy at regular intervals throughout each testing session of the study. One hour prior to testing the analyzers and pumps were switched on to insure their correct functioning.

A Parkinson Cowan Ventilometer was employed to measure the volume of inspired air taken in by the running subjects. Prior to the study the calibration of the ventilometer was verified by the use of a Collins Chain-Compensated 120 Liter Tissot Tank.

The subject's inspired air was recorded as mentioned on the ventilometer via hosing and a Collins Triple J valve and mouth piece. The valve and mouth piece were sterilized and suspended from the treadmill at a convenient height for each subject.

A Quinton Model 640 treadmill provided the facility on which the subjects ran. The treadmill speeds were checked for accuracy using the treadmill revolution counter and the known exact elapsed time at the programmed speed.

Data Collection

Subjects were weighed nude on a Homs full capacity beam bench scale with blank tare, Model 300 t, both before and after the testing to determine the sweat loss incurred (Appendix C). The subjects dressed only in gym shorts and running shoes for the study.

For five minutes prior to running the subjects rested standing on the treadmill. A nose clip sealed the nose and the mouth piece was inserted in the mouth. The expired air was directed into a small mixing chamber. The inspired air as was previously mentioned was drawn through and recorded on the P.C. Ventilometer. Expired air samples for analyzation of oxygen and carbon dioxide content were drawn from the small mixing chamber into 700 cc vacuumed "mini" bags by a Neptune Pressure Dyna Pump, Model 4K. The procedure of open-circuit metabolism measurement adapted for the study was that described by Consolazio, Johnson and Pecora (21).

During the final minute of rest (5th minute) the volume of inspired air was recorded and a sample of expired air was taken over the minute duration. Heart rate was also recorded during this last minute of rest with the aid of a stethoscope.

The treadmill was now started and the subjects ran at their predetermined speeds at zero percent grade for forty-five minutes. In order to clear the dead air space, one minute prior to the commencement of every fifth elapsed minute interval the subjects were instructed to replace the breathing apparatus and nose clips while still running. The volume of inspired air was then recorded and an expired gas sample taken for the duration of a minute. At the end of the sampling minute the subjects removed the mouth piece and continued to run without it for another five minutes until the next sample was ready to be taken. Nine samples were taken throughout the 45-minute running period and the timing of these minute samples appears in Table 4.

Table 4

Sampling Protocol

Time	Time (continued)
Resting	
4-5 Resting Sample 1	29-30
Running	
4-5 After Start of Run	34-35
9-10	39-40
14-15	44-45
19-20	0-5 Recovery Sample 1
24-25	5-10 Recovery Sample 2

At the end of 45 minutes running the subjects stopped the treadmill and rested standing on the stationary treadmill with the breathing apparatus still in their mouths. Immediately the treadmill stopped, heart rate was taken for a 30-beat count and converted to a minute heat heart. The volume of inspired air and expired gas samples were taken over two five-minute recovery periods, see Table 4.

Statistical Treatment of Data

A two-way analysis of variance design for repeated measures was used for statistical analysis of the data. When a statistically significant F was obtained a Least Significant Difference (LSD) technique was applied to identify precisely where the difference occurred, The 0.05 level of probability was selected as the statistical criterion for significance.

The computer facilities of the Computing Center at Kansas State University, Manhattan, Kansas were used to perform all calculations.

Chapter 4

RESULTS AND DISCUSSION

INTRODUCTION

The purpose of this study was to observe the parameters of VO_2, RQ and work-end heart rate following continuous treadmill running on differing dietary conditions of normal and three consecutive days of carbohydrate restricted diet. The results obtained are presented and discussed in this chapter.

As previously mentioned this study adopted the statistical analysis technique of the two-way ANOVA. The Fisher technique of Least Significant Difference was used to make multiple comparisons of means following rejection of the overall null hypothesis with the two-way analysis of variance.

Heart Rate

Resting heart rates of subjects were recorded and appeared in Appendix D. Many physiological and psychological factors can affect resting heart rates and as a result these data were not found to be of any significance to this study.

Work-end heart rates were taken immediately as the exercise period finished and this data was assembled in Table 5.

The results of the two-way analysis of variance (ANOVA) appeared in Table 6 and indicate that a significant difference exists between the mean work-end heart rate and the diet-day regime variables. Figure 1 graphed the daily mean work-end heart rates.

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.

Figure 1. Daily Mean Work-End Heart Rates

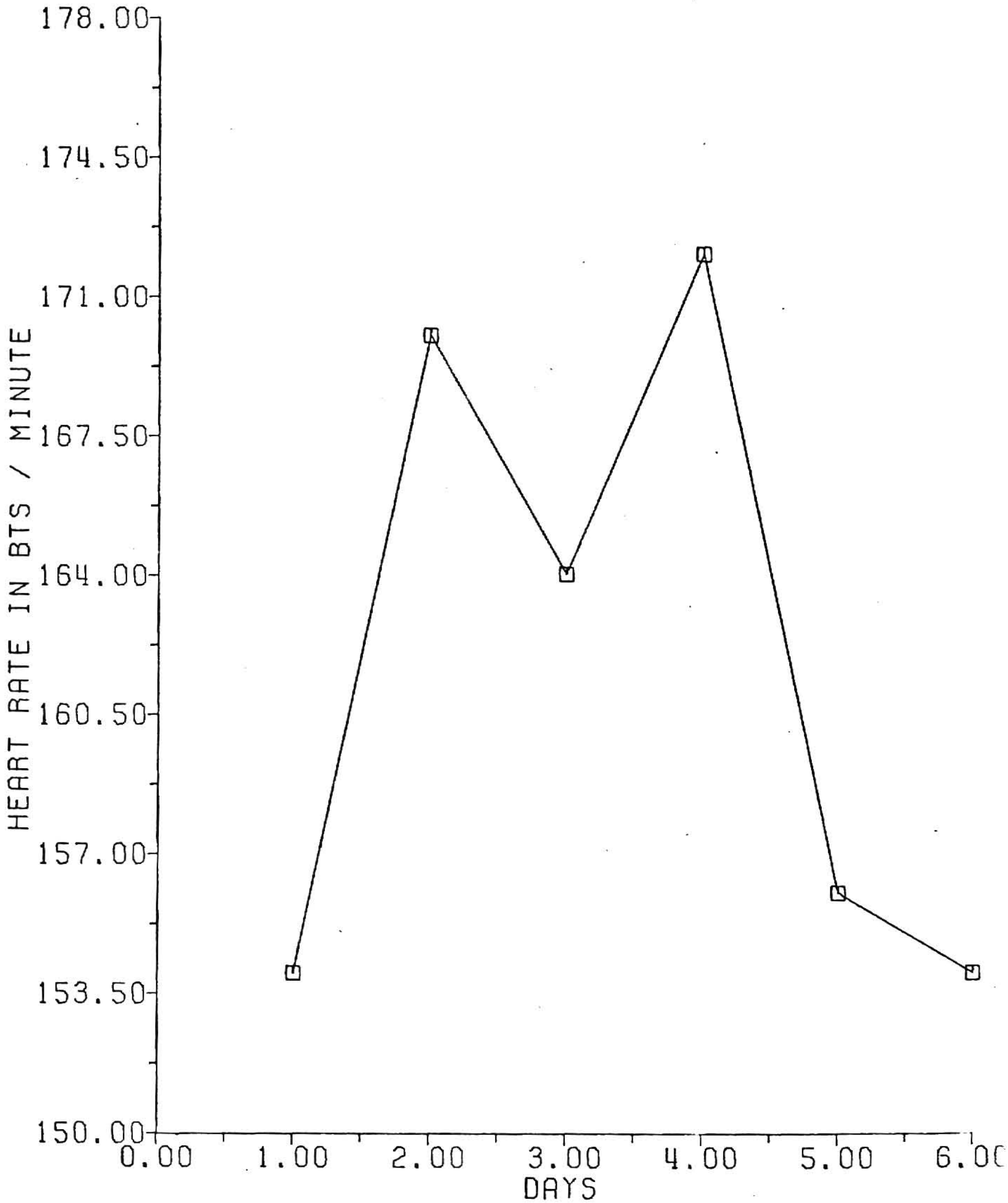

Table 5

Work-End Heart Rates

	days					
Subject	1	2	3	4	5	6
1	155	168	167	178	171	*
2	149	180	161	170	146	150
3	162	152	157	167	158	159
4	137	165	161	170	159	161
5	170	188	176	178	145	143
$\overline{X}$	154.6	170.6	164.4	172.6	155.8	154.3

*Subject 1 was unable to finish study due to injury.

Table 6

Summary of Two-Way ANOVA for Work-End Heart Rates and Day-Diet Variables

Source	df	SS	MS	F
Subject	4	367.9157	91.9789	0.861
Day-Diet	5	1650.6988	330.1396	3.089*
Residual	19	2030.8312	106.8858	

*Significant at the .05 level.

The Fisher LSD summary in Table 7 established that on days 6, 1 and 5, the mean work-end heart rates for these days were significantly lower than those achieved on the carbohydrate restricted diet days of 2, 3 and 4. The mean work-end heart rates for days 1, 5 and 6 were found to have no significant difference between them. Similarly days 2, 3 and 4 were found to have no significant difference.

Volume of Oxygen Uptake

The mean VO_2 in liters/min for each day-diet are illustrated in Figure 2. These means ranged from 3.126 liters/min to 3.338 liters/min. Statistical analysis utilizing the two-way ANOVA revealed that the variables of day-diet and VO_2 differed significantly. The complete statistical summary of the two-way ANOVA appears in Table 8.

By means separation, the six daily VO_2 means were all found to be significantly different from each other, Table 9. The normal diet days 1, 5 and 6 were all found to be significantly different from each other

Table 7

Work-End Heart Rates Treatment Means and Non Significant Groupings Determined by Fisher's LSD*

Day-Diet		Heart Rate	
6		154.3	NS
1		154.6	NS
5		155.8	NS
3	NS	164.8	
2	NS	170.6	
4	NS	172.6	

*NS bar denotes groupings of no significant difference.

Figure 2. Daily Mean VO_2's

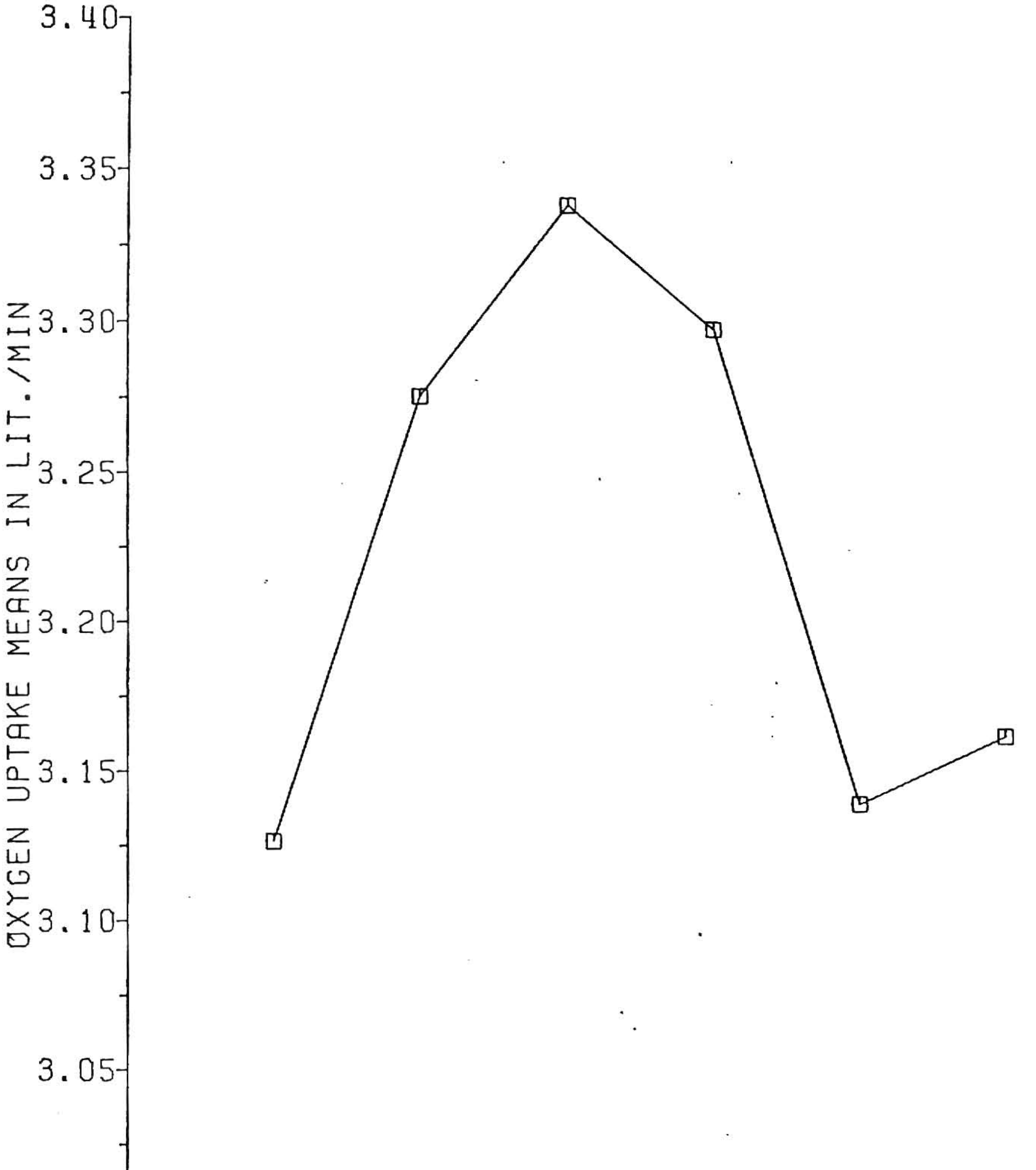

Table 8

Summary of Two-Way ANOVA for the VO_2 in liters/min, Day-Diet and Time Variables

Source	df	SS	MS	F
Subject	4	2.211294	1.80282	4333.682*
Day-Diet	5	2.45840	.491681	1181.919*
Error (A)	19	.007904	.000416	
Time	11	318.24572	28.93142	519.872*
Day-Diet x Time	55	3.78068	.68739	1.235
Error (B)	253	14.07971	.055651	

*Significant at the .05 level.

Table 9

VO_2 in liters/min Treatment Means and Non Significant Groupings Determine by Fisher's LSD

Day-Diet	VO_2 liters/min
1	3.12621
5	3.13805
6	3.16033
2	3.27473
4	3.29661
3	3.338315

NS bar denotes groupings of no significant differences.

with day one attaining the lowest mean VO_2. These figures are statistically significant but in a true physiological sense these differences are not that great. The diet-day regime groupings do however reveal a true physiological difference that would effect performance. Days of normal diet, 1, 5 and 6, were significantly different from the means for the carbohydrate restricted diet-days 2, 3 and 4 in that they achieved significantly lower VO_2's than the mean VO_2 for days 2, 3 and 4, the carbohydrate restricted diet-days.

Of the three carbohydrate restricted diet-days the VO_2 means also differed significantly with day two achieving a lower mean VO_2 than day 4 and 3, respectively. Interestingly though, day 3, the middle day of the carbohydrate restricted period, was significantly different from day 4, in that the mean VO_2 was higher for day 3. Figure 2 clearly illustrates these day-diet, VO_2 variables differences.

A significant difference was found in the time, and VO_2 variables, Table 8. This difference occurred in samples taken during rest and recovery. The LSD summary in Appendix E shows that no significant difference exists between time during exercise and VO_2 uptake means.

The individual exercise VO_2's in liters/min data for each subject were graphed and appear in Figures 3 through 7. A close study of these figures further established the trend more clearly shown by the mean daily VO_2 data graphed in Figure 2, that being the fact that higher VO_2 values were achieved on the carbohydrate restricted diet-days. The individual VO_2 ranges are presented in Table 10.

Figure 3. Daily Exercise VO_2 for Subject #1

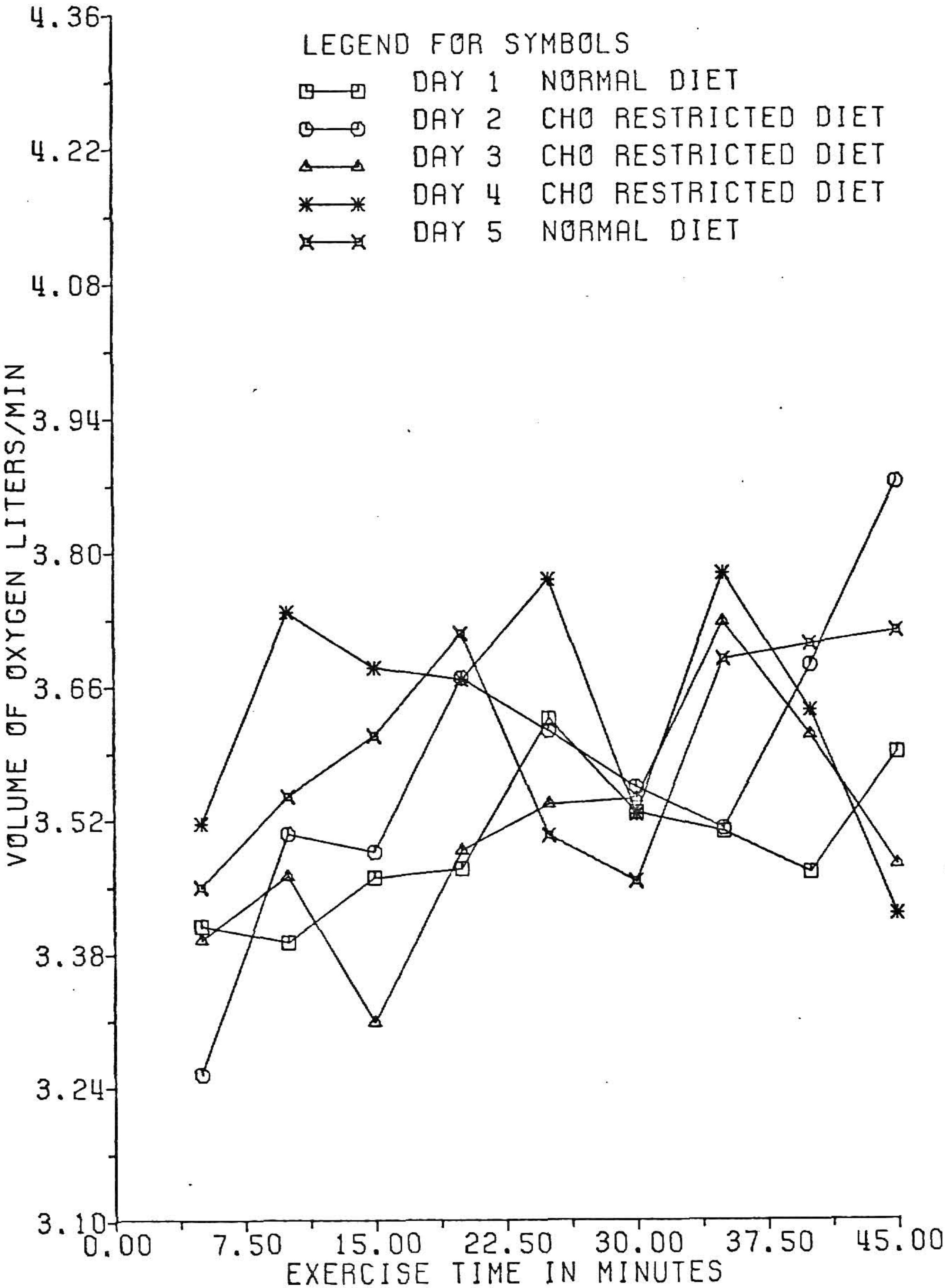

Figure 4. Daily Exercise VO_2 for Subject #2

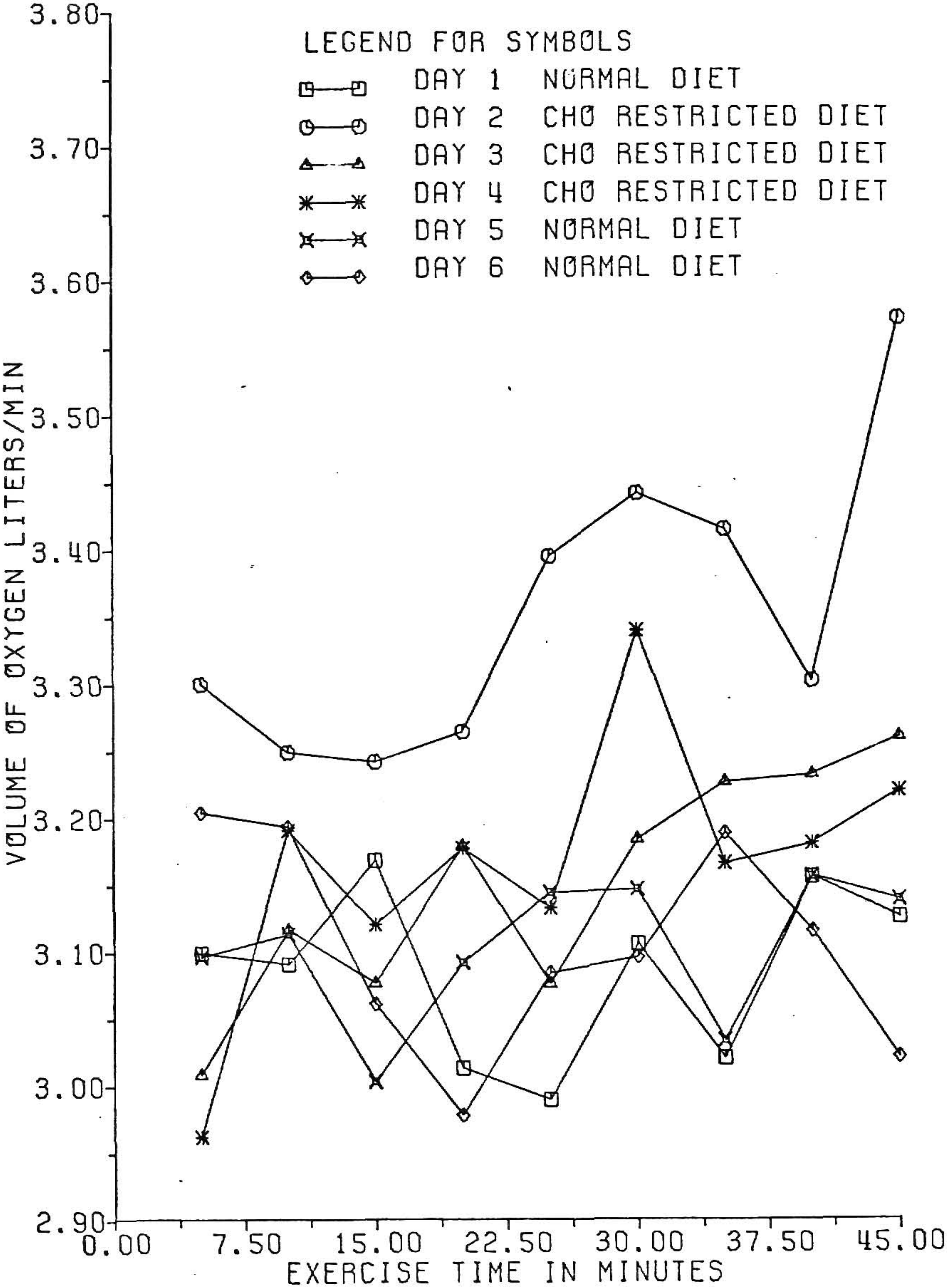

Figure 5. Daily Exercise VO_2 for Subject #3

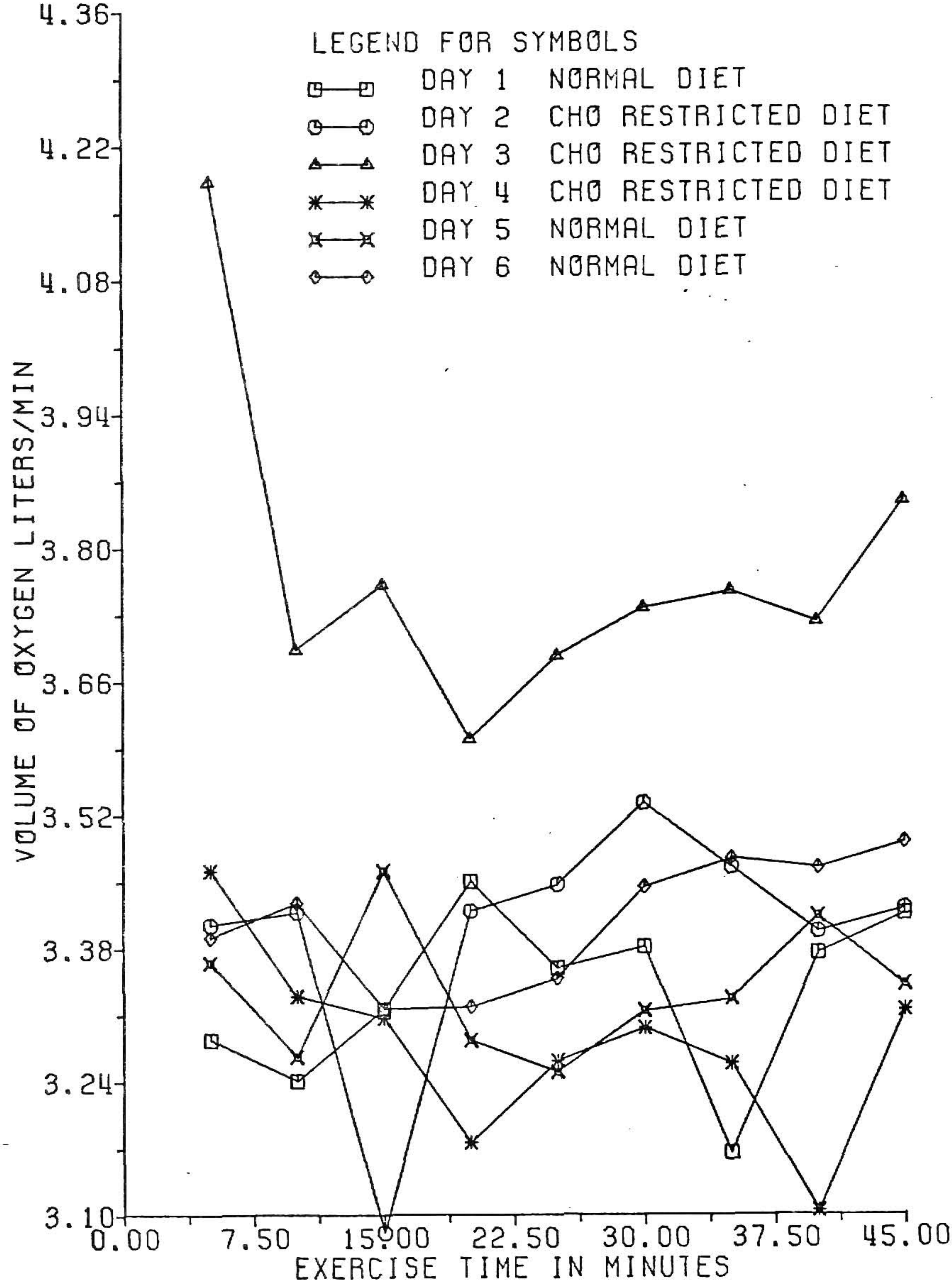

Figure 6. Daily Exercise VO_2 for Subject #4

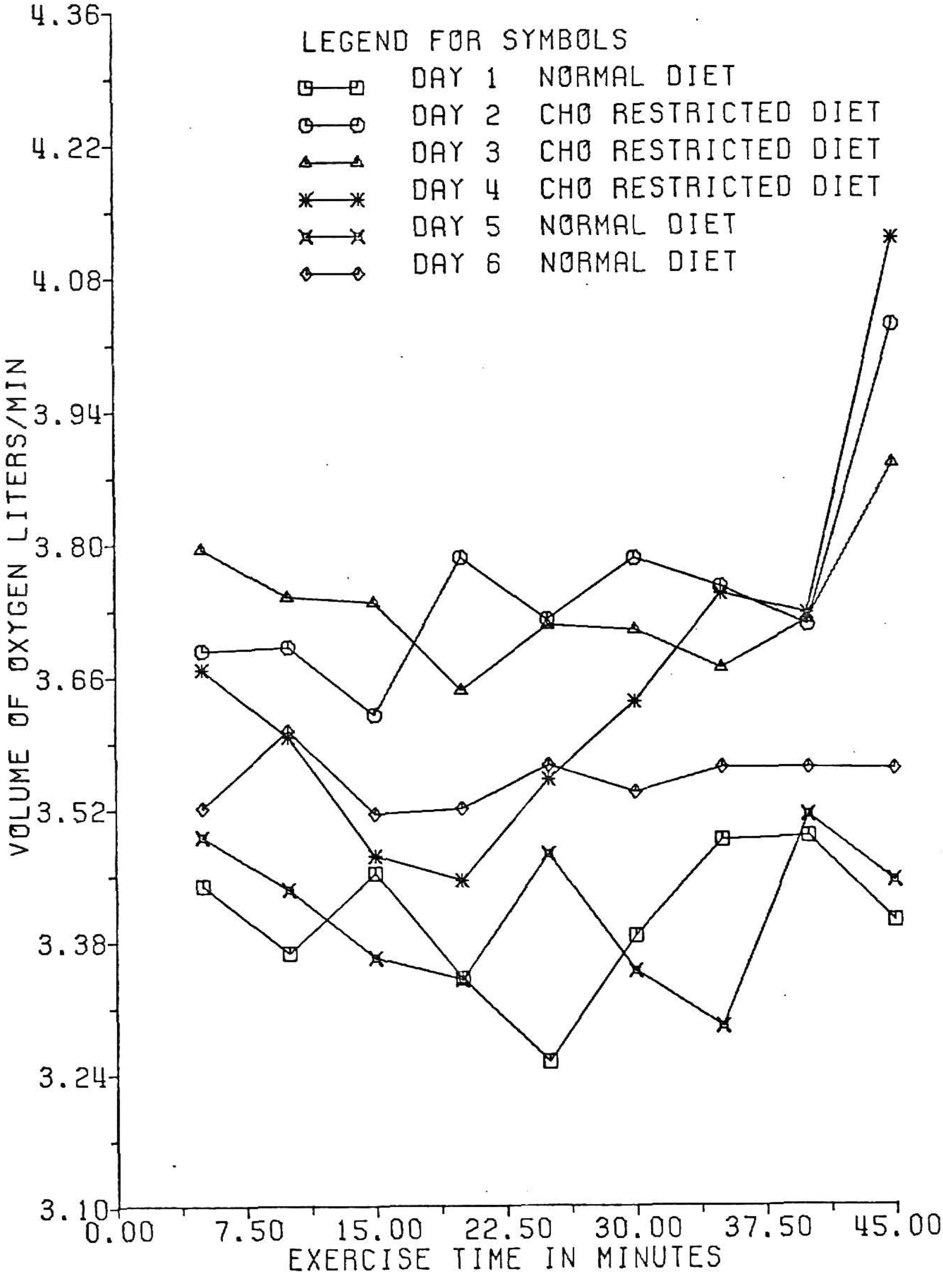

Figure 7. Daily Exercise VO_2 for Subject #5

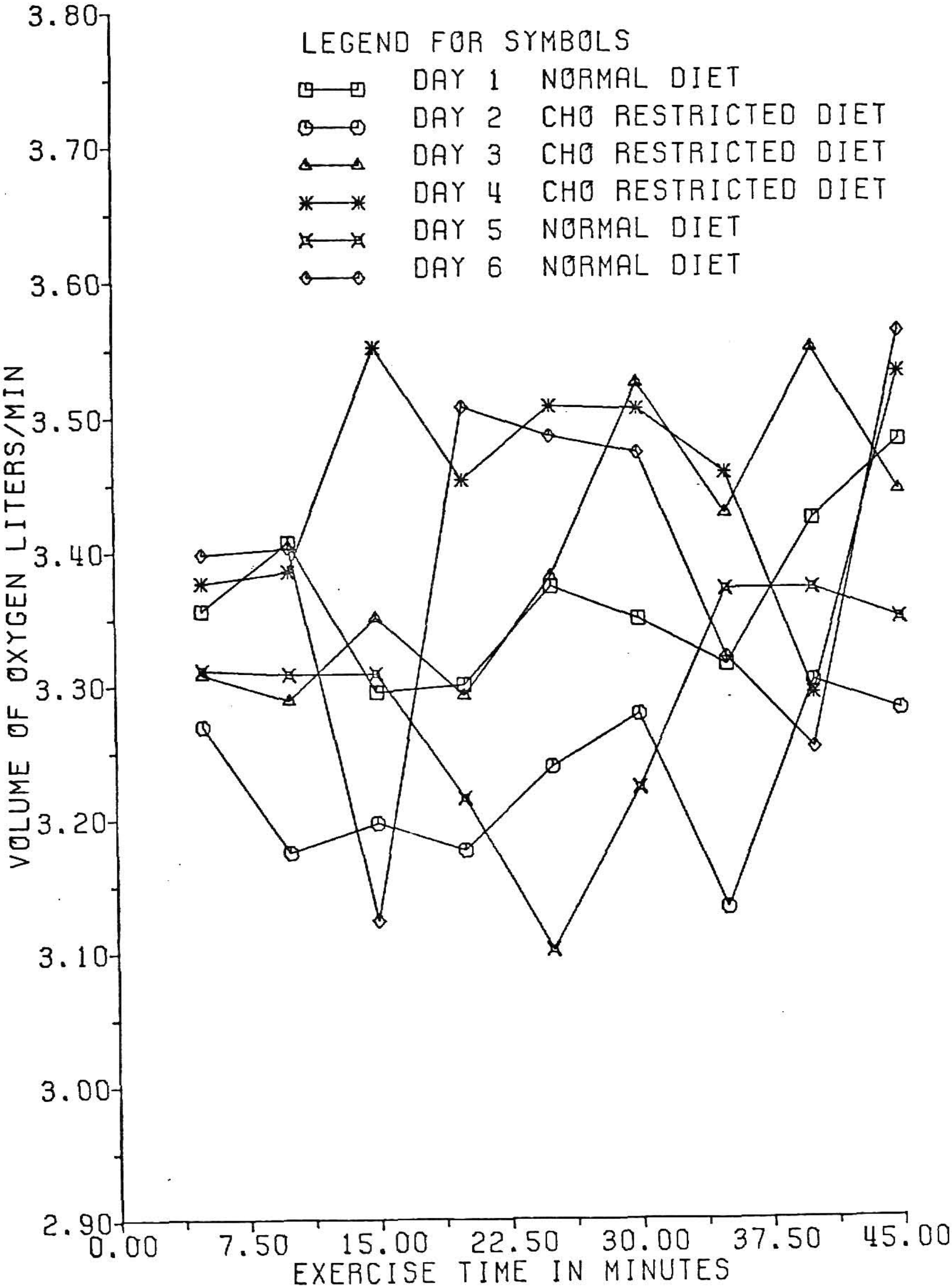

Table 10

Range of Subject VO_2 in liters/min

Subject #	Low	Day	High	Day
1	3.25	2	3.87	3
2	2.98	1	3.57	2
3	3.08	2	3.85	3
4	3.25	1	3.85	3
5	3.10	5	3.56	6

The mean volume of oxygen uptakes also measured in milliliters/ Kilogram of body weight/minute (ml/Kg/min) were calculated and statistically analyzed and the results obtained appear in Table 11. The range of values obtained were from 38.817 ml/Kg/min to 42.08 ml/Kg/min. The two-way ANOVA results indicated that significant differences exist between the variables, day-diet, time and day-diet x time and the VO_2 uptake means. These results mirror very closely the results obtained for the VO_2 in liters/min variable except for the day-diet x time interaction. The normal diet-days 1, 6 and 5 were found to be significantly lower than the carbohydrate restricted diet-days. Mean separations by LSD technique in Table 12 identified these differences. It should be established again that day 3, the middle day of the carbohydrate restricted diet period, was significantly higher in VO_2 in ml/Kg.min than day 4.

Sample time and VO_2 means were found to be significantly different following the two-way ANOVA treatment. The LSD technique established that

Table 11

Summary of Two-Way ANOVA for the VO_2 in ml/Kg/min, Day-Diet, and Time Variables

Source	df	SS	MS	F
Subject	4	969.9326	242.4832	3277.926*
Day-Diet	5	582.3536	116.4707	1574.470*
Error (A)	19	1.4055	.0739	
Time	11	49913.4451	4537.5820	605.781*
Day-Diet x Time	55	614.7102	11.5402	1.541*
Error (B)	253	1895.0871	7.4905	

*Significant at the .05 level.

Table 12

VO_2 in ml/Kg/min Treatment Means and Non Significant Groupings Determined by Fisher's LSD

Day-Diet	Mean VO_2 ml/Kg/min	
1	38.8173	
6	39.3607	NS
5	39.3633	NS
2	41.1715	
4	41.7774	
3	42.0829	

NS bar denotes groupings of no signficant differences.

test, exercise and recovery samples all differed, as would be expected. No real appreciable trend was noted during exercise sample times. This data appears in Appendix F.

As we previously mentioned, Table 11 showed that the two-way ANOVA determined a significant F value for the day-diet x time interaction for VO_2 in ml/Kg/min variable means. This meant that sample time values of the VO_2 variables were affected by the day-diet regime. Significant differences were obtained with the VO_2 means when samples were taken at different times and were also interacted upon an effected by the differing day-diet conditions of the study. The mean separations were again determined by Fisher's LSD and this summary was assembled in Table 13. From this table it can be seen that days, 3, 4 and 6 behaved in a very similar pattern, achieving no significant differences at any sample time throughout the exercise period. Days 1 and 2 also had similar time interactions with the inclusion of the 2nd five-minute recovery period. Day five's response between sample time and the VO_2 variable was much different from the other days in that two step-like groupings were achieved when the sample times x day interactions were considered.

Respiratory Quotient

A significant difference was found to exist between the day-diet regime and the mean RQ variables and the two-way ANOVA results appear in Table 14. Application of the Fisher LSD technique determined that the mean RQ's for each day were all significantly different from each other for the six individual days of the study, Table 15. It was found that the three carbohydrate restricted diet-days all had significantly lower

Table 13

Day-Diet x Time, VO2 in ml/Kg/min Treatment Means and Non-Significant Groupings Determined by Fisher's LSD

Day	Sample Time	VO_2	Day	Sample Time	VO_2	Day	Sample Time	VO_2
1	1[a]	4.84	2	1[a]	6.63	3	1[a]	5.54
1	12[b]	30.44	2	12[b]	36.33	3	12[b]	36.60
1	4	40.54	2	6	43.18	3	5	43.23
1	5	41.34	2	7	43.21	3	9	43.26
1	9	41.68	2	5	43.60	3	2	43.33
1	6	41.89	2	3	43.63	3	4	43.73
1	2 NS	42.07	2	8 NS	43.71	3	6 NS	43.94
1	7	42.07	2	2	43.74	3	3	44.06
1	8	42.17	2	4	43.80	3	7	44.21
1	10	42.31	2	10	44.41	3	8	44.42
1	3	42.41	2	9	44.84	3	10	44.87
1	11[b]	53.99	2	11[b]	56.96	3	11[b]	67.80

NS bar denotes groupings of no significant differences.

[a]Rest sample.

[b]5-minute recovery samples.

Table 13 (Continued)

Day	Sample Time		VO_2	Day	Sample Time		VO_2		Day	Sample Time		VO_2
4	1[a]		4.53	5	1[a]		3.11		6	1[a]		5.64
4	12[b]		35.55	5	12[b]		33.98		6	12[b]		32.29
4	5		43.11	5	4		39.99		6	8		41.43
4	4		43.14	5	2		40.73		6	3		41.53
4	3		43.34	5	3		41.04		6	5		41.72
4	6		43.53	5	8		41.68		6	2		41.76
4	2	NS	44.30	5	5	NS	41.72		6	6	NS	41.77
4	7		44.30	5	9		41.91	NS	6	4		42.04
4	8		44.62	5	6		42.00		6	7		42.16
4	9		44.64	5	7		42.45		6	9		42.53
4	10		44.84	5	10		43.91		6	10		42.78
4	11[b]		65.44	5	11[b]		59.83		6	11[b]		56.62

NS bar denotes groupings of no significant differences.

[a]Rest sample.

[b]5-minute recovery samples.

Table 14

Summary of Two-Way ANOVA for
RQ, Day-Diet and Time Variables

Source	df	SS	MS	F
Subject	4	.11947	.02987	1371.7*
Day-Diet	5	.29778	.05954	2734.151*
Error (A)	19	.00041	.00002	
Time	11	.13208	.01201	13.924*
Day-Diet x Time	55	.04552	.00083	.960
Error (B)	253	.21818	.00086	

*Significant at the 0.05 level.

Table 15

RQ Treatment Means and Non Significant Groupings as Determined by Fisher's LSD

Day-Diet	Mean RQ
3	.8284
4	.8441
2	.8505
6	.8866
1	.9003
5	.9027

NS bar denotes groupings of no significant differences.

mean RQ's than did the three normal diet-days. The total range for the mean daily RQ's was from 0.8283 on day three to 0.9027 on day five. The daily mean RQ's are graphed in Figure 8.

The individual RQ data for each subject daily throughout the study were recorded, graphed and appear in Figures 9 through 13. The ranges of exercise RQ's achieved during the study by each subject are presented in Table 16.

Table 16

Range of Subject RQ's

Subject #	Low	Day	High	Day
1	.8000	4	.9548	5
2	.7677	2	.9696	4
3	.7374	3	1.0001	6
4	.8003	3	.9703	6
5	.8043	4	.9444	1

These overall ranges do follow the pattern of the highest RQ's being on a normal diet-day and the lowest on a carbohydrate restricted diet-day. However, there is a lot of variation as to which day these highs and lows appear.

The sample time and RQ variables were found by the two-way ANOVA to be significantly different, Table 14. Mean separation showed that all exercise RQ's were not significantly different and that the differences occurred between rest, recovery and exercise sample times, Table 17.

Figure 8. Daily Mean RQ's

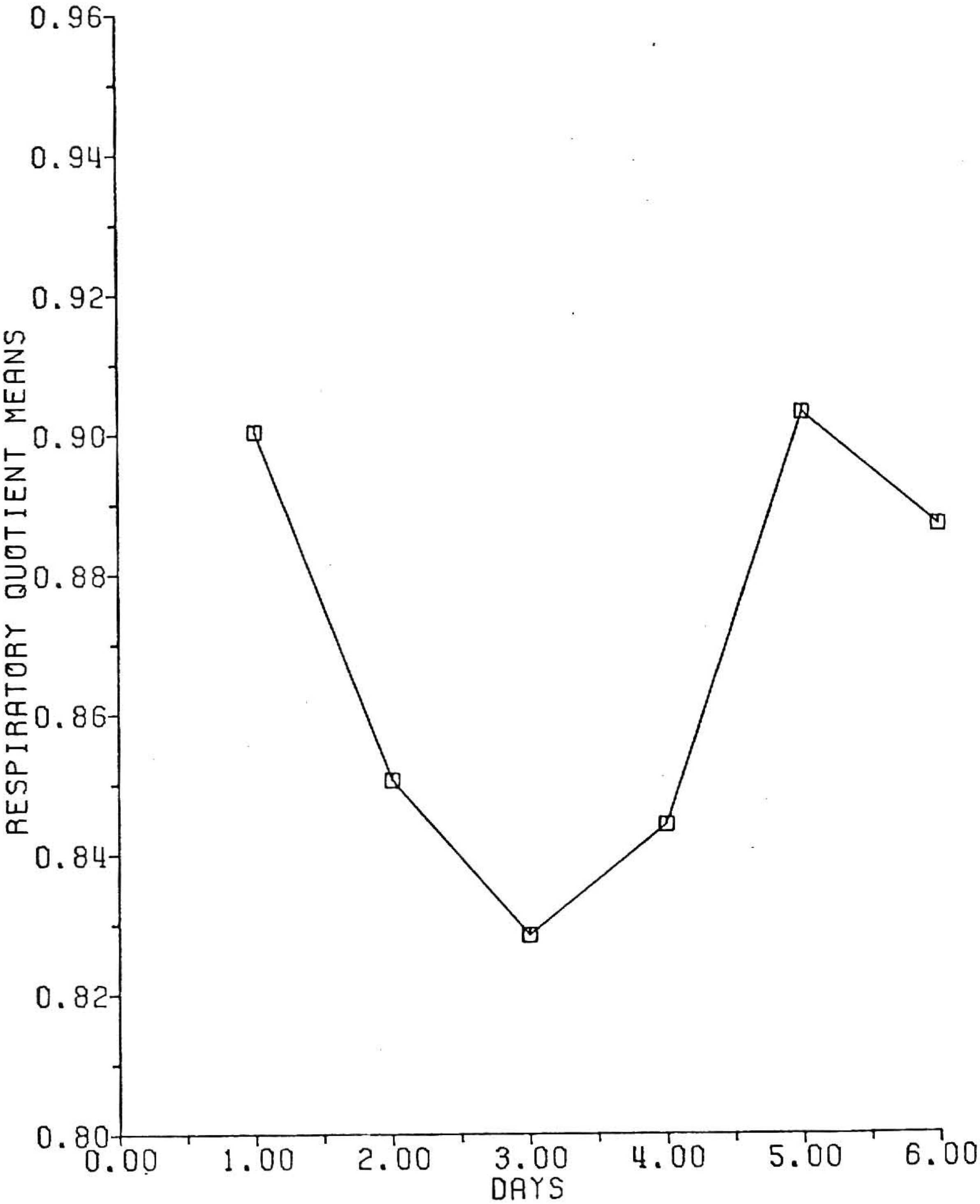

Figure 9. Daily RQ's for Subject #1

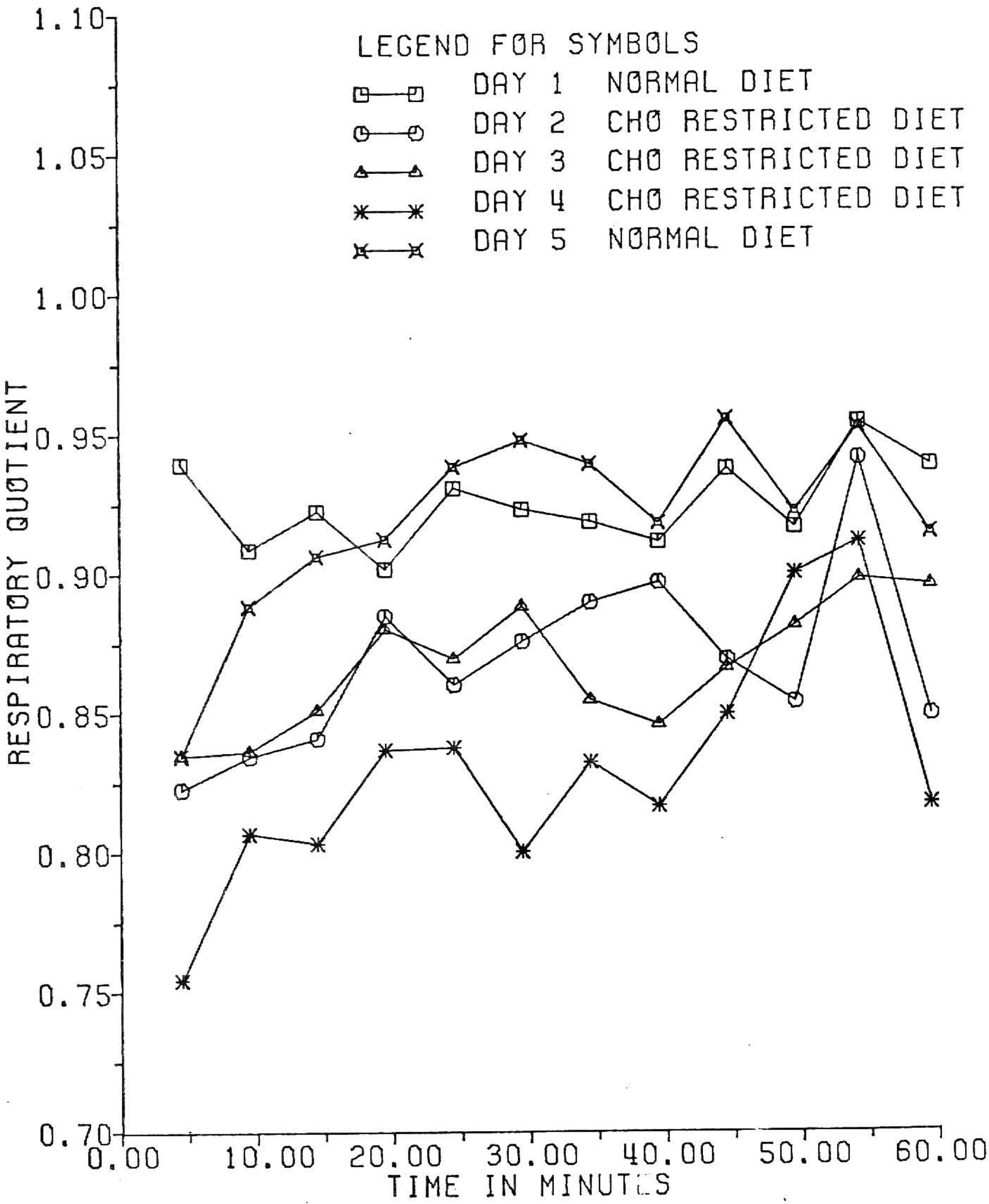

Figure 10. Daily RQ's for Subject #2

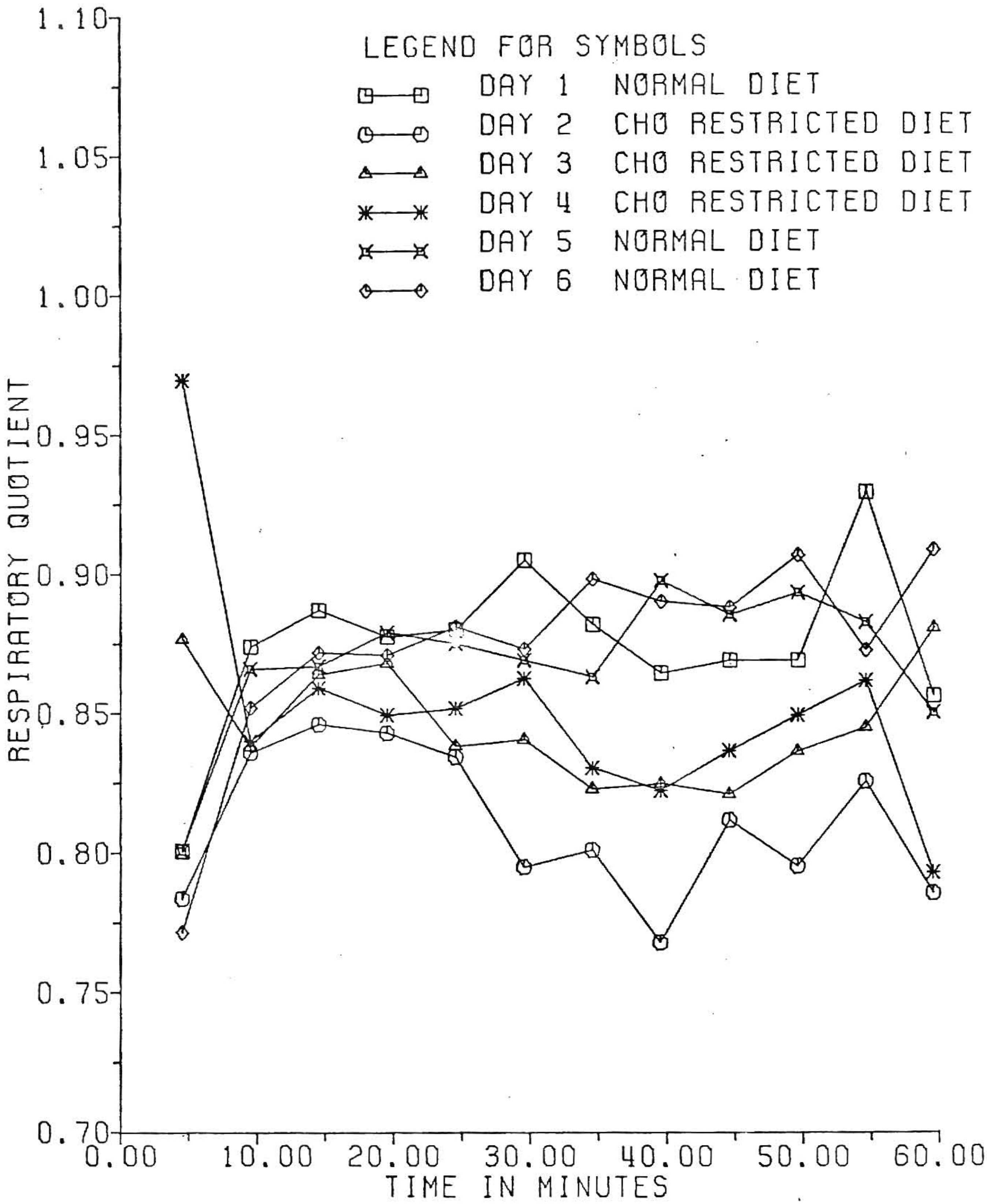

Figure 11. Daily RQ's for Subject #3

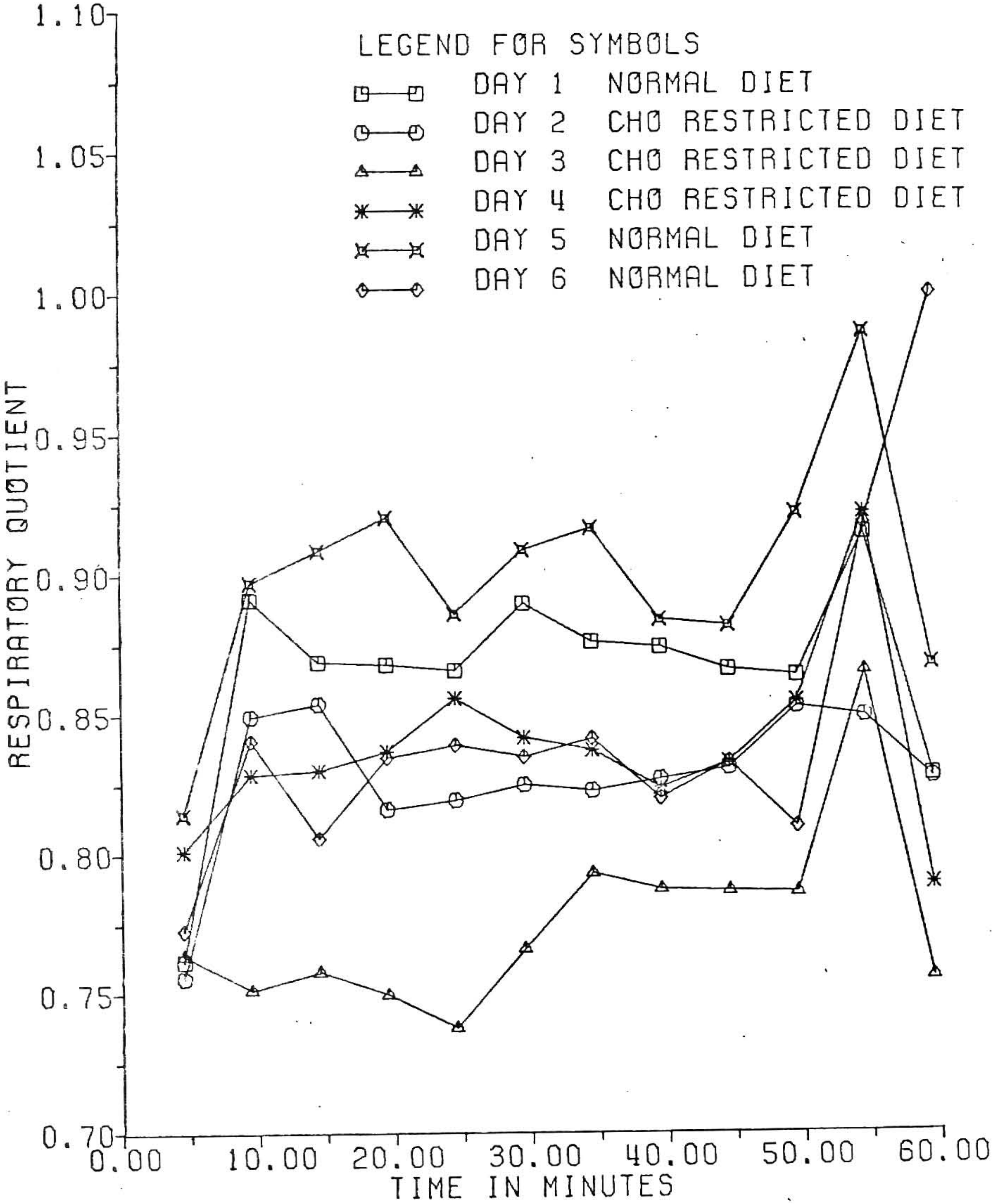

Figure 12. Daily RQ's for Subject #4

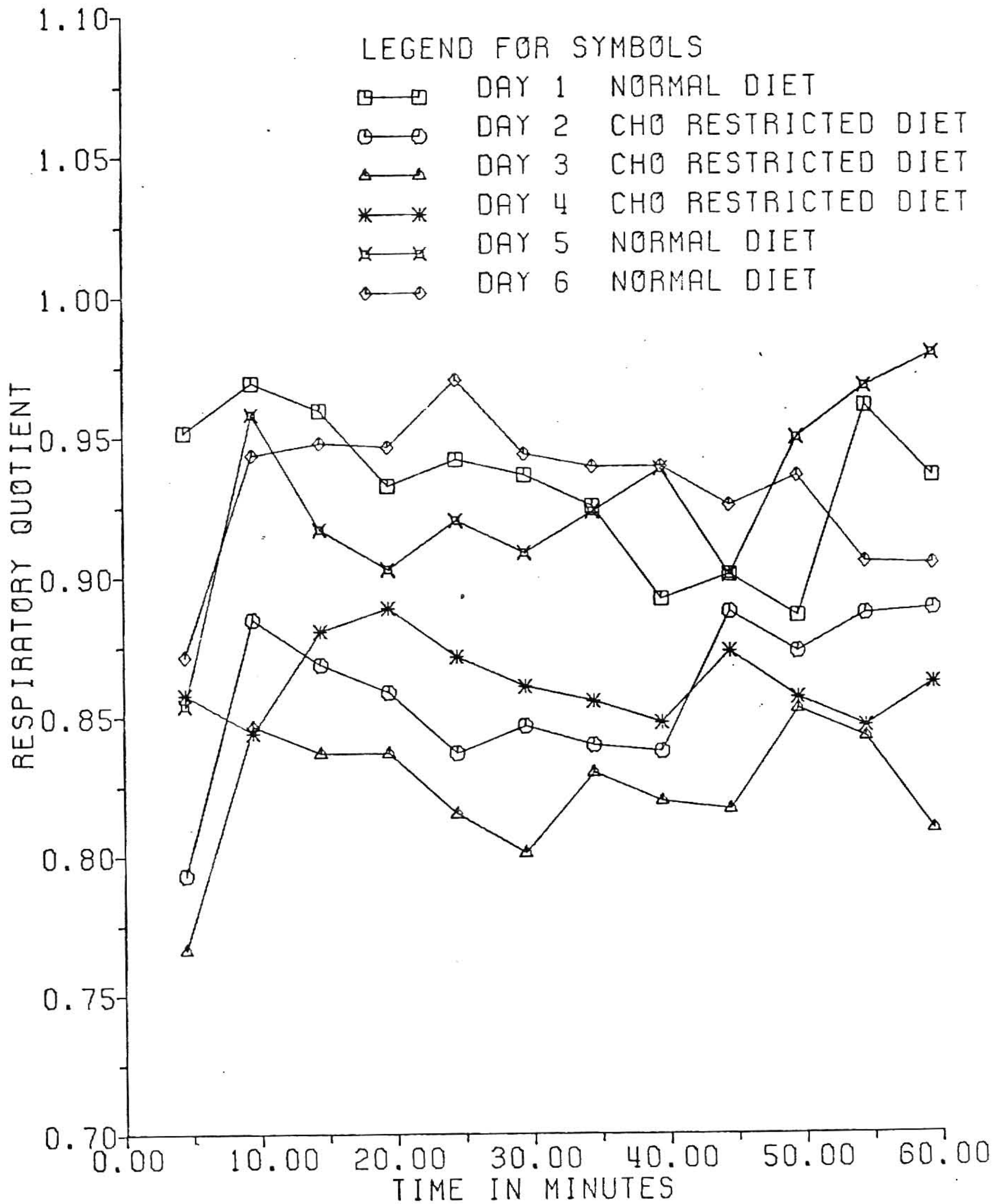

Figure 13. Daily RQ's for Subject #5

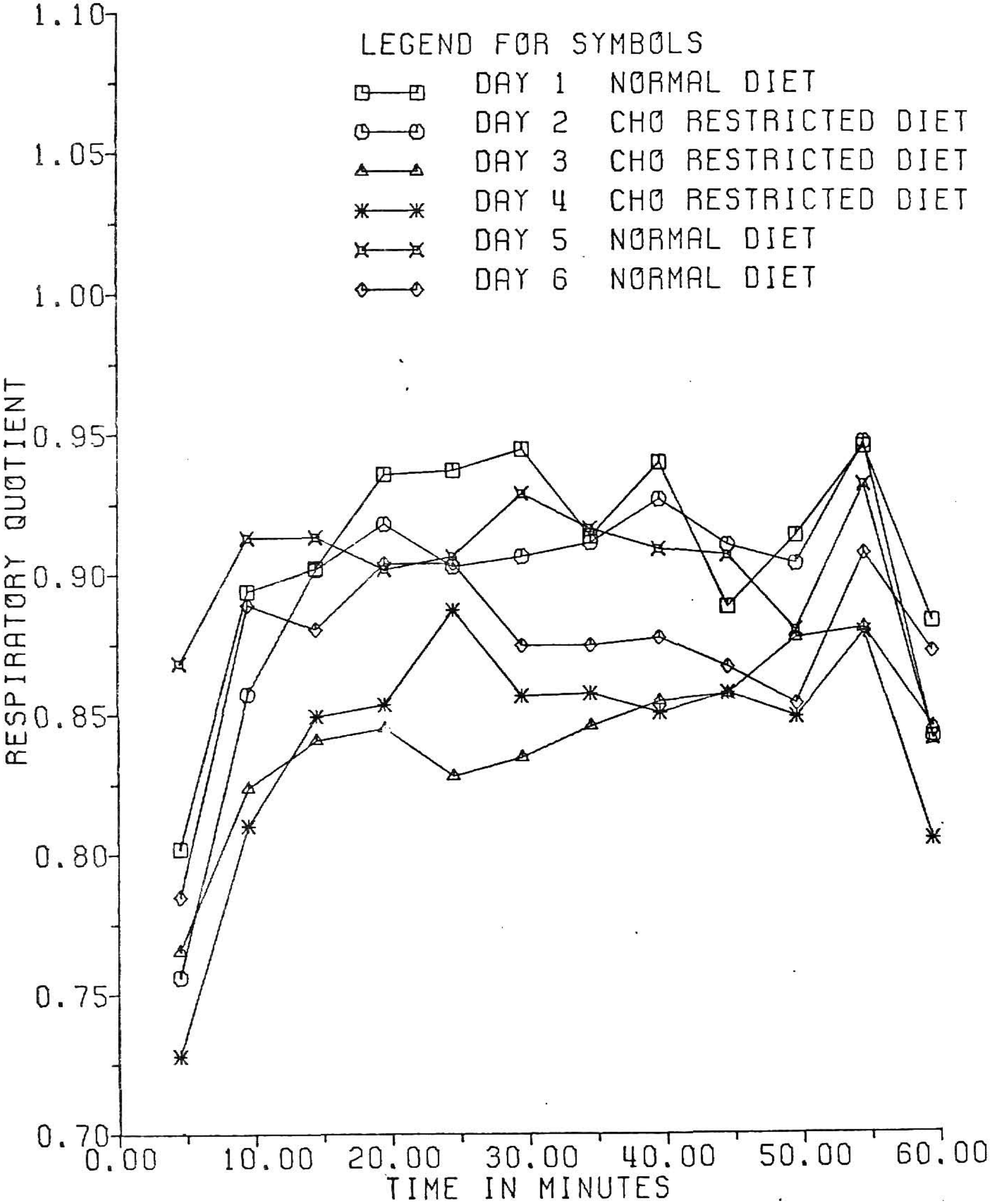

Table 17

RQ Treatment Means and Non-Significant
Groupings as Determined by Fisher's LSD

Sample Time		Mean RQ
1[a]		.8125
2	NS (start)	.8656
8	NS	.8863
12[b]	NS	.8674
9	NS	.8697
3	NS	.8701
7	NS	.8712
6	NS	.8735
5	NS	.8740
10	NS	.8741
4	NS (end)	.8751
11[b]		.9044

NS bar denotes groupings of no significant difference.

[a]Rest sample.

[b]5-minute recovery.

Caloric Cost

The caloric cost was determined from the RQ obtained, which was placed in the prediction table of the caloric equivalents in Consolazio et al. (21). These caloric costs were recorded in both Kcal/liter/min and Kcal/Kg/min. Treatment means and two-way ANOVA summaries appear in Appendices G and H.

DISCUSSION OF THE RESULTS

The primary purpose of the study was to observe the response that would occur to exercise energy production from fat as a fuel as a result of three consecutive days on a carbohydrate restricted diet. Mean work-end heart rates were achieved that reflected that the body was working under more difficulty and less efficiently as shown by significantly higher mean work-end heart rates on the carbohydrate restricted diet-days. A consistent response as indicated by work-end heart rates appeared to take place. The three mean work-end heart rates of the carbohydrate restricted diet-days showed no significant difference amongst themselves, however, as preciously mentioned, they were significantly higher than the three normal days. Table 10, page 43, and Figure 1, page 30, further clarify this occurrence. Even though the workload on the treadmill remained constant for each day, days 2, 3 and 4 mean work-end heart rates were significantly higher. These results concurred with the results obtained by Christensen and Hansen (20) in their 1939 study.

The inefficient usage of fat for fuel for muscular energy was clearly seen by the significantly higher mean VO_2 uptakes for the three carbohydrate restricted diet-days; Figure 2 illustrated these higher VO_2 uptakes. The same physical workload for each subject remained constant on the treadmill for the entire study, yet VO_2's were significantly lower when exercise was performed on a normal diet. Fat as a fuel requires more oxygen to oxidize it and has been determined to be much less efficient (15, 20). The subjects having restricted the intake of the more efficient fuel of carbohydrate were forced to utilize fat as a major source of fuel for energy metabolism. A greater demand was placed on the cardiovascular system to supply more oxygen to oxidize fuel to perform exercise that previously with carbohydrate as the major fuel could have been achieved with a much less oxygen demand. Variations were noted that were significantly different within the VO_2 means for the three carbohydrate restricted days. Not enough data was available to enable it to be seen what trend there was in these variations of response. Perhaps a trend in the response could have been noted if the restriction had been continued for a further period. No conclusions regarding the response can be made due to the limited data available.

Repiratory quotient data results were similar to studies in which carbohydrate restricted diets were imposed (20, 35, 43, 52, 53). The three normal diet-days achieved higher mean RQ's indicating a lesser role played by fat in energy metabolism (18). As was previously mentioned the three carbohydrate restricted diet-day mean RQ's were all significantly lower than the three normal diet-day mean RQ's. The mean RQ's for the three carbohydrate restricted diet-days ranged from 0.8284 to 0.8504 indicating that fat was contributing approximately 59% and 53% to the total energy metabolism (21). The three normal diet-days however had mean RQ's ranging from 0.8866 to 0.9027 which denoted approximately 39% and 36% fat contribution to energy metabolism (21). It was clear then that fat increased considerably its contribution to the energy production on the three carbohydrate restricted diet-days. Still further variations were observed with the RQ responses in the three carbohydrate restricted days. Just what these variations mean in terms of a trend, if any at all, are purely a matter of conjecture at this point because again of the limited response data.

An occurrance that was observed from the results of the data that cannot be explained by the author was the irregularity of response of the three variable means for RQ and VO_2. Day three, the middle day of the carbohydrate restriction period achieved a significantly higher mean VO_2 and a significantly lower RQ than the two other carbohydrate restricted diet-days. This appears to be completely out of any sequence. If a uniform response was to result from energy production from the fuel source of fat, then the variables would be expected to change progressively from day to day until a consistent response was achieved. This study was limited in its ability to observe a uniform response. Perhaps in order to achieve an observable uniform response by the body to prolonged energy production from predominantly fat, a further extended carbohydrate restricted diet period would be required. But no reason can be offered for the seemingly irregular response obtained in this study without further data.

Chapter 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

In this study five well-trained male recreational runners ran on the treadmill at speeds that corresponded to approximately 75% of their MVO_2 for 45 minutes a day for six consecutive days. It was the purpose of this study to determine the effects of an extended carbohydrate restricted diet on continued treadmill running performance as reflected by changes in the parameters of work-end heart rate, RQ and VO_2. For days 2, 3 and 4 of the study the subjects were required to consume a carbohydrate restricted diet of no more than 50 grams of carbohydrate per day, while continuing the running regime.

The results obtained show that statistically significant higher mean work-end heart rates were obtained in the three carbohydrate restricted diet-days than those of the three normal diet-days. All subjects reached their highest elevated heart rate during the carbohydrate restricted period.

Mean VO_2's were also elevated during exercise on the three carbohydrate restricted diet-days and were statistically higher than the VO_2 means for the three normal diet-days. These results were achieved even though the same daily workload was performed. The VO_2 means obtained for each of the three carbohydrate restricted diet-days however were all found to be significantly different from each other. This indicated no apparent uniform response.

RQ data also revealed the detrimental effects of the three carbohydrate restricted days. Mean RQ's for these days were significantly lower than the RQ's for the three normal diet-days. Significant differences were also found to exist among the mean RQ's for the three carbohydrate restricted diet-days.

These results indicated that all subjects resorted to the use of fat as the major fuel source for energy production as reflected by the previously mentioned significant changes in heart rate, VO_2 and RQ parameters. It also was calculated that to perform a standard work load the subjects turning to fat for fuel were much less efficient.

CONCLUSIONS

The following conclusions regarding the effects of a carbohydrate restricted diet on running performance are based on and supported by the data from this study and are explained and applied only with consideration within the limits of this study.

1. It was concluded that with a carbohydrate restriction on the diet, that the athlete will utilize fat for energy metabolism as reflected by low RQ's and increased VO_2 at exercise levels of 75% MVO_2.

2. The necessity to use fat as a fuel places a very large limiting factor on performance in that fat was an inefficient means of energy production. The inefficiency of fat for fuel was shown when more oxygen was needed to perform workloads that before, on a normal diet, could be performed at a lower VO_2, thus placing greater stress on the cardiovascular system and as a consequence limiting performance.

3. Increased work heart rates are associated with exercise on a carbohydrate restricted diet. It was concluded that this was a result of the

increased demand for oxygen delivery which was required for the oxidation of the inefficient fat fuel, which in turn must be supplied by increased cardiac output.

4. A normal diet will allow a more efficient performance, as reflected by heart rate, RQ and VO_2 parameters, than exercise performed while on a carbohydrate restricted diet.

RECOMMENDATIONS

The results of this study form the basis for the following recommendations for those who are interested in running performance and further research.

Recommendations for athletes interested in performance:

1. Joggers and runners, either recreational or competitive, who wish to perform with the greatest efficiency from the fuels taken in the diet, should not restrict the intake of carbohydrates while on an exercise program.

2. For maximum performance to be achieved, carbohydrate should form an integral and essential part of the diet.

Recommendations for further research incorporate:

1. The results of this study were somewhat inconclusive in determining whether a bodily adaptation would take place to the supply of energy mainly from fat as the fuel. Needed is further study that would adopt a longer carbohydrate restricted diet period to obtain more significant data.

2. This study should be repeated using women athletes to determine these effects on women.

3. Further study should be performed on carbohydrate restricted diets, but with complete control exercised over the caloric intake. Carbohydrate

restriction and differing caloric intake levels and their effects on continued endurance running needs to be examined.

BIBLIOGRAPHY

1. Andres, R., G. Cader and K. L. Zierler. "The Quantitatively Minor Role of Carbohydrates in Oxidative Metabolism by Skeletal Muscle in Intact Man in the Basal State," Journal of Clinical Investigation, 35:671, 1956.

2. Astrand, P.O. "Interrelationship Between Physical Activity and Metabolism of Carbohydrates, Fat and Protein," Symposia of the Swedish Nutrition Foundation, Nutrition and Physical Activity, Stockholm, Sweden: Hulmquist and Wiskells/Uppsala, 1967.

3. Astrand, P.O. "Diet and Athletic Performance," Federation Proceedings, 26:1772-1777, 1967.

4. Astrand, P.O. "Human Physical Fitness with Special Reference to Age and Sex," Physiological Review, 36:307-335, 1956.

5. Astrand, P.O. and K. Rodahl. Textbook of Work Physiology. New York: McGraw-Hill Book Company, 1970.

6. Bergstrom, J. and E. Hultman. "Nutrition for Maximal Sport Performance," Journal of the American Medical Association, 221:999, 1972.

7. Bergstrom, J. and E. Hultman. "A Study of the Glycogen Metabolism During Exercise in Man," Scandinavian Journal of Clinical Laboratory Investigation, 19:218, 1967.

8. Bergstrom, J., L. Hermansen, E. Hultman and B. Saltin. "Diet Muscle Glycogen and Physical Performance," Acta Physiologica Scandinavica, 71:140, 1967.

9. Best, C.H., K. Furusawa and J. H. Ridout. "R.Q. of Excess Metabolism of Exercise," Royal Society of London Proceedings Series B Biological Sciences, 104:119-151, 1929.

10. Bock, A.V., C. Vancaulaert, D.B. Dill, A. Folling, and L.M. Hurxthall. "Studies in Muscular Activity IV. The 'Steady State' and Respiratory Quotient During Work," Journal of Physiology, 66:161-174, 1928.

11. Boje, O. "Development of Hypoglycemia During Muscular Work Following Ingestion of Dextrose; Preliminary Report," Scandinavica Arch Physiologica, 83:308, 1940.

12. Brooke, J.D. and L.F. Green. "The Effects of a High Carbohydrate Diet on Human Recovery Following Prolonged Work to Exhaustion," Ergonomics, 17:489, 1974.

13. Bullen, B., J. Mayer and F.J. Stare. "Athletics and Nutrition," American Journal of Surgery, 98:343, 1959.

14. Carlson, L.A. and B. Pernow. "Studies of Blood Lipids During Exercise," Journal of Laboratory and Clinical Medicine, 53:833, 1959.

15. Carlson, L.A. "Plasma Lipids and Lipoproteins and Tissue Lipids During Exercise," Symposia of the Swedish Nutrition Foundation, Nutrition and Physical Activity, Stockholm, Sweden: Hulquist and Wickells/Uppsala, 1967.

16. Carlson, L.A. "Lipid Metabolism and Muscular Work," Federation Proceedings, 26:1775, 1967.

17. Carpenter, T. Tables, Factors and Formulas For Computing Respiratory Exchange and Biological Transformations of Energy. Washington, D.C.: Institute of Washington Publications, 1964.

18. Cathcart, E.P. and W.A. Burnett. "Influence of Muscular Work on Metabolism in Varying Conditions of Diet," Proceedings of the Royal Society (Biol), 99:405, 1926.

19. Cho, M. and B.A. Fryer. "What Foods do Physical Education Majors and Basic Nutrition Students Recommend for Athletes?" Journal of the American Diet Association, 65:541, 1974.

20. Christensen, E. and O. Hansen. "Arbeitsfahrigheit Uhrnahrung," Scandinavian Archives of Physiology, 81:160-171, 1939.

21. Consolazio, Pecora and Johnson. Physiological Measurements of Metabolic Functions in Man. New York: McGraw-Hill Book Company, 1963.

22. Costill, D., R. Bowers, G. Branham and K. Sparks. "Muscle Glycogen Utilization During Prolonged Exercise on Successive Days." Journal of Applied Physiology, 31:834, 1971.

23. Costill, D. and E. Fox. "Energetics of Marathon Running," Medicine and Science in Sports, 1:81-86, 1969.

24. Costill, D. "Physiology of Marathon Running," Journal of the American Medical Association, 221:1024-1029, 1972.

25. Courtice, F.C. and C.G. Douglas. "The Effects of Prolonged Muscular Exercise on Metabolism," Proceedings of the Royal Society of London, Series B, 119:381-439, 1936.

26. Dole, V.P. "A Relation Between Non-esterified Fatty Acids in the Plasma and the Metabolism of Glucose," Journal of Clinical Investigation, 35:150, 1956.

27. Edwards, H.T., A. Thorndike and D.B. Dill. "The Energy Requirements of Strenuous Work," New England Journal of Medicine, 213:532, 1935.

28. Friedberg, S.J. and E. Estes, Jr. "Direct Evidence for the Oxidation of Free Fatty Acids by Peripheral Tissue," Journal of Clinical Investigation, 41:677, 1962.

29. Friedberg, S.J., W.R. Harlan, Jr., D.L. Trout and E.H. Estes, Jr. "The Effects of Exercise on the Concentration and Turnover of Plasma Non-Esterified Fatty Acids," Journal of Clinical Investigation, 39: 215, 1960.

30. Fritz, I.B., D.G. Davies, R.H. Holtrop and H. Dundee. "Fatty Acid Oxidation by Skeletal Muscle During Rest and Activity," American Journal of Physiology, 194:379, 1958.

31. Furusawa, K. "Muscular Exercise, Lactic Acid and the Supply and Utilization of Oxygen," Proceedings of the Royal Society (Biol), 98:65, 1925.

32. Gemill, C.L. "The Fuel for Muscular Exercise," Physiological Review, 22:32, 1942.

33. Goldsmith, R., G.S. Riddell, I.F. Russell, M.M. Sawyer and R.B. Smith. "Energy Cost of a Task After Ingestion of Protein, Fat and Carbohydrate," Proceeds of the Nutrition Society, 30:1, 1971.

34. Guyton, A.C. Textbook of Medical Physiology. 3rd Ed., Philadelphia: W.B. Saunders, 1967.

35. Havel, R.J., A. Naimark and C.F. Borchgrevink. "Turn Over Rate and Oxidation of Free Fatty Acids of Blood Plasma During Exercise," Journal of Clinical Investigation, 42:1054, 1963.

36. Hedman, R. "The Available Glycogen in Man and the Connection Between Rate of Oxygen Intake and Carbohydrate Usage," Acta Physiologica Scandinavica, 40:305, 1957.

37. Henschel, A. "Diet and Muscular Fatigue," Research Quarterly, 13:280-285, 1942.

38. Hermansen, L., E. Hultman and B. Saltin. "Muscle Glycogen During Prolonged Severe Exercise," Acta Physiologica Scandinavica, 71:129, 1967.

39. Himwich, H.E. and W.B. Castle. "Studies in Metabolism of Muscle, The Respiratory Quotient of Resting Muscle," American Journal of Physiology, 83:92, 1927.

40. Himwich, H.E. and M.I. Rose. "Studies in the Metabolism of Muscle," American Journal of Physiology, 88:663-679, 1929.

41. Hultman, E. and J. Bergstrom. "Muscle Glycogen Synthesis in Relation to Diet Studied in Normal Subjects," Acta Medica Scandinavica, 182: 109, 1967.

42. Hultman, E. "Studies on Muscle Metabolism of Glycogen and Active Phosphate in Man with Special Reference to Exercise and Diet," Scandinavica Journal of Clinical Laboratory Investigation, 19:56, 1967.

43. Issekutz, B., N.C. Birkhead and K. Rodahl. "Effects of Diet on Work Metabolism," Journal of Nutrition, 79:109, 1963.

44. Issekutz, B., H.I. Miller and K. Rodahl. "Lipids and Carbohydrate Metabolism During Exercise," Federation Proceedings, 25:1415, 1966.

45. Issekutz, B., H.I. Miller, P. Paul and K. Rodahl. "Aerobic Work Capacity and Plasma Free Fatty Acid Turnover," Journal of Applied Physiology, 20:293, 1965.

46. Itallie, T.B. Van, L. Sinisterra and F.J. Stare. "Nutrition and Athletic Performance," Journal of the American Medical Association, 162:1120, 1975.

47. Johnson, R.H., J.L. Walton, H.A. Krebs and D.A. Williamson. "Metabolic Fuels During and After Severe Exercise in Athletes and Non-Athletes," Lancet, 2:452-455, 1969.

48. Karlsson, J. and B. Saltin. "Muscle Glycogen and Endurance Performance," Journal of Applied Physiology, 31:203-206, 1971.

49. Karpovich, P.V. and W.E. Sinning. Physiology of Muscular Activity. 7th Ed., Philadelphia: W.B. Saunders, 1971.

50. Kelman, G.R., R.J. Maughan and C. Williams. "The Effects of Dietary Modifications on Blood Lactate During Exercise," Journal of Physiology, 251:35-36, 1975.

51. Keys, A. "Physical Performance in Relationship to Diet," Federation Proceedings, 2:164, 1943.

52. Krogh, A. and J. Lindhard. "The Relative Value of Fat and Carbohydrate as Sources of Muscular Energy," Biochemical Journal, 14:290, 1920.

53. March, M.E. and J.R. Murlin. "Muscular Efficiency on a High Carbohydrate and High Fat Diets," Journal of Nutrition, 1:105, 1928.

54. Masoro, E.J., L.B. Rowell and R.M. McDonald. "Intracellular Muscle Lipids as Energy Sources During Muscular Exercise and Fasting," Journal of the American Medical Association, 25:1421, 1966.

55. Mayer, J. and B. Bullen. "Nutrition and Athletic Performance," Physiological Review, 40:369, 1960.

56. Nelson, R.A. "What Should Athletes Eat? Unmixing Folly and Facts," The Physician and Sports Medicine, 3:11, 1975.

57. Pruett, E.D.R. "Glucose and Insulin During Prolonged Work Stress in Men Living on Different Diets," Journal of Applied Physiology, 28:199-208, 1970.

58. Rennie, M.J., S.N. Jennett and R.H. Johnson. "The Metabolic Effects of Strenuous Exercise: a Comparison Between Untrained Subjects and Racing Cyclists," Quarterly Journal of Experimental Physiology, 59: 201-212, 1974.

59. Rennie, M.S. and R.H. Johnosn. "Effects of an Exercise-Diet Program on Metabolic Changes with Exercise in Runners," Journal of Applied Physiology, 37:821-825, 1974.

60. Rodahl, K., H.I. Miller and B. Issekutz, Jr. "Plasma Free Fatty Acids in Exercise," Journal of Applied Physiology, 19:489, 1964.

61. Saltin, B. and L. Hermansen. "Glycogen Stores and Prolonged Severe Exercise," Symposia of the Swedish Nutrition Foundation, Nutrition and Physical Activity, Stockholm, Sweden: Hulmquist and Wicksells/ Uppsala, 1967.

62. Simonson, E. ed. Physiology of Work Capacity and Fatigue, Springfield: Charles C. Thomas, 1971.

63. Taylor, A.W., D.S. Shoeman and R. Lovlin. "Plasms Free Fatty Acid Mobilization with Graded Exercise," Journal of Sports Medicine and Physical Fitness, 11:234, 1971.

64. Taylor, H.L., J. Anderson and A. Keys. "Studies on Diet, Physical Activity and Serum Cholesterol Concentration," Circulation, 24:1055, 1961.

65. Tuttle, W.W., M. Wilson and K. Daum. "Effects of Altered Breakfast Habits on Physiological Responses," Journal of Applied Physiology, 1:545, 1949.

66. Williams, C., G.R. Kelman, D.G. Couper and G.G. Harris. "Changes in Plasma FFA Concentrations Before and After Reduction in High Intensity Exercise," Journal of Sports Medicine and Physical Fitness, 15:2, 1975.

67. Willson, H.E.C. "The Influence of Muscular Work on Protein Metabolism," Journal of Physiology, 75:67, 1932.

APPENDIX A

SUBJECT PARTICIPATION CONSENT FORM

Exercise Physiology Research
Department of Health, Physical
Education, and Recreation
Kansas State University
Manhattan, Kansas

Date ____________________

I ______________________ have voluntarily consented to have the personnel of the Department of Physical Education study my performance on a carbohydrate restricted diet and treadmill running performed in conjunction with research. I understand that I will run for 45 minutes at a constant treadmill speed on each of 7 consecutive days. Dietary restrictions will be required of me in that I will restrict the intake of carbohydrates to no more than 50 grams per day for 3 consecutive days. I further understand that my weight, heart rate, oxygen consumption and respiratory quotient will be taken at five-minute intervals during the 45-minute treadmill running. I recognize that I will be required to breathe into a mouthpiece apparatus for the collection and analysis of expired gases during each test.

I waive any possibility of personal damage which may accrue to such a study in the future and accept the responsibility for consenting to participate in this study. To my knowledge, I am not infected with a contagious disease, or limiting physical conditions or disability, especially with respect to my heart, that would preclude the treadmill running and diet regime.

Should additional information be required by myself concerning the study, it will be readily available from the personnel conducting the study.

I understand that I may drop out of this study at any time.

Date ________

____
Subject's Signature

APPENDIX B

DIET GUIDELINES AND RECOMMENDATIONS

Diet Day 1

Breakfast: normal.

Lunch: bouillon soup, cheese, diet soda, add snack item.

Dinner: beef or steak, lettuce salad with oil and vinegar, one-half cup of frozen or fresh green peas with butter, coffe or tea - no sugar. Add snack item.

Diet Day 2

Breakfast: eggs any style, except scrambled, bacon, one-half slice of whole wheat bread, 6 oz of tomato juice.

Lunch: soup broth, cheese, diet soda.

Dinner: fish (not breaded), salad, boiled cauliflower with cheese, coffee or tea - no sugar; add snack item.

Diet Day 3

Breakfast: same as day 2.

Lunch: same as either day 1 or 2.

Dinner: select meat, no gravy, salad - cole slaw if diet dressing used, boiled vegetables- beans, asparagus, cauliflower, broccoli, coffee or tea - no sugar.

Diet Day 4

Breakfast: same as day 2 or 3.

Resume normal eating for rest of sequence.

Snack Items: 1 cup of milk each day, 1 beer or 3 lite beers each day, cheese, eggs, no real limit on the following: lettuce tomatoes, celery, carrots, cabbage, raw onions, beef jerky.

APPENDIX C

DAILY SWEAT LOSS

Subject	Daily Sweat Loss in Lbs					
	1	2	3	4	5	6
1	2.81	2.69	3.44	2.62	2.56	*
2	2.49	2.56	2.44	2.63	2.50	2.48
3	2.30	2.25	2.29	2.30	2.21	2.17
4	2.12	2.37	2.32	2.44	2.25	2.37
5	3.57	3.00	3.18	2.81	3.06	3.94

*Subject #1 was unable to finish the study due to injury.

APPENDIX D

DAILY RESTING HEART RATES
IN BEATS/MIN

Subject	Day					
	1	2	3	4	5	6
1	56	53	55	58	58	*
2	59	68	64	73	67	79
3	48	54	58	55	52	53
4	66	45	52	56	52	54
5	64	66	65	62	64	59

*Subject #1 was unable to finish the study due to injury.

APPENDIX E

VO_2 IN LITERS/MIN TREATMENT MEANS AND NON-SIGNIFICANT GROUPINGS DETERMINED BY FISHER'S LSD

Sample Time		VO_2 liters/min	
1[a]		0.402	
12[b]		2.728	
4		3.362	NS
5		3.382	NS
3	NS	3.398	NS
2	NS	3.399	NS
6	NS	3.403	NS
8	NS	3.425	NS
7	NS	3.430	NS
9	NS	3.437	NS
10	NS	3.495	
11[b]		4.806	

NS bar denotes groupings of no significant differences.

[a]Rest sample.

[b]5-minute recovery samples.

APPENDIX F

VO_2 IN ML/KG/MIN TREATMENT MEANS AND NON-SIGNIFICANT GROUPINGS DETERMINED BY FISHER'S LSD

Sample Time		VO_2 in ml/Kg/min	
1[a]		5.048	
12[b]		34.199	
4		42.207	┐
5		42.454	│
2		42.655	│
3	┐	42.668	│ NS
6	│	42.718	│
8	NS │	43.012	│
7	│	43.073	│
9	│	43.144	┘
10	┘	43.858	
11[b]		60.106	

NS bar denotes groupings of no significant differences.

[a]Rest sample.

[b]5-minute recovery samples.

APPENDIX G

CALORIES/LITERS/MIN AND CALORIES/KG/MIN TREATMENT MEANS AND NON-SIGNIFICANT GROUPINGS DETERMINED BY FISHER'S LSD

Sample Time	Cal/liter		Sample Time		Cal/Kg	
1[a]	4.816		1[a]		.06070	
2	4.881	NS (2–10)	2		.06135	NS (2–4)
8	4.882		12[b]	NS (12–5)	.06137	
12[b]	4.883		8		.06139	
9	4.886		6		.06141	
3	4.888		3		.06144	
7	4.888		7		.06147	
6	4.891		9		.06155	
5	4.891		4		.06158	
10	4.892		5		.06159	
11[b]	4.929		11[b]		.06198	

NS bar denotes groupings of no significant differences.

[a]Rest Sample.

[b]5-minute recovery samples.

CALORIC COST TREATMENT MEANS AND NON-SISNIFICANT GROUPINGS DETERMINED BY FISHER'S LSD

Day-Diet		Kcal/Kg/min		Day-Diet	Kcal/liter/min	
2		.0611		3	4.836	
3		.0612	NS	4	4.855	
1	NS	.0612		2	4.863	
6		.0613		6	4.907	
4		.0617		1	4.924	NS
5		.0619		5	4.927	

Sample Time		Kcal/Kg/min		Sample Time	Kcal/liter/min	
1[a]		.0607		1[a]	4.816	
2		.0613		2	4.881	
12[b]		.0614		8	4.882	
8		.0614		12[b]	4.883	
6		.0614		9	4.886	
3	NS	.0614	NS	3	4.888	NS
10		.0615		7	4.889	
7		.0615		6	4.891	
9		.06.6		5	4.892	
4		.0616		10	4.892	
5		.0616		4	4.923	
11[b]		.0620		11[b]	4.929	

NS bar denotes groupings of no significant differences.
[a]Rest sample.
[b]5-minute recovery samples.

CALORIES/LITER/MIN AND CALORIES/KG/MIN TREATMENT MEANS AND NON-SIGNIFICANT GROUPINGS DETERMINED BY FISHER'S LSD

Day-Diet	Cal/liter/min		Day-Diet		Cal/Kg/min	
3	4.836		2	NS (2, 3, 1)	.0612	
4	4.855		3		.0612	NS (3, 1, 6)
2	4.863		1		.0612	
6	4.907		6		.0613	
1	4.924	NS (1, 5)	4		.0617	
5	4.927		3		.0619	

NS bar denotes groupings of no significant differences.

APPENDIX H

SUMMARY OF TWO-WAY ANOVA FOR THE
CALORIC COST, DAY-DIET AND TIME VARIABLES

Kcal/liter/min

Source	df	SS	MS	F
Subject	4	.1792	.0448	79.567*
Day-Diet	5	.4468	.0894	158.737*
Error (A)	19	.0107	.0005	
Time	11	.1981	.0180	13.894*
Day-Diet x Time	55	.0681	.0012	.55
Error (B)	253	.3279	.0013	

Kcal/Kg/min

Source	df	SS	MS	F
Subject	4	.00643	.001609	10771.06*
Day-Diet	5	.00003	.000006	46.-95*
Error (A)	19	.000003	.000001	
Time	11	.000026	.000002	8.082*
Day-Diet x Time	55	.000015	.0000003	.989
Error (B)	253	.000074	.0000003	

*Significant at the .05 level.

THE EFFECTS OF AN EXTENDED CARBOHYDRATE RESTRICTED DIET ON CONTINUED TREADMILL RUNNING PERFORMANCE

by

JOHN S. CARLSON

B.P.E. University of Alberta, 1975

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Health, Physical Education and Recreation

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1976

Carlson, John S. "The Effects of an Extended Carbohydrate Restricted Diet on Continued Treadmill Running Performance." Unpublished Master's thesis, Kansas State University, Manhattan, Kansas, 1976.

The purpose of this study was to determine the effects of an extended carbohydrate restricted diet on continued treadmill running performance. Five well-trained male recreational runners, whose ages ranged from 25 to 42 years, ran on the treadmill at speeds that corresponded to approximately 75% of their MVO_2 for 45 minutes a day for six consecutive days. Three consecutive days of carbohydrate restricted diet were observed by the subjects.

Open circuit metabolism measurements were taken at five-minute intervals throughout each 45-minute running period on the treadmill. The parameters of work-end heart rate, VO_2, and respiratory quotient were observed to establish the effects of the diet and exercise regime.

A two-way ANOVA for repeated measures was adopted for statistical analysis of the data. Fisher's Least Significant Difference performed the mean separations when significance was established by the two-way ANOVA. The results revealed that statistically significant higher work-end heart rates were obtained on the three carbohydrate restricted diet-days than those of the three normal diet-days.

Mean VO_2's were also elevated during exercise on the three carbohydrate restricted diet-days and were significantly higher than the VO_2 means for the three normal diet-days. The VO_2 means for the three carbohydrate restricted diet-days however were all found to be significantly different from each other.

RQ data revealed the detrimental effects of the three carbohydrate

restricted diet-days. Mean RQ's for these days were significantly lower than the RQ's for the three normal diet-days. Significant difference was also found to exist among the RQ's for the three carbohydrate restricted diet-days.

These results indicated that all subjects resorted to the inefficient use of fat as the major fuel source for energy production as reflected by significant changes in heart rate, VO_2 and RQ parameters. No apparent uniform response was indicated to the diet and exercise regime.