The effect of a low carbohydrate diet versus an optimal percentage of carbohydrate on handball playing performance

by Alison Anne Boe

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Physical Education
Montana State University

Abstract:
The purpose of this study was to determine the effect of a low carbohydrate diet versus an optimal percentage of carbohydrate on handball playing performance using blood glucose, blood lactate, total points, point spread, win/loss records, and anecdotal comments as measured parameters. Five male handball players were used as subjects.

The general design of this study was a double round robin tournament of test matches. Each test match consisted of a control and experimental two consecutive day sequence. Within the round robin tournament, each subject played each other subject, once on the low carbohydrate diet and again when the carbohydrate intake was optimal. Blood samples were drawn immediately following the experimental match and analyzed for blood glucose and blood lactate levels.

Subjects responded to a questionnaire before and after the control and experimental matches. Scores for each game were recorded on the same questionnaire and used to determine the total points, point spread, and the win/loss record for each subject.

Test protocol was identical for all matches and no subject played more than one test match per week. Subjects were restricted from performing any strenuous exercise 24 hours prior to the control match and in the 23 hour period between the control and experimental match.

Dietary carbohydrate did not significantly affect blood glucose or blood lactate values. In all cases subjects scored more points, had a greater point spread, won more games, and felt better at the conclusion of the experimental match when the carbohydrate intake was optimal. Results of this study indicate that the ingestion of optimal percentage of carbohydrate positively affects handball playing performance.

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APPROVAL

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Alison Anne Boe

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

The purpose of this study was to determine the effect of a low carbohydrate diet versus an optimal percentage of carbohydrate on handball playing performance using blood glucose, blood lactate, total points, point spread, win/loss records, and anecdotal comments as measured parameters. Five male handball players were used as subjects.

The general design of this study was a double round robin tournament of test matches. Each test match consisted of a control and experimental two consecutive day sequence. Within the round robin tournament, each subject played each other subject, once on the low carbohydrate diet and again when the carbohydrate intake was optimal. Blood samples were drawn immediately following the experimental match and analyzed for blood glucose and blood lactate levels.

Subjects responded to a questionnaire before and after the control and experimental matches. Scores for each game were recorded on the same questionnaire and used to determine the total points, point spread, and the win/loss record for each subject.

Test protocol was identical for all matches and no subject played more than one test match per week. Subjects were restricted from performing any strenuous exercise 24 hours prior to the control match and in the 23 hour period between the control and experimental match.

Dietary carbohydrate did not significantly affect blood glucose or blood lactate values. In all cases subjects scored more points, had a greater point spread, won more games, and felt better at the conclusion of the experimental match when the carbohydrate intake was optimal. Results of this study indicate that the ingestion of optimal percentage of carbohydrate positively affects handball playing performance.

CHAPTER 1

INTRODUCTION

Athletes continually attempt to improve upon their best performances. New training techniques and improved health care, among others, have assisted the athlete to develop his abilities.

Ergogenic (work-producing) aids are thought to be capable of assisting the athlete to reach or exceed his inherent potential. Mechanical, pharmacological, psychological, and nutritional aids have been tried for many years. Numerous ergogenic aids do not produce any noticeable change in performance. Others are considered illegal and/or immoral. As a result, ergogenic aids, in general, are not endorsed by supervisory athletic agencies (35).

The importance of nutrition in athletic performance has been extensively investigated. Early investigators, Pettenkofer and Voit (1, 9), ruled out protein as a major contributing energy source. In 1939, Christensen and Hansen ascertained that both carbohydrate and free fatty acids were utilized as energy sources contingent on the type of diet consumed and the intensity of the work performed (9). Researchers are continuing to unfold the relative roles carbohydrate and free fatty acids play in exercise metabolism and the extent to which they affect performance.

The type of diet and the time it is consumed will affect blood glucose, blood lactate, and muscle glycogen levels (4, 6, 11, 15, 20,22). Elevation of the level of muscle glycogen stores above normal by carbohydrate loading has been shown to increase the length of time an athlete can perform in submaximal long term exercise (17, 19, 22).

There are many forms of exercise that are very strenuous but not endurance in nature. Exercise such as handball, racquetball, tennis, and football may be classified as high intensity intermittent sports. These sports are characterized by brief bursts of intense exercise followed by short periods of reduced activity with the sequence being continually repeated throughout a typical contest. Competition in this type of activity often culminates in a tournament where an individual or team may compete several times in a two to three day period.

The effect of varying carbohydrate intake prior to high intensity intermittent exercise has not been investigated. This study will attempt to determine the relative effect of an optimal percentage of carbohydrate in comparison to a low carbohydrate diet on handball playing performance.

Statement of the Problem

The purpose of this study was to determine the effect of an optimal percentage of carbohydrate versus a low carbohydrate diet on handball playing performance.

Specific Objectives

1. To record the score of each game.
2. To record the total number of points accumulated by each subject.
3. To record the win/loss record of each subject.
4. To record the pre- and post-match weight of each subject.

5. To record any exercise that may influence performance by a subject prior to the test sequence.
6. To record each subject's perceived mental and physical feelings before and after the control and experimental matches.
7. To analyze by computer the dietary composition, including the percentage of carbohydrate consumed by each subject during the twenty-three hours prior to the experimental match.
8. To measure each subject's blood glucose level immediately following the experimental match.
9. To measure each subject's blood lactate level immediately following the experimental match.

Delimitations

This study was delimited to five experienced handball players, all faculty and staff members, at Montana State University, during the 1982-83 academic year.

Limitations

1. All five subjects were male.
2. Subjects were all low to high "B"* ranking handball players. Due to the age variable, some subjects are placed in the "Masters" or "Golden Masters" in tournament play.
3. Injury to or illness of any subject during the testing period.

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*General skill rankings of handball players begin with "beginner" or "novice" and proceed with increased ability to "C," "B," "A," and "open."

4. The varying amounts of exercise performed by subjects prior to the test sequence.
5. The motivation of each subject.
6. The subject's adherence to the experimental low and optimal percentage of carbohydrate diets.
7. The subject's ability to accurately record his experimental diet.
8. The researcher's ability to interpret the foodstuffs and the amounts recorded by each subject.
9. The listing of food codes in the Agnet Dietcheck program.
10. The relative fitness of each subject.
11. The handball skill of each subject at the initiation of the study.
12. The amount of improvement by each subject due to practice and tournament play.
13. The ability of the researcher to accurately take skinfold measurements with the use of Lange Skinfold Calipers.
14. The ability to obtain blood samples at a constant time at the conclusion of the experimental match.
15. The uniformity of play intensity throughout tournament play.
16. A psychological effect on the subject due to some prior knowledge as to what match results might be after consumption of each dietary regimen.

Definitions

1. Carbohydrate (CHO): Sugars and starches.
2. High Carbohydrate Diet (HCHO): A diet which is at least seventy percent carbohydrate relative to the daily caloric intake.

3. Low Carbohydrate Diet (LCHO): A diet which is 30 percent or less carbohydrate relative to the daily caloric intake.

4. Normal Diet: A diet which is 10-15 percent protein, 35 percent or less fat, and approximately 55 percent carbohydrate (32).

5. Optimal Carbohydrate (OCHO): An amount of carbohydrate at least 70 percent of the daily caloric intake.

6. Agnet Diet: A computer program which analyzes the nutrient content of foods.

7. Diet Exchange List: A list of foodstuffs by food groups in which food items are approximately equal in calories, fat, protein, and carbohydrate.

8. Glycogen: The form in which glucose is stored in the liver and muscles.

9. Control Match: The match played on the first day of the two day sequence in which the diet of the subject is normal.

10. Experimental Match: The match played on the second day of the two day sequence in which the percentage of carbohydrate in the diet has been specified.

11. Test Match: The two day test sequence comprised of the control and experimental matches.

CHAPTER 2

REVIEW OF LITERATURE

Coaches and athletes have been searching for that "vital" ingredient which would enhance performance a step beyond that which is genetically inherent. A wide range of ergogenic (work-producing) aids such as hypnosis, massage, and various drugs, among others, have been employed for the sole purpose of aiding performance. One type of ergogenic aid that has received much investigation as to its role in athletic performance is dietary carbohydrate. Diet composition, time of consumption, and the number of calories consumed are the variables which have been manipulated in various combinations.

This review will be confined to those studies involving energy metabolism which are closely related to the effect of diet on handball performance. In the following review of literature, studies are presented under the following headings:

1. Energy Cost of Handball
2. High/Low Carbohydrate Diets and Their Effect on Muscle Glycogen and Performance
3. The Effect of Prior Carbohydrate Ingestion on Exercise and Athletic Performance.
4. Muscle Fiber Type and Performance.

Energy Cost of Handball

Energy cost can be defined as the number of calories utilized or "burned" in a given time period. Determining the energy cost of an activity can be estimated by two methods, direct and indirect. The direct method is a measure of oxygen consumption during exercise while the indirect method is a measure of heart rate under conditions where heart rate and oxygen consumption are directly related (2).

Banister (3) determined the energy cost of handball using the direct method. Four subjects, two experienced (E) and two inexperienced (I), played each other subject for fifteen minutes. Oxygen samples were collected in a Kofranyi-Michaelis respirometer for ten minutes prior to the game, during the game and at five and fifteen minutes after the conclusion of the game. Results showed that when subjects were evenly matched, the caloric expenditure was approximately the same (E versus E = 652.8 KCal per hour, I versus I = 656.4 KCal per hour). When one subject was more skilled than his opponent, his energy cost was much less (E versus I = 449.4 KCal per hour). Conversely, the lesser skilled player, when matched against a more highly skilled player, utilized a greater amount of calories (I versus E = 734.1 KCal per hour).

In a more recent study by Schwarzkopf (27) the indirect method was used to estimate the energy cost of handball. Two skilled (B ranked) handball players played competitively against each other several times with one player's heart rate being monitored with a telemetry system. Simultaneous heart rate and oxygen consumption ($\dot{V}O_2$) were measured in the laboratory using a bicycle ergometer to elicit incremental increases in work output. Heart rates from play were then used to estimate $\dot{V}O_2$

(converted to caloric expenditure) from play by extrapolation from the laboratory curve of heart rate - $\dot{V}O_2$.

Schwartzkopf (27) reported a mean KCal expenditure of 1,078 KCal and 1,341 KCal per one hour of play, the 148 pounds and 178 pounds competitor respectively. Other investigators report an approximate expenditure of 10-11 KCal per minute for handball (30, 33). Other results found that when the outcome of the match was determined in two games, the heart rate (therefore energy cost) decreased up to ten beats per minute (bpm) in the third game. Where opponents of lesser skill were matched with the test subject the heart rate was found to be 20-30 beats per minute less than when playing someone of equal ability. Schwarzkopf (27) showed that skill level and both investigators found the intensity of play are the two factors which must be taken into account when the energy cost of an activity is being calculated (3, 27).

High/Low Carbohydrate Diets and Their Effect on Muscle Glycogen and Performance

Muscle glycogen concentrations at the initiation of exercise and the rate of utilization determine to what extent muscle glycogen stores become depleted (11, 13, 18) and therefore limits an individual's exercise time to exhaustion (11, 18, 19, 22).

It has been determined that carbohydrates are the most efficient source of energy for rebuilding muscle glycogen prior to endurance events (4, 5, 11, 19, 21). A diet high in carbohydrate is more effective than a mixed (normal) diet or a diet high in fat and protein in restoring muscle glycogen to its normal level (1, 5, 11, 19, 21).

The practice of carbohydrate loading is a method used to attain maximal muscle glycogen stores prior to competition. Carbohydrate loading is accomplished by initially depleting the existing muscle glycogen stores. The athlete continues to train and simultaneously consumes a low carbohydrate diet as reported by some researchers but not all (1, 28, 36). Current research indicates that muscle glycogen levels are similar if the amount of carbohydrate in the daily diets remains the same (33). The athlete concludes the loading process with the cessation of training and consumes a diet high in carbohydrate.

An overview of studies pertaining to the amount of carbohydrate in the diet and its effect on muscle glycogen are presented in Table 1.

Table 1. High/Low Carbohydrate Diets and Their Effect on Muscle Glycogen and Performance.

Author	N	Protocol	Results
Karlsson (19)	10	Two 19 mile races in a three week period. Six subjects followed a CHO-loading regimen, the others, a normal diet. The procedure was reversed after the first race. Muscle biopsies were taken after each race.	Mean muscle glycogen after the CHO-loading regimen was 35 g/kg wet muscle. Mean muscle glycogen content was 17 g/kg wet muscle after the normal diet. Better race times were recorded after the CHO-loading regimen.
Costill (11)	4	16.1 km run at 80% $\dot{V}O_2$ max followed by five one-minute sprints on a treadmill at 130% $\dot{V}O_2$ max. Treadmill sprints were separated by 3-minute rest intervals. Subjects consumed one of four diets:	Muscle Glycogen (MG): wet muscle - mmol/kg Post-exercise: HCHO2: 55.3 ± 12.0 LCHO2: 71.3 ± 14.3 M2: 49.3 ± 9.4 HCHO7: 46.8 ± 9.4

Table 1. Cont'd.

Author	N	Protocol	Results
		1. HCHO - two feedings (HCHO2) 2. LCHO - two feedings (LCHO2) 3. Mixed - two feedings (M2) 4. HCHO - seven feedings (HCHO7)	Post-dietary regimen - 24 hours later: HCHO2: 125.6 ± 10.9 LCHO2: 66.6 ± 7.8 M2: 74.2 ± 3.9 HCHO7: 101.2 ± 20.9
		Muscle biopsies were taken immediately following exercise and 24 hours later.	A significant reduction (P<0.05) in MG was recorded after the LCHO diet when compared to the M2 diet.
		Subjects performed a 300 m spring following the dietary regimen	A significant increase (P<0.05) was recorded after the HCHO2 diet when compared to the M2 diet.
Bergstrom (4)	9	Subjects rode a bicycle ergometer at 75 $\dot{V}O_2$ max to exhaustion. Subjects were assigned to one of the following diets for a three day period, 1. Mixed (M) 2. Fat/Protein (FP) 3. HCHO	Muscle Glycogen: (MG) $\bar{X}$ - g/100g muscle PRE POST M: 1.75 0.17 FP: 0.63 0.13 HCHO: 3.31 0.43 Work Time: minutes
		Muscle biopsies were taken. Subjects performed the same test. Upon exhaustion, muscle biopsies were taken again.	M: 113.6 FP: 56.9 HCHO: 166.5

Table 1. Cont'd.

Author	N	Protocol	Results
Maughan (22)	6	A supramaximal test on a bicycle ergometer at 105% $\dot{V}O_2$ max was performed followed by a four-six hour rest period. At this time subjects performed another test at 75% $\dot{V}O_2$ max until exhaustion.	Exercise time to exhaustion was influenced by the diet consumed. Normal: 4.87 ± 1.07 min. LCHO: 3.32 ± 0.87 min. ($P<0.005$) HCHO: 6.65 ± 1.39 min. ($P<0.05$)
		A LCHO diet was consumed for the remainder of the test day and for two more days. Subjects performed the above test again on the fourth day followed by a HCHO diet for three days. The same test was then performed again.	Resting BL levels were lower after the LCHO diet and higher after the HCHO diet. Normal: 1.54 ± 0.33 mmol/l LCHO: 0.98 ± 0.37 mmol/l ($P<0.01$) HCHO: 2.20 ± 0.82 mmol/l ($P<0.05$)
		Blood samples were drawn prior to the test and at at two, six, 10, and 14 minutes after the tests. Samples were analyzed for blood lactate (BL) and blood glucose (BG).	Post exercise BL peaked 2-6 minutes after exhaustion. Normal: 11.66 ± 1.16 mmol/l LCHO: 8.60 ± 1.58 mmol/l ($P<0.01$) HCHO: 12.86 ± 1.42 mmol/l ($P<0.05$)
		Gas samples were taken during the final minute of the test.	Prior to exercise, the BG levels of subjects on the LCHO diet were lower than those of subjects on the HCHO and Normal diets. Normal: 4.57 ± -.16 mmol/l LCHO: 4.02 ± 0.16 mmol/l ($P<0.05$) HCHO: 4.82 ± 0.41 mmol/l Post-exercise BG levels were somewhat higher.

Table 1. Cont'd.

Author	N	Protocol	Results
Haldi (15)	59	Nine day test period in which 500 KCal breakfasts were consumed. 1. HCHO 2. High fat and protein (FP) Subjects followed their normal routine. Blood samples were drawn three hours after the meal.	Blood Glucose (BG): mgm % FP: 101 mgm % HCHO: 99 mgm % No significant difference in BG was found three hours after consuming the prescribed diet.
	50	Identical test protocol. The caloric value of the breakfast was increased to 600 KCal. Blood samples were drawn once every three hours.	BG: LCHO / HCHO Hour: 1. 116 / 132 2. 109 / 113 3. 105 / 100 Samples were all found to be within the normal range.
	88	Arterial blood samples (A) from the finger tip were added to the protocol. These were compared to the venous (V) samples. Samples were taken every three hours.	A-BG: LCHO / HCHO Hour: 1. 117 / 139 2. 114 / 120 3. 108 / 108 V-BG: LCHO / HCHO Hour: 1. 85 / 117 2. 83 / 114 3. 85 / 108 All samples were considered to be within the normal range.

Table 1. Cont'd.

Author	N	Protocol	Results
Martin (21)	4	Subjects performed on a treadmill at 70% $\dot{V}O_2$ max followed by a consumption of one of the control diets: 1. Normal (N) 2. LCHO 3. HCHO Diets were consumed for three days. Subjects performed the same test on the treadmill again after the three day period. Blood samples were drawn after each exercise bout and analyzed for blood glucose and blood lactate levels. Gas samples were taken and analyzed for their CO_2 and O_2 content.	Blood glucose levels increased as the pre-work dietary carbohydrate increased. An increase in blood lactate while at rest and during exercise was found after the high carbohydrate diet. The utilization of carbohydrate after the low carbohydrate diet was significantly ($P<0.005$) reduced during the initial half-hour of work. A high correlation ($P<0.001$) existed between endurance time and the use of carbohydrate for energy. A decrease in work time after the low carbohydrate was significant ($P<0.05$) when compared to the normal diet and the carbohydrate diet ($P<0.01$). The difference in work time after the high carbohydrate and normal diet was insignificant.

The Effect of Prior Carbohydrate Ingestion on Exercise and Athletic Performance

The consumption of carbohydrate within approximately two hours of intense exercise has been shown to cause a marked decrease in work output (13, 20). Carbohydrate consumption increases the blood glucose level, which in turn, increases the blood insulin level (8, 10). Insulin depresses hepatic glucose production and actively transports blood glucose from the blood into the cells resulting in a reduction in blood glucose. When exercise is performed, following the intake of carbohydrate, blood glucose is prevented from rising due to the effect of the insulin. To compensate, a larger percentage of exercise energy must be supplied by muscle glycogen resulting in earlier depletion (1, 6, 8, 20). Studies pertaining to the effect of carbohydrate prior to exercise are reviewed in Table 2.

Table 2. The Effect of Prior Carbohydrate Ingestion on Exercise and Athletic Performance.

Author	N	Protocol	Results
Foster (13)	16	Fifty minutes prior to the test, subjects ingested: 1. water 2. glucose solution 3. balanced liquid meal Subjects performed on a bicycle ergometer six separate times, three times and 80% $\dot{V}O_2$ max and three times at 100% $\dot{V}O_2$ max. Diet and exercise were controlled prior to the six test periods. Blood samples were drawn before, at 10 and 30 minute intervals in the test period, and at the completion of the test. Samples were analyzed for blood glucose and blood lactate.	The balanced liquid meal showed no effect on the mean exercise time to exhaustion. The mean exercise time to exhaustion was reduced by 4% at 100% $\dot{V}O_2$ max and by 19% at 80% $\dot{V}O_2$ max when comparing the ingestion of glucose to water.

Table 2. Cont'd.

Author	N	Protocol	Results
Bonen (6)	31	Existing liver and muscle glycogen stores were depleted by fasting and exercise. Subjects were divided into four groups: 1. Exercise-no glucose 2. Pre-exercise glucose ingestion 3. During exercise glucose ingestion (minutes two-three after the initiation of exercise) 4. No exercise-glucose ingestion. This was the control group. Subjects performed at 80% $\dot{V}O_2$ max on a bicycle ergometer for 30 minutes unless exhaustion was reached sooner. Blood samples were taken two times prior to exercise, during exercise at 10 and 20 minute intervals, at the completion of exercise, and at 15 and 30 minute intervals post-exercise. Samples were analyzed for blood glucose and blood lactate. Oxygen consumption was monitored.	<u>Blood Glucose:</u> Group 1: a decrease in blood glucose upon completion of exercise and post-exercise levels remained low. Group 2: increase ($P<0.05$) prior to exercise until about the 10 minute mark at which point a sharp decrease ($P<0.05$) in blood glucose was recorded. Group 3: blood glucose level were significantly ($P<0.05$) higher during exercise and the recovery period. Group 4: increased levels of blood glucose which peaked 45-60 minutes after ingestion.

Muscle Fiber Type and Performance

The type of muscle fiber, fast or slow twitch, is an influencing factor in muscle glycogen storage and utilization. Fast twitch fibers are capable of storing and utilizing more muscle glycogen (17, 31) as well as produce lactate at a more rapid rate than do slow twitch muscle fibers (29, 31).

The amount of blood lactate produced by an individual is contingent on several factors: the rate of lactate production, the rate in which it diffuses from the cell to the blood, the rate of removal, the physical condition of the individual, and the intensity of exercise must all be considered (16, 29). According to Hermansen (16), the amount of blood lactate produced by a trained athlete is less than that produced by someone who is untrained for equal submaximal workloads. However, at a maximum workload a trained individual will produce more lactic acid than an untrained individual (26).

Summary

In summarizing the review of related literature, it may be concluded that:

1. The energy cost of handball is directly related to the skill level of each player and the intensity of play.
2. When exhaustive exercise is concerned, diets high in carbohydrate are more effective in restoring muscle glycogen to its normal level or better than are diets comprised of fat and protein.
3. The consumption of carbohydrate within two hours of intense exercise has been shown to cause a decrease in work output.
4. The number of feedings of carbohydrate in the twenty-four hour period after depletion and prior to prolonged exercise plays no factor in the amount of muscle glycogen resynthesis.

5. Fast twitch muscle fibers are capable of storing more muscle glycogen, using more muscle glycogen, and produce lactic acid at a faster rate than do slow twitch muscle fibers.

CHAPTER 3

RESEARCH METHODS

The general design of this study was a double round robin tournament of test matches. Each test match consisted of a control and experimental two consecutive day sequence. Within the round robin tournament, each of the five subjects played each other subject, once on the low carbohydrate diet and again when the carbohydrate intake was optimal.

Sample

The sample consisted of five male handball players selected for their ability and interest in the research topic. All subjects were faculty and staff members at Montana State University during the 1982-83 academic year.

All subjects were advised of the nature of the study, the restrictions on activity, diet, time commitment, and blood sampling. A university committee on The Use of Human Subjects in Research reviewed the research design and provided a release form that was signed by each subject (Appendix A).

The physical characteristics of each subject--height, weight, and age--were recorded. Skinfold measurements of each subject were taken by the researcher using a Lange Skinfold Caliper. The sites for measurement were the chest, abdomen, thigh, triceps, and subscapular as described by McArdle, Katch, and Katch (23). The formulas of Pollock (24) and Forsyth (12) were used to estimate body density. The formula of Brozek (7) was used to convert density to percent body fat (Appendix B). An average of the percentages of both formulas was used for the estimate of body fat. Physical characteristics of each subject are presented in Table 3.

Table 3. Physical Characteristics of Subjects.

Subject	Height (ft. in.)	Weight (lbs)	Age (yrs)	Body Fat (%)
B	5'10"	143	43	6.81
C	5' 9"	163	35	9.89
D	6' 1"	202	46	10.15
J	6' 1"	160	55	7.97
R	5'10"	156	29	13.82
$\bar{X}$	5'11"	164.8	41.6	9.72

Subjects had a mean weight of 164.8 pounds, ranging from 143 pounds to 202 pounds. The mean age of the subjects was 41.6 years, ranging from 29 years to 55 years. The mean percent body fat of the subjects was 9.72 percent, ranging from 6.81 percent to 13.82 percent.

Test Protocol

Subjects played in a double round robin tournament of test matches. Each test match consisted of a control and experimental two consecutive day sequence. The first day was the control match (CM) and the second day was the experimental match (EM). Dietary restrictions were placed on each subject following the CM. One subject consumed a prescribed 70 percent (or more) carbohydrate diet and the other a 30 percent (or less) carbohydrate diet. No subject played more than one set of test matches per week (testing lasted 17 weeks). Subjects were restricted in physical activity for the twenty-four hour period prior to the CM by a recommendation of abstaining from any strenuous exercise and to further strenuous activity before the EM.

Before and after the CM and EM, each subject responded by completing an open ended questionnaire containing statements related to perceived mental and physical feelings. Pre- and post-match body weights were also recorded on the same questionnaire (Appendix C).

Play was initiated after a brief warm-up period prior to twelve noon when play commenced for one hour. Rest periods during match play were not allowed and time-outs were permissible only for equipment repair or injury.

Subjects played as many 21-point games as time permitted in one hour. The score of any uncompleted game counted toward the total point tally (part games did not count as games won or lost). Tournament results were based on the win/loss record as well as the total number of points accumulated.

Following the CM, one subject was placed on a low carbohydrate diet with the guidelines set by the Diet Exchange List (Appendix D) for consuming approximately 30 percent carbohydrate. His opponent was to consume an optimal diet consisting of 70 percent or more carbohydrate. Subjects recorded all the foods and beverages consumed during the 23-hour period prior to the experimental match for complete analysis.

Blood samples were drawn as soon as possible following the experimental match. The diagram (Figure 1) illustrates the test protocol time schedule.

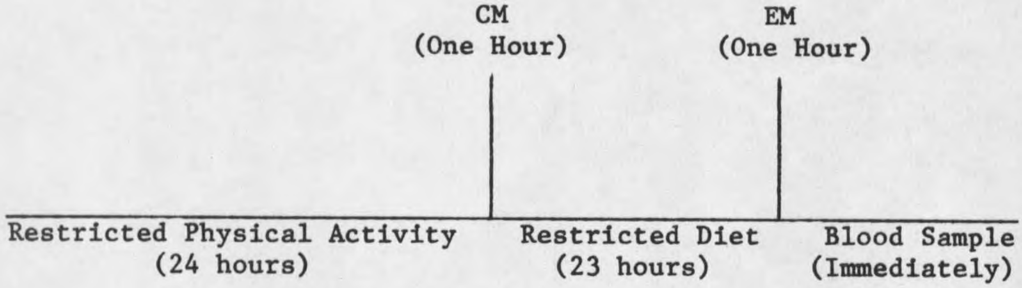

Figure 1. Test Protocol Time Schedule.

Test Battery

The test parameters were as follows:

1. The Agnet Dietcheck
    A. Optimal carbohydrate
    B. Low carbohydrate
2. Blood Samples
    A. Blood glucose levels
    B. Blood lactate levels
3. Tournament Results
4. Perceived Mental and Physical Feelings
5. Pre- and Post-Match Body Weight
6. Statistical Analysis

Agnet Dietcheck

The Agnet Dietcheck is a computer program which analyzes the caloric value and the nutrient content of food. Subjects recorded all foods and beverages consumed in the 23-hour period prior to the experimental match. These entries were analyzed with the Agnet Dietcheck program. Subjects consuming an optimal percentage of carbohydrate attempted to consume at least 70 percent carbohydrate while those on the low carbohydrate diet consumed 30 percent, or less, carbohydrate.

Blood Samples

Approximately seven milliliters (ml) of blood were drawn from each subject by a trained medical technologist as soon as possible following the experimental match. The waiting subject ran until the technologist had completed drawing the blood sample on the first subject. Each sample was analyzed for blood glucose (Worthington Diagonostics Statzyme Glucose Kit, Worthington Diagnostics, Freehold, New Jersey 07728) and lactic acid (Sigma Chemical Lactic Acid Kit, Sigma Chemical Company, P.O. Box 14508, St. Louis, Missouri 63178). All samples were analyzed by the same medical technologist using the same equipment at Marsh Laboratory, Montana State University.

Tournament Results

Total points for each game and partial game were recorded for each subject on each dietary condition, low or optimal carbohydrate. Point spread was determined by taking the difference in game scores and averaging them for each dietary condition, low or optimal carbohydrate. The number of wins and losses of completed games for each subject on each dietary condition, low or optimal carbohydrate were recorded.

Perceived Mental and Physical Feelings

Subjects responded to a questionnaire before and after the control and experimental matches (Appendix C). A frequency rating of responses was made. Responses were tallied only by the number of times they appeared and were not weighted. Comments were classified as positive, negative, and neutral.

Pre- and Post-Match Weights

Subjects recorded body weight before and after the control and experimental matches. Subjects weighed themselves in the same manner of dress each time and recorded their weights on the questionnaire provided (Appendix C).

Statistical Analysis

Blood samples were analyzed using a paired T between group analysis. Significance was accepted beyond the 0.05 level.

Anecdotal comments were analyzed using binomial probability. Significance was accepted at the 0.05 level.

Total points and average point spread were analyzed using a paired t-test with "within team" analysis to measure the difference in points accumulated and point spread when the carbohydrate intake was low or optimal. Significance was accepted at the 0.05 level.

CHAPTER 4

RESULTS

The results of this study are presented in this chapter with a discussion of the results following in Chapter 5. The results are presented under the following headings.

1. Diet Composition and Caloric Intake
2. Blood Samples
    A. Blood glucose
    B. Blood lactate
3. Win/Loss Record
4. Total Points/Point Spread
5. Anecdotal Comments
6. Weight Loss

Diet Composition and Caloric Intake

Subjects recorded their food intake for the 23-hour period between the control and experimental match. Results of the Dietcheck analysis are presented in Table 4. Headings show dietary parameters averaged over all experimental matches.

The meals consumed by subjects were prepared at home, consequently, strict controls were not possible. Sample menus were provided for each subject to illustrate the proper percentage of carbohydrate (Appendix E). All subjects succeeded in consuming a low carbohydrate diet on

Table 4. Diet Composition and Caloric Intake.

	X̄ KCal		X̄ CHO		X̄ PRO		X̄ FAT	
Subject	OCHO	LCHO	OCHO	LCHO	OCHO	LCHO	OCHO	LCHO
B	2313.6	1979.3	69.17%	32.42%	12.17%	20.40%	17.89%	47.32%
C	1516.1	1565.2	46.37%	27.37%	19.65%	19.70%	29.82%	48.62%
D	2881.2	2906.7	44.10%	35.57%	19.37%	21.75%	36.65%	42.77%
J	1822.5	3391.0	62.77%	14.90%	11.32%	21.25%	21.05%	62.62%
R	2883.5	2301.3	58.92%	27.90%	8.20%	21.47%	30.07%	48.97%

specified days. However, only one subject was close to consuming an optimal percentage of carbohydrate, two other subjects were moderately close and the remaining two subjects were quite low.

Blood Samples

Blood samples were drawn from each subject as soon as possible following the experimental match. Samples were analyzed on the same day for blood glucose and blood lactate levels. Three of the five subjects had higher blood glucose levels on the low carbohydrate diet and three of the five subjects had higher blood lactate levels when on the low carbohydrate diet. The mean blood lactate level on the optimal carbohydrate diet was 3.25 mmol/l as opposed to 3.38 mmol/l on a diet low in carbohydrate. The mean blood glucose level on an optimal percentage of carbohydrate was 144.24 mg/dl as opposed to 152.55 mg/dl when consuming a low carbohydrate diet. Mean values for blood glucose and blood lactate are presented in Figure 2 and Figure 3, respectively.

Total Points/Point Spread

Without exception, fewer points (895) were scored by subjects when consuming a low carbohydrate diet ($P<0.06$) as opposed to an optimal

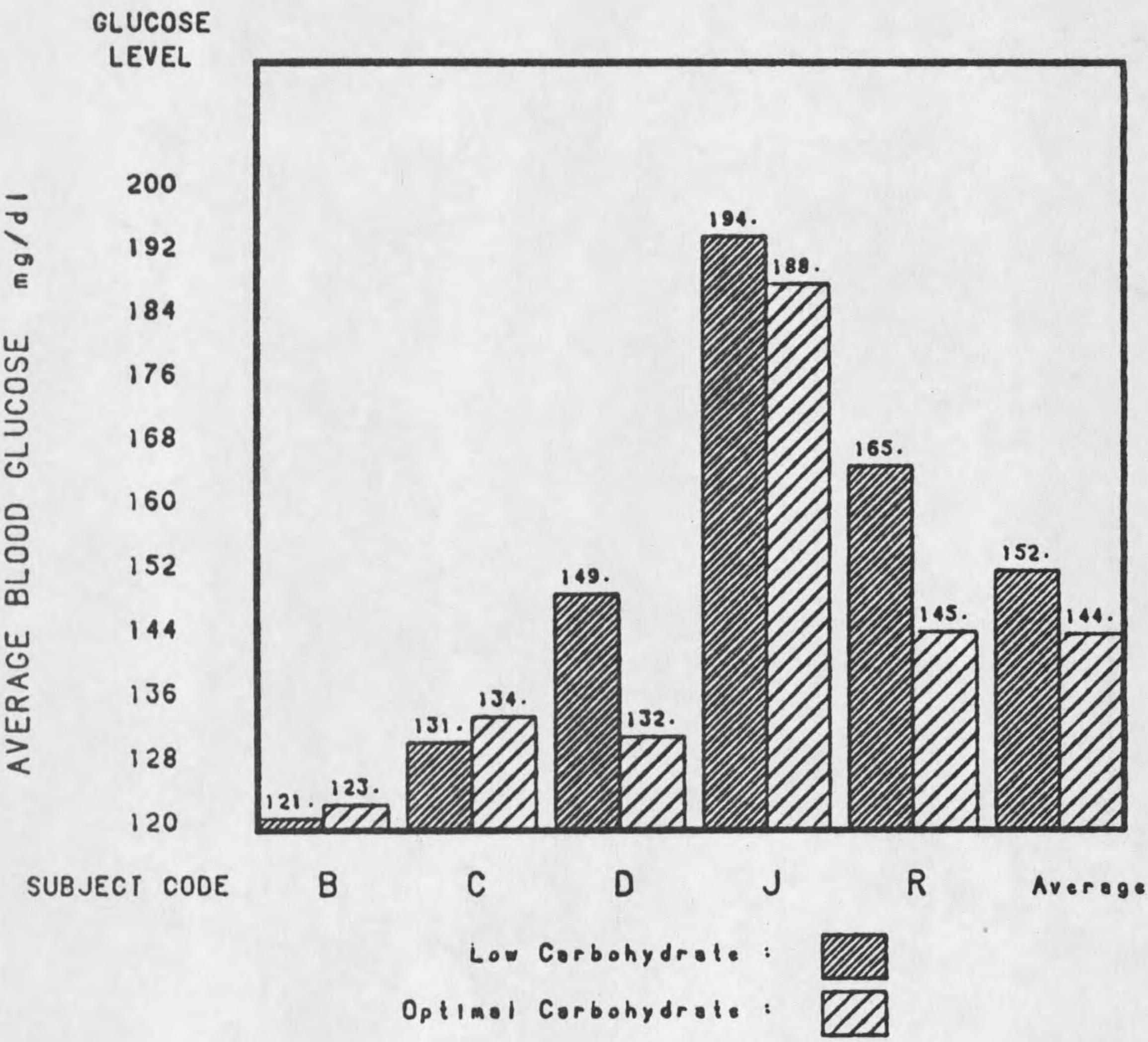

Figure 2. Mean Blood Glucose Values - mg/dl.

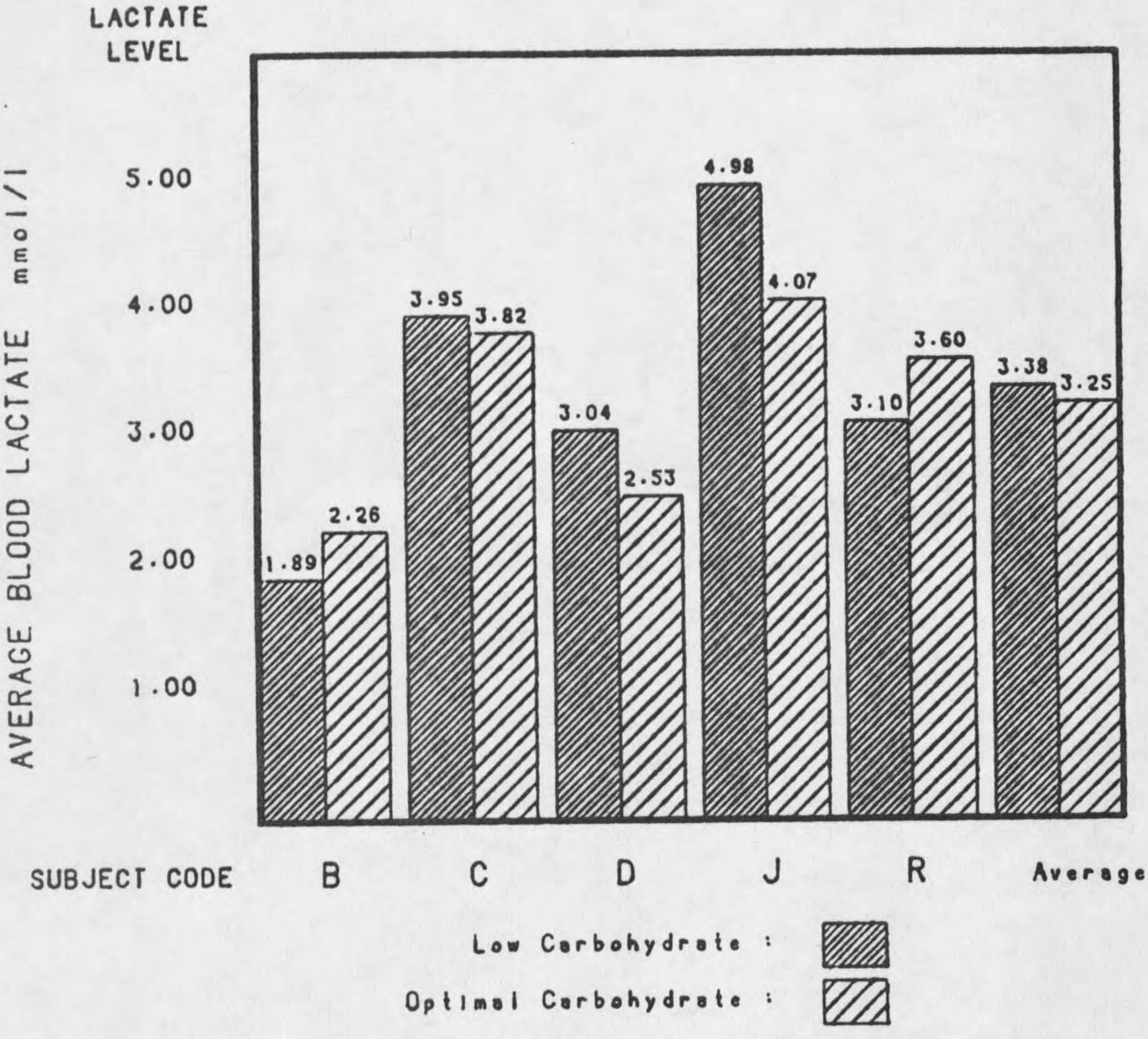

Figure 3. Average Blood Lactate Values - mmol/l.

percentage of carbohydrate (984). The average number of points scored when consuming the low carbohydrate diet was 179.0 with a range of 134-212. The average number of points scored when consuming an optimal percentage of carbohydrate was 196.8 with the range of points between subjects being 142-219. When the two lowest subjects below the desired optimal percentage of carbohydrate intake were eliminated the results became highly significant ($P<0.003$). Subjects' total points when consuming the low carbohydrate diet and an optimal percentage of carbohydrate are presented in Figure 4.

The point spread between games when consuming the low carbohydrate diet and on the optimal percentage of carbohydrate (each condition separately) were averaged. When subjects consumed the low carbohydrate diet, the mean point spread was -5.3. This contrasts with the mean point spread of +5.3 when subjects consumed an optimal percentage of carbohydrate ($P<0.07$). Two subjects were substantially below the desired optimal carbohydrate intake. Again, when subjects C and D were eliminated, the difference in point spread became significant ($P<0.023$). The results of the average point spread are presented in Figure 5.

Win/Loss Record

Subjects consuming an optimal percentage of carbohydrate (OCHO) won eight matches and lost seven. On the low carbohydrate diet, subjects won seven matches and lost eight. The win/loss record is presented in Figure 6.

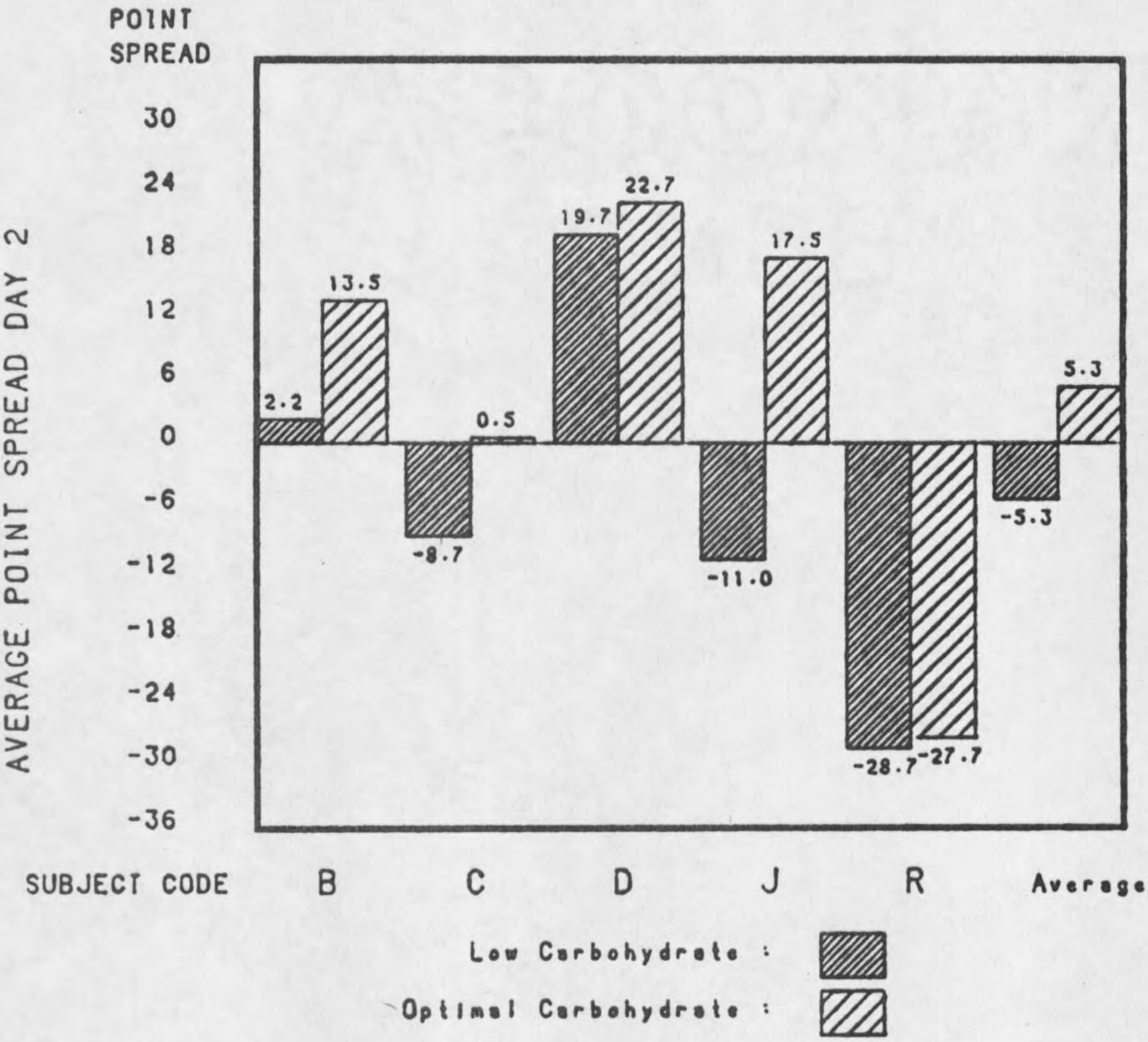

Figure 4. Average Point Spread.

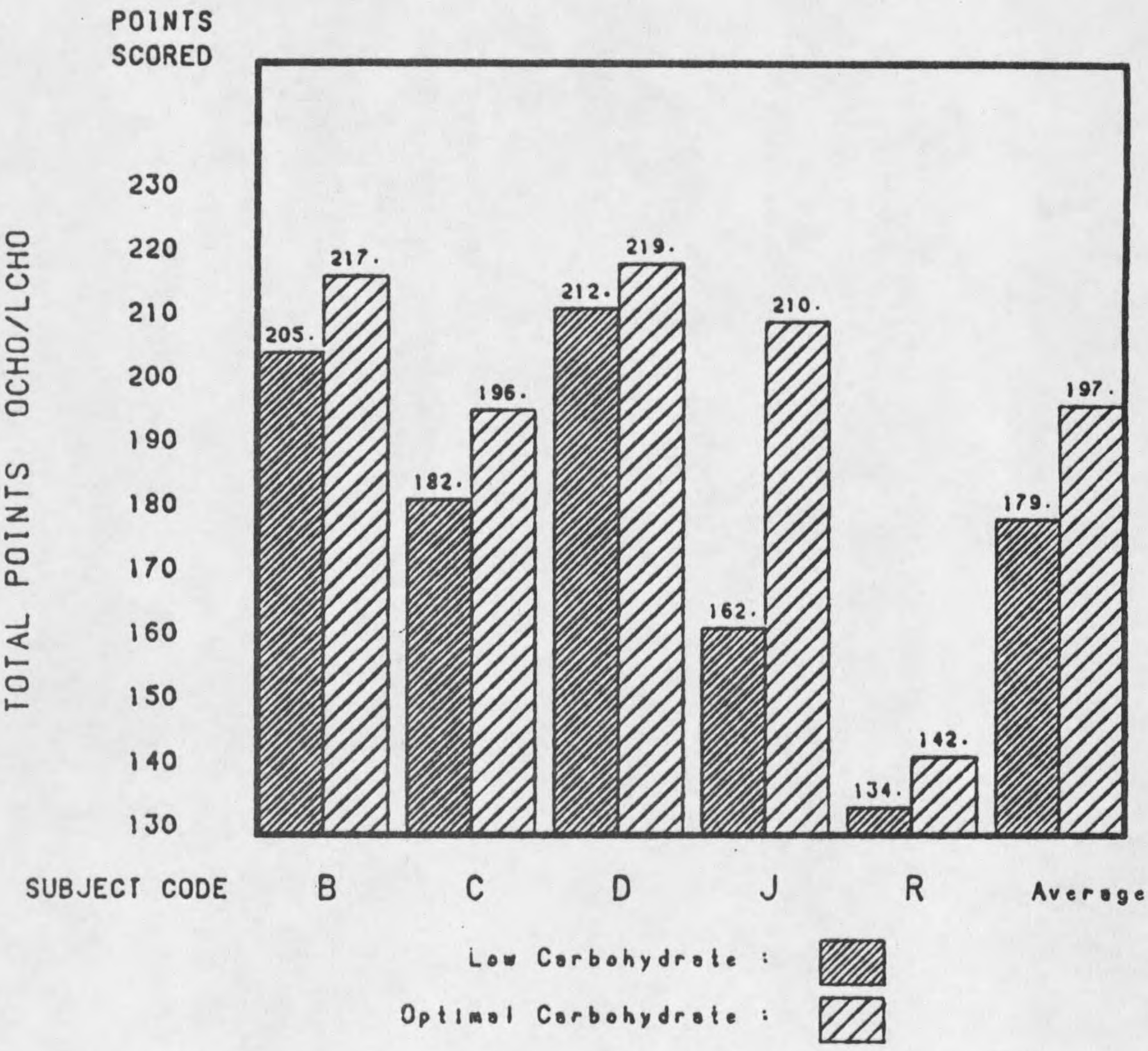

Figure 5. Total Points.

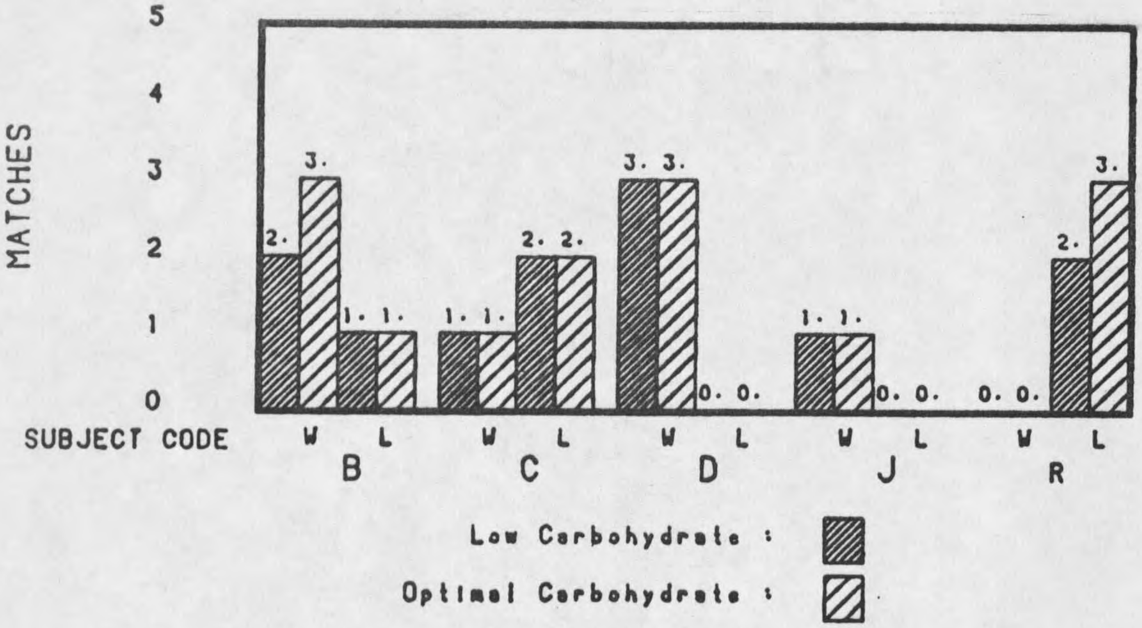

Figure 6. Win/Loss Record.

Anecdotal Comments

Comments were grouped in three categories: positive, negative, and neutral. Positive comments included: above average, good, very good, great, strong, energetic, and could play longer as opposed to the negative comments which included: a little tired, tired, weak, fatigued, sluggish, dizzy, stiff, exhausted, and match play more difficult. A response of "average" ranked as average. Results of the before and after match response tally are presented in Table 5.

Table 5. Subjects' Perceived Mental and Physical Feelings.

	Positive		Negative		Neutral	
Diet	Pre	Post	Pre	Post	Pre	Post
OCHO	7	15	4	2	15	1
LCHO	3	0	6	25	17	3

Subjects generally felt good or average prior to most matches. When the low carbohydrate diet had been consumed, there was a slight tendency to feel somewhat less than average.

Post match comments by subjects, when on the low carbohydrate diet, often included reports of dizziness and an inability to keep score. Comments on an optimal percentage of carbohydrate indicated a subject was tired but could have played more (Appendix F). The comparison of the number of responses shows a highly significant ($P<0.001$) number of negative responses at the conclusion of the match when on a low carbohydrate diet.

Weight Loss

Subjects recorded their before and after match weights. Subjects consuming the optimal percentage of carbohydrate usually equalled their control match pre-match weight before playing the experimental match whereas subjects consuming the low carbohydrate diet often showed a weight loss of one to two pounds. All subjects showed a weight loss of approximately two pounds between their before and after match weights.

Summary

From the results presented in this chapter, it may be concluded that:

1. Subjects have a tendency to score more points when consuming an optimal percentage of carbohydrate.
2. Subjects have a greater point spread between their games when consuming an optimal percentage of carbohydrate.

3. Dietary carbohydrate did not significantly affect the blood glucose levels.
4. Dietary carbohydrate did not significant affect the blood lactate levels.

CHAPTER 5

ANALYSIS OF DATA

The purpose of this study was to determine the effect of low carbohydrate diet versus an optimal percentage of carbohydrate on handball playing performance. The measured parameters were blood glucose, blood lactate, point spread, total points, games won and lost, anecdotal comments, and weight loss. Results presented in Chapter 4 are discussed in this chapter.

Blood Glucose

At the conclusion of the experimental match, three of the five subjects exhibited slightly higher than expected, though insignificant ($P>0.05$) blood glucose levels after consuming a diet low in carbohydrate. These results do not concur with investigations by Costill (11), Martin (21), and Maughan (22), who all found blood glucose levels to be higher after the consumption of a high carbohydrate diet.

The type of diet consumed after performing strenuous exercise dictates to what extend muscle glucogen is restored. Consumption of a diet low in carbohydrate results in partial muscle glycogen resynthesis in a 24-hour period (1, 4, 11, 17, 19). Muscle glycogen stores can be depleted sooner after only partial muscle glycogen resynthesis (1, 4, 19). Free fatty acids are utilized inversely with the existing muscle glycogen stores to meet the energy demands. Costill et al. (10) reports reduced muscle glycogen concentrations cause an elevation in free fatty acid utilization and is associated with a rise in blood glucose.

Several factors may account for the slightly higher blood glucose values found in the subjects when consuming the low carbohydrate diet.

1. Upon completion of exercise, blood glucose rapidly returns to its normal level (25, 28). Blood samples were not always drawn immediately following the completion of the experimental match. As a result, blood glucose values may have already begun to normalize.
2. Subjects were not restricted from consuming food prior to the experimental match. In several instances, subjects did consume a mid-morning snack. As to whether or not these snacks were consumed four hours or fifteen minutes prior to the match is unknown. Ingestion of carbohydrate within two hours of exercise may affect the blood glucose values; Bonen (6) reports a fall in blood glucose at the end of exercise after pre-exercise consumption. If carbohydrate has been consumed at least four hours prior to exercise, blood glucose and insulin have adequate time to normalize.
3. Glycogen is stored to a larger extend in the liver when only partial rebuilding of glycogen occurs (17). Subjects on the low carbohydrate diet with incomplete muscle glycogen resynthesis may have had higher blood glucose levels due to the hepatic release of glucose.

Blood Lactate

At the conclusion of the experimental match, three of the five subjects exhibited a slightly higher, though insignificant ($P>0.05$) blood lactate value when on the low carbohydrate diet. These findings are not in agreement with Martin (21) and Maughan (22) who found blood lactate values to be lower after the consumption of a low carbohydrate diet.

Blood lactate values are influenced by several variables: intensity of exercise, physical condition of the subject, and muscle fiber type. Of these, one may be responsible for the varying blood lactate values. It has been shown that an increased workload/intensity tends to cause a greater lactate production (16, 29). Subjects consuming the low carbohydrate diet may have played at a greater intensity to compensate for poorer general play resulting in higher blood lactate values. Conversely, subjects consuming an optimal percentage of carbohydrate may have "eased up" or played at a lesser intensity resulting in lower blood lactate values.

Total Points/Point Spread

The intake of an optimal percentage of carbohydrate was related to the number of points scored and the point spread ($P<0.05$) with subjects on the optimal percentage of carbohydrate diet scoring more points and having a larger positive point spread. This concurs with the results of investigations by Bergstrom (4), Karlsson (19), and Young (37), who all found that individuals consuming a diet high in carbohydrate were able to perform longer than when on a low carbohydrate diet. The ability to perform longer could mean the subjects consuming an optimal percentage of carbohydrate were able to maintain a higher quality of play longer, therefore scoring more points.

Win/Loss Record

When a low carbohydrate diet had been consumed, subjects won seven matches and lost eight. Conversely, when an optimal percentage of carbohydrate had been consumed, subjects won eight matches and lost seven indicating a slight trend to win more and lose less when an optimal percentage of carbohydrate had been consumed.

Due to a variance in player ability, the win/loss record of each subject may not be indicative of the effects of the dietary carbohydrate and subject performance. If all subjects were evenly matched, the percentage of carbohydrate consumed may have been found to be a deciding factor in the outcome of the match.

Anecdotal Comments

The amount of carbohydrate, optimal or low, had a definite effect on the subjects' perceived feelings at the conclusion of the experimental match. Subjects consuming an optimal percentage of carbohydrate felt much better, stronger, and able to continue after the hour of play was up in contrast to being exhausted after consuming the low carbohydrate diet. These results concur with those of Young (37), Gollnick (14), and Haldi (15), all of whom reported subjects feeling better after the consumption of a diet high in carbohydrate.

Individuals participate in an activity because it is enjoyable, as is the case with most forms of exercise. The consumption of a diet high in carbohydrate may not only enhance performance, but also positively effect how the individual feels during the contest. Possibly more important, is that the individual feels good at the conclusion of the activity. If an individual enjoys himself, he will be motivated to continue to use the sport as a form of exercise.

CHAPTER 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of this study was to determine the effect of a low carbohydrate diet versus an optimal percentage of carbohydrate on handball playing performance. Measured parameters included blood glucose, blood lactate, total points, point spread, win/loss records, and anecdotal comments.

The sample consisted of five male handball players selected for their ability and interest in the research topic. Subjects were scheduled in a double round robin tournament of test matches. Each test consisted of a control match followed 23-hours later by the experimental match. Within a round robin tournament, each subject played each other subject under each dietary condition, optimal and low carbohydrate. No subject played more than one test match per week. Test protocol was presented in Figure 1.

Blood samples were drawn as soon as possible following the experimental match and analyzed for blood glucose and blood lactic acid levels. The same testing procedure was followed for each match.

Conclusions

Results of this study indicate that the ingestion of an optimal percentage of carbohydrate positively affects high intensity intermittent exercise, consequently the following conclusions were drawn:

1. Blood glucose values were not consistently affected by dietary carbohydrate ($P>0.05$).
2. Blood lactate values were not consistently affected by dietary carbohydrate ($P>0.05$).
3. More points were accumulated by subjects on the optimal carbohydrate diet ($P<0.05$).
4. The average point spread on the optimal carbohydrate diet was greater than on the low carbohydrate diet ($P<0.05$).
5. Subjects felt significantly better at the conclusion of the experimental match after consuming an optimal percentage of carbohydrate ($P<0.05$).
6. Subjects won more games and lost less games when on an optimal percentage of carbohydrate indicating subjects were able to perform at a higher level when on the optimal percentage of carbohydrate diet.

Recommendations

Based on the results of this study, the following recommendations are suggested.

1. Extend play during the control match to induce more complete muscle glycogen depletion.
2. Perform muscle biopsies before and after the experimental match to determine muscle glycogen loading and depletion levels relative to different muscle groups.
3. Perform muscle biopsies to determine the percent of fast and slow twitch muscle fibers in each subject.
4. Schedule a controlled warm up period prior to all matches.
5. Cater standardized optimal and low carbohydrate meals to ensure compliance with carbohydrate guidelines.
6. Eliminate all food consumed within four hours of the experimental match.
7. Vary the dietary matching for the experimental matches so that each match tests only one variable, optimal or low carbohydrate. The opponent could consume a normal diet of approximately 50 percent carbohydrate.
8. Implement a single or double blind design such that subjects would not know if they were on optimal or low carbohydrate diets therefore eliminating any bias.

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APPENDICES

APPENDIX A

CONSENT FORM

Appendix A. Consent Form

Montana State University
Committee on Human Subjects in Research

CONSENT FORM

Title of Project:

Name of Researcher:

Name of Person Briefing Subject:

I, ______________________________ am a willing participant in this
(please print name of participant)
project and have been informed of the following items:

I. I have been informed of the general description of the project, its purpose and benefits;

II. I have been given an explanation as to why I have been asked to participate;

III. I have been given an explanation of my specific involvement and potential risks, if any;

IV. I understand as a participatn that I may withdraw from the experiment at any time that I desire;

V. I have been given the opportunity to ask questions about the experiment from the principal investigator and these questions have been answered to may satisfaction.

____
Signature

If the Person giving consent is not the participant, a statement that he/she is legally authorized to represent the participant must be included, e.g. I am the parent or legal guardian of __________________.

If drugs are involved, this form will not be used as we need specific information about the drug being used.

APPENDIX B

BODY DENSITY AND PERCENT BODY FAT FORMULAS

Appendix B. Body Density and Percent Body Fat Formulas.

Body Density

D_B = 1.09716 - 0.00065 (Chest) - 0.00055 (Subscapular) - 0.0008 (Thigh) (24)

D_B = 1.1043 - 0.001327 (Thigh) - 0.00131 (Subscapular) (12)

Percent Body Fat

$$\text{Percent Body Fat} = \left[\frac{4.570}{D_B} - 4.142\right] \times 100 \qquad (7)$$

APPENDIX C

QUESTIONNAIRE

Appendix C. Questionnaire.

QUESTIONNAIRE

NAME ______________________________ DATE ____/____/____

OPPONENT ___________________________

DAY 1: LENGTH OF GAMES: ______ ______ ______ ______

SCORES: ___-___ ___-___ ___-___ ___-___

WEIGHT PRIOR TO THE FIRST MATCH: ______ POST FIRST MATCH: ______

WEIGHT PRIOR TO THE SECOND MATCH: ______ POST SECOND MATCH: ______

SELECT THE ADJECTIVES THAT BEST DESCRIBE HOW YOU FEEL PRIOR TO THE FIRST MATCH:

______ STRONG ______ FATIGUED OTHER: ____________

______ PEAKED ______ WEAK ____________

______ HUNGRY ______ ENERGETIC ____________

______ AVERAGE

SELECT THE ADJECTIVES THAT BEST DESCRIBE HOW YOU FEEL PRIOR TO THE SECOND MATCH:

______ STRONG ______ FATIGUED OTHER: ____________

______ PEAKED ______ WEAK ____________

______ HUNGRY ______ ENERGETIC ____________

______ AVERAGE

GENERAL COMMENTS:

LIST ANY EXERCISE DONE PRIOR TO THE FIRST MATCH:

DIET: HIGH LOW TOTAL POINTS: ______

BG: ______ MATCHES WON: ______

APPENDIX D

GUIDELINES FOR USING FOOD EXCHANGE LISTS

Appendix D. Guidelines for Using Food Exchange Lists.

KCal/Day	2000	2500	3000	3500	4000
70% CHO	1400	1750	2100	2450	2800
30% CHO	600	755	905	1050	1200

CARBOHYDRATE:

Bread = 15g = 60 KCal/Exchange
Fruit = 10g = 40 KCal/Exchange
Veg. = 3g = 12 KCal/Exchange

NON-CARBOHYDRATE:

Fat = 5g = 45 KCal/Exchange
Meat = 5a = 55 KCal/Exchange
5b = 75 KCal/Exchange
5c = 90 KCal/Exchange

Method of Exchange

1. Estimate your KCal/Day.
2. I will inform you as to whether or not you will be eating a 70% or 30% carbohydrate diet.
3. Estimate exchanges of carbohydrate (bread, fruits and vegetables) to equal carbohydrate KCal.
4. Complete menu with meat and fat exchanges.
5. Milk (2 cups equals 2 exchanges) and contains 100 KCal carbohydrate.

APPENDIX E

DIETARY GUIDELINES

Appendix E. Dietary Guidelines.

High Carbohydrate Diet

	Amount
Breakfast:	
corn flakes	1½ C
toast, whole wheat	2 slices
sugar	1 tsp
milk, skim	1 C
orange juice	1 C
jelly	1 T
Snack:	
apple	1
Lunch:	
carrot sticks	9
bread, whole wheat	2 slices
lettuce	2 leaves
tomato	3 slices
bacon	1 strip
mayonnaise	1½ tsp
peach	1
cider	1 C
Snack:	
banana	1
orange juice	1 C
Dinner:	
potato, baked	1
steak	2 oz.
tomato	1 slice
lettuce	2 leaves
cucumber	¼ C
french dressing	1 tsp
bread, whole wheat	2 slices
margarine	1½ tsp
ear of corn	1 medium
peach	1
tomato juice	1 C
Snack:	
banana	1

Appendix E. Cont'd.

Low Carbohydrate Diet

	Amount
Breakfast:	
eggs, fried	2
bacon	4 slices
toast, whole wheat	2 slices
butter	2 tsp
bacon fat	½ tsp
Lunch:	
bread, whole wheat	2 slices
peanut butter	1 T
jelly	1 T
milk	1 C
cheddar cheese	1 oz.
Dinner:	
steak	6 oz.
broccoli	½ C
cottage cheese	½ C
pineapple	¼ C
french dressing	1½ tsp
bread, whole wheat	1 slice
butter	1 tsp
Snack:	
milk	1 C

APPENDIX F

ANECDOTAL COMMENTS

Appendix F. Anecdotal Comments: General Responses by Subjects.

Optimal Percentage Carbohydrate

Pre-Match	Post-Match
okay, above average, slightly stiff, strong, hungry, average, weak, good	pretty good, had to work harder than yesterday, frustrated, could have played harder, could have played longer, not as tired but had a hard match, less than average, not tired, good, strong, energetic

Low Carbohydrate

Pre-Match	Post-Match
fatigued, legs like dead wood, average, hungry, weak, strong, tired, good	dizzy, light headed, weaker than yesterday, pooped, tired, hungry, average, stiff, fatigued, weak, shakey hands, very tired, never felt so weak after a match, feel real sluggish, beginning of last game was like the last mile of a marathon, mentally beat