UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

THE EFFECT OF THE GLYCEMIC INDEX ON ENDURANCE PERFORMANCE

by

ETRESIA VOGEL

Submitted in fulfilment of the requirements for the degree

Magister Artium (HMS)

FACULTY OF ARTS
University of Pretoria

October 1999

SOLI DEO GLORIA

ACKNOWLEDGMENTS

It is a privilege to thank the following people for their help and support in completing this study.

1. **Prof. PE Krüger**, Department of Human Movement Science, for his valuable input and support during the course of this study.
2. **Prof. GA Smith**, Department of Agriculture and Food Science, for his assistance in the initial planning of the study project as well as his advice concerning the nutritional side of the study.
3. **Mr Kobus de Wet**, Department of Sport Science, Technicon Pretoria, for his assistance in all the tests and measurements.
4. **Mr Wayne Viljoen**, Departmentof Sport Science, Technicon Pretoria, for his time and assistance in the calibration of the equipment.
5. **Prof. Jacques Rossouw**, Department of Sport Science, Technicon Pretoria, for allowing me to use the facilities for the study.
6. **Christine Smit**, Afrestat Researchers, for assisting me in processing and interpreting the statistical side of the study.
7. **Eugene**, for the hours of patience and lots of love and support.
8. **My parents**, for their encouragement from the start of the study and support throughout.
9. **Lizelle Bester**, 1 Military Hospital, Biokinetic Department, for granting me the time and opportunity to finish my degree.
10. **All the participants** in the study, for their time and commitment, without the success of the study wouldn't be possible.

11. **My Heavenly Father, for the ability to finish something I would be unable to do without His guidance.**

SYNOPSIS

TITLE : The effect of the glycemic index on endurance performance.

CANDIDATE : Etresia Vogel

PROMOTOR : Prof. P E Krüger

DEPARTMENT : Human Movement Studies, University of Pretoria

DEGREE : MA (MHS)

There exist a wide variety of metabolic responses to different types of carbohydrates and their influence on metabolism during endurance training. Recent studies revealed that the physiological responses to food are far more complex than was previously appreciated. The rapid release of insulin and the decline in blood sugar levels during the first stages of endurance training are linked to the **Glycemic Index** of foods.

Researchers cannot still make use of the old distinction between **starchy** and **sugary** food or **simple** and **complex** carbohydrates. These distinctions are based on the chemical analysis of the food, which does not totally reflect the effects of these foods on the body. The Glycemic Index is a more reliable guideline to apply in nutritional management for endurance athletes.

The major object of the study was to indicate the importance of utilizing the **Glycemic Index (GI)** as part of the nutritional preparation for endurance events. The study investigated the advantages of ingesting a Low Glycemic Index meal prior to exercise and compared it with the ingestion of a High Glycemic Index meal.

A pretest-posttest design was used. Twelve healthy, male and female cyclists participated in the study. Subjects were selected according to their level of training. The total test period consisted of 14 days, which included **two different dietary interventions** of 7 days each.

Diet -and training analysis were done on the subjects prior to the commencement of the study. Each subject completed three exercise trials. The first exercise trial consisted of a VO_{2max} test until exhaustion. Two submaximal trials (65 – 70 % of VO_{2max}) followed and were preceded by two dietary interventions. The dietary interventions (7 days each) had the same amount of CHO, fat and protein but differed in the **Glycemic Index** of the pre-exercise meals. The first pre-exercise meal was a **High Glycemic Index (HGI)** meal. The second pre-exercise meal was a **Low Glycemic Index (LGI) meal.**

The results of the study indicated the advantages of ingesting a Low Glycemic Index meal prior to endurance exercise. The drop in blood glucose levels significantly differed ($p<0.05$) with an average of **0.68 mmol/L** between the two tests after **10 minutes** of cycling. It took 20 minutes for the blood sugar level of the **first test** to reach the same level of the blood sugar level of the **second test.** After the ingestion of the **High Glycemic Index** meal in Test 1, the blood lactate levels were significantly higher ($p<0.05$) during the first 15 minutes.

The total distance covered by the subjects was ***22.86 km*** after the first dietary intervention **(High glycemic Index food)** and ***27.43 km*** after the second dietary intervention **(Low glycemic Index food)** although it is not statistically significant due to the small sample size. The difference in the distance covered of the two tests is **4.57 km** in a period of 50 minutes. Subjects indicated that they experienced more physical strain **(higher RPE values)** in Test 1 **(High Glycemic Index food) than** in Test 2 **(Low Glycemic Index food)** ($p<0.05$).

The study results support the fact that **Low glycemic index** food may confer an advantage when eaten **prior** to prolonged strenuous exercise by providing a **slow-releasing source of glucose** to the blood without causing extensive hypoglycemia.

Proper preparation and the correct choice of the pre-exercise meal can exclude the occurrence of sudden drops in the blood sugar levels. The Glycemic Index can also be successfully applied **during** and **after** events to improve performance.

KEY WORDS

GlycemicIndex
High GlycemicIndex foods
Low GlycemicIndex foods
Hypoglycemia
Pre-exercise meal
Energy metabolism
Carbohydrate ingestion
Insulin response
Dietary guidelines
Endurance training
Blood glucose response
Glycogen replenishment

SAMEVATTING

TITEL : Die invloed van die Glisemiese Indeks op uithouvermoë prestasie

KANDIDAAT : Etresia Vogel

PROMOTOR : Prof P E Krüger

DEPARTMENT : Departement Menslike Bewegingskunde, Universiteit van Pretoria

GRAAD : MA (MBK)

Daar bestaan ‘n wye verskeidenheid van metaboliese reaksies ten opsigte van verskeie tipes koolhidrate asook hul invloed op metabolisme gedurende uithouvermoë sportdeelname. Onlangse studies het aangetoon dat die fisiologiese reaksies van voedsel baie meer kompleks is as wat voorheen aangetoon is. Die vinnige vrystel van insulien in die bloed wat lei tot die daling van bloedglukose gedurende die eerste fases van sportdeelname word geassosieer met die Glisemiese Indeks van die voedsel.

Daar kan dus nie meer ‘n onderskeid getref word tussen koolhidrate met ‘n **styselbasis** of met ‘n **suikerbasis** nie, of tussen sogenaamde **komplekse** -en **eenvoudige** koolhidrate nie. Hierdie onderskeid tussen koolhidrate was voorheen gebasseer op die chemiese samestelling van die voedsel en was nie ‘n korrekte aanduiding van die moontlike invloed wat die voedsel op die liggaam kan uitoefen nie. Die Glisemiese Indeks is ‘n meer betroubare riglyn wat toegepas moet word in dieet beplanning vir uithouvermoë atlete.

Die hoofdoel van die studie was om die belangrikheid van die aanwending van die **Glisemiese Indeks** in dieetvoorbereiding vir atlete aan te toon. Die voordele van die inname van 'n Lae Glisemiese Indeks (LGI) maaltyd in vergelyking met die van 'n Hoë Glisemiese Indeks maaltyd voor sportdeelname is ondersoek.

'n Voortoets-natoets ontwerp is gebruik. Twaalf gesonde manlike en vroulike fietsryers het deelgeneem aan die studie. Die toetspersone is geselekteer na aanleiding van hul vlak van fiksheid. Die totale toetsperiode het bestaan uit 14 dae wat onder andere **2 verskillende dieetingrepe** van 7 dae elk ingesluit het.

Die studie is voorafgegaan deur 'n volledige 7-dag analise van die deelnemers se oefen –en eetgewoontes. Elke proefpersoon het aan drie oefentoetse deelgeneem. Die eerste toets was 'n volledige VO_{2maks} evaluasie wat tot en met totale uitputting voortgeduur het. Die daaropvolgende toetse het bestaan uit twee submaksimale toetse (65 – 70 % van VO_{2maks}) wat onmiddelik gevolg is deur die onderskeie dieetingrepe. Die twee dieetingrepe van 7 dae elk het dieselfde hoeveelhede koolhidrate, vette en proteïne ingesluit. Die dïete het slegs verskil ten opsigte van die **Glisemiese Indekswaardes** van die voorkompetisie-maaltyd. Die eerste voorkompetisie-maaltyd was 'n **Hoë Glisemiese Indeks maaltyd (HGI)** en die tweede was 'n **Lae Glisemiese Indeks (LGI) maaltyd.**

Die resultate van die studie dui baie duidelik die voordele van die inname van 'n **Lae Glisemiese Indeks** maaltyd voor kompetisedeelname aan. Die daling van die bloedglukose vlakke ná **10 minute** het 'n statisties beduidende ($p<0.05$) verskil aangetoon met 'n gemiddeld van **0.68 mmol/L** bloed. Dit het 20 minute geneem vir die bloedglukose vlakke van **Toets 1** om die selfde waarde te bereik as die van **Toets 2**. Ná die inname van die **Hoë Glisemiese Indeks** maaltyd van Toets 1 was die bloedlaktaatvlakke beduidend hoër ($p<0.05$) na 15 minute as die van Toets 2. Die totale afstand wat voltooi is na die eerste dieetingreep **(Hoë Glisemiese Indeks voedsel)** is ***22.86 km***, en ***27.43 km*** na die tweede dieet ingreep **(Lae Glisemiese indeks voedsel)** alhoewel dit nie statisties beduidend is nie weens die klein toetspopulasie. Die verskil tussen die totale afstand wat afgelê is tussen die twee toetse is ***4.57 km*** oor 'n periode van 50 min. Die proefpersone het ook aangedui dat hulle meer fisieke inspanning ondervind **(Hoër RPE waardes)** gedurende Toets 1 **(Hoë Glisemiese Indeks voedsel)** as gedurende Toets 2 **(Lae Glisemiese Indeks voedsel)** ($p<0.05$).

Die resultate van die studie bevestig die aanname dat die inname van 'n **Lae Glisemiese Indeks** voedsel **vóór** deelname aan uithouvermoë sportsoorte voordelig vir die atleet mag wees. Lae voedsel voorkom **hipoglisemie** deurdat bloedglukose **stadig** en **geleidelik** vrygestel word in die bloed. Die korrekte voorbereiding van die voor-kompetisie maaltyd kan die moontlikheid van 'n skielike daling in bloedglukose uitskakel. Die Glisemiese Indeks kan ook suksesvol aangewend word **gedurende,** asook **ná,** oefening om sodoende prestasie te verbeter.

SLEUTELWOORDE

Glisemiese Indeks
Hoë Glisemiese Indeks voedsel
Lae Glisemiese Indeks voedsel
Hipoglisemie
Glikogeen aanvulling
Voor-kompetisie maaltyd
Koolhidraat inname
Insulien reaksie
Dieet riglyne
Uithouvermoë oefening
Bloed glukose reaksie

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURES **PAGE**

LIST OF PHOTO'S

CHAPTER 1 - INTRODUCTION

1.1 BACKGROUND OF NUTRITION FOR ENDURANCE ATHLETES

Endurance athletes spend a lot of time and effort to improve techniques whereas adequate rest and proper nutrition is usually ignored. The high physiological demands of endurance sport may cause a decline in performance if energy intake is inadequate (El-Sayed *et al.*, 1997). From studies of dietary practices of elite athletes, and from the observation of sports nutritionists, researchers concluded that many athletes do not achieve the practices of nutrition for optimal performance (Burke *et al.*, 1995(a); Frentsos & Baer., 1997). Their demanding training schedules in addition to a possible lack of nutritional knowledge may prohibit them from maintaining an optimal dietary intake. Sound scientific data about the nutritional habits of elite athletes are however limited and, therefore, it is not clear as to whether elite athletes are following nutritional recommendations and maintaining nutritionally sound diets (Economos *et al.*, 1993).

1.2 CARBOHYDRATE INGESTION AND PERFORMANCE

Optimizing muscle glycogen levels before training and blood glucose during training is essential for most cyclists. The physiological and biochemical effects of the ingestion of various forms of carbohydrate, either before or during prolonged exercise, have received some experimental investigation. Most of the attention has centered on five major issues: a) the **time** at which carbohydrate should be ingested; b) the **amount** that should be ingested; c) the ideal **type** and **form** (solid or liquid) to be ingested; d) the effect of exercise **duration** (Wright *et al.*, 1991; Wilber & Moffat., 1992), and e) the influence of the percentage of $\mathbf{VO_{2\,max}}$ at which exercise is performed on the utilization of exogenous carbohydrate . All of the above mentioned factors may have an influence on the duration and magnitude of the insulin response to a meal, which may influence substrate metabolism during subsequent exercise (Bergstrom *et al.*, 1967(b)).

The most common variables in the above mentioned studies have been **exercise time** to exhaustion, the **respiratory exchange ratio (RER)** (Bonen *et al.*, 1981; Wilber & Moffat., 1992), blood glucose concentration, ratings of perceived exertion (RPE) and changes in muscle glycogen content. More specific variables are needed to indicate the influence of carbohydrate ingestion on performance.

The wide variety of metabolic responses to different types of carbohydrates and their influence on **blood glucose levels** and CHO oxidation during subsequent exercise makes it difficult for the endurance cyclist to choose the correct type of CHO foods. The **Glycemic Index** was developed by Jenkins *et al.*, (1981) to classify the metabolism of carbohydrates more accurately. This index ranks carbohydrates according to the degree which they raise blood sugar concentration according to a reference food.

The **Glycemic Index** is applied in diabetes research, but it is also successfully applied in research to enhance sport performance. Pre-exercise ingestion of **High Glycemic index foods** such as glucose results in hyperglycemia followed by a large rise in plasma insulin (Hargreaves *et al.*, 1985). This results in rebound **hypoglycemia,** lower circulating free fatty acids (Sherman *et al.*, 1989), and increased CHO oxidation and muscle glycogen utilisation (Hargreaves *et al.*, 1985).

During endurance events, hypoglycemia and/or depleted muscle glycogen stores are linked to the poor performance and the inability to exercise at a desired intensity (Bergstrom *et al.*, 1967(a)).

Exercise requires the skeletal muscles of the body to convert large amounts of chemical energy into mechanical energy. The chemical energy is provided through the dietary intake of food, which is metabolised by the muscles to produce mechanical energy. Consequently, the relationship between dietary intake, and skeletal – muscle metabolism is obvious, and has been examined experimentally for over 100 years.

Aside from genetics and physical training, it is commonly accepted that the nutritional intake of an elite athlete is a critical determinant of performance. Indeed, it is not uncommon to trace the deterioration of an athlete's performance back to poor nutrition. For this reason, over the past 3 decades sports nutrition has become a major interest to physiologists, nutritionists, coaches, athletes, and a variety of other professionals in the field of sports and human performance.

1.3 PROBLEM STATEMENT

In an attempt to avoid early fatigue and improve performance, athletes are encouraged to consume carbohydrates to allow for sufficient muscle glycogen stores **prior** to exercise and maintain blood glucose levels **during** exercise. The draw back is the limited amount of information regarding the **type** of carbohydrate foods that should be ingested (Walton & Rhodes, 1997). In addition to this there exist some inconsistency within the literature that may be related to the rate of **absorption** and **oxidation** of ingested carbohydrates (the primary energy substrate during endurance exercise) (Leeds *et al.*, 1998).

Some CHO test meals are absorbed at different rates and consequently have different effects on **levels of circulating hormones and blood glucose** levels. This in turn has an influence on endurance performance.

1.3.1 Primary Aim

- To determine the **physiological** responses and **performance advantages** after the ingestion of a **low glycemic index** -and a **high glycemic index** food, prior to prolonged submaximal exercise in trained cyclists.

- To demonstrate that the ingestion of a **Low Glycemic Index food** prior to exercise result in a slow release of glucose in the blood stream to prevent the onset of hypoglycemia during the early stages of endurance exercise.

1.3.2 Secondary Aims

- Assessment of the **dietary habits** of competitive cyclists to contribute to the limited pool of data which already exists. This may be useful to apply in future nutritional guidelines for cyclists.
- To demonstrate the advantages of maintaining constant blood sugar levels throughout the exercise period by using the correct **choice** and **timing** of CHO.
- To determine whether the inclusion of popular food choices, have the same advantages as previous test foods used by researchers.
- To develop effective nutritional guidelines which will ensure optimal glycogen stores **prior to** and **during** endurance training and competition.
- To emphasize the important role of the Biokineticist in assisting endurance athletes in event preparation through proper training-and nutritional knowledge.

1.3.3 Hypothesis

Endurance athletes may benefit from the ingestion Low Glycemic Index foods prior to exercise and events. Consuming Low Glycemic Index foods will decrease the likelihood of creating hyperglycaemia or rebound hypoglycemia during the first 10 – 20 minutes of exercise, while providing exogenous carbohydrate throughout exercise. **Low glycemic index** foods eaten prior to prolonged strenuous exercise may provide a slowly releasing source of blood glucose for the working muscles. The combination of the correct **amount, type (Glycemic Index)** and **timing** of carbohydrate ingestion can optimise endurance performance.

1.4 DEFINITION OF CONCEPTS

1.4.1 Glycemic Index

This index ranks carbohydrates according to the degree that they raise blood sugar concentration according to a reference food. The Glycemic Value of the reference food *(glucose or white bread)* is **100** (Jenkins *et al.*, 1981) and the glycemic value for a certain carbohydrate is then calculated as a percentage of an equivalent amount of the reference food.

1.4.2 Low Glycemic Index foods (LGI foods)

These types of foods have a slow and sustained release of glucose into the blood stream which prevents the occurrence of hyperinsulinemia or rebound hypoglycemia (Leeds *et al.*, 1998).

1.4.3 High Glycemic Index foods (HGI foods)

These types of food are quickly digested and absorbed and release glucose rapidly into the bloodstream causing a high release of insulin (Leeds *et al.*, 1998).

1.4.4 Hypoglycemia

The fall of blood sugar levels below normal levels. From the Greek words *hypo* meaning under and glycemia which means blood sugar (Leeds *et al.*, 1998).

1.4.5 Pre-exercise meal

For the purpose of this study it represents the last meal eaten 1 – 2 hours prior to an endurance event (Burke, 1995 (a)).

CHAPTER 2 - LITERATURE STUDY

2.1 NUTRITIONAL NEEDS OF CYCLISTS

2.1.1 Introduction

Competitive and recreational cycling involve the separate sports of track and road cycling as well as the growing sport of mountain bike racing. The long distances and hours of training undertaken by cyclists call for adequate nutrition to meet energy demands. A diet which is high in carbohydrates (Lagenfeld *et al.*, 1994), protein, vitamins, and minerals is therefor essential to achieve maximum performance. Endurance athletes are advised to consume **65 – 70 %** of their daily energy intake in the form of carbohydrate to allow for glycogen repletion (Costill, 1988) *(Refer to* ***chapter 2.1.3.3*** *on glycogen replenishment after endurance events).*

Cyclists consuming less than their recommended amount of daily calories may have difficulty meeting nutrient needs, particularly for iron and calcium. Inadequate diets can result in weight loss, glycogen depletion, dehydration (Grandjean & Ruud, 1994) and poor performance.

Dietary strategies to enhance or maintain the body's carbohydrate stores are necessary for performance, especially for cyclists with **high training miles**, or participating in road racing and endurance events.

2.1.2 Diet analysis of elite cyclists during endurance events.

Very few studies describe the dietary intake and patterns of top level athletes during endurance competition events **over several days**, or during intensive training periods (Saris *et al.*, 1989) **(Table 2.1)**.

Some Dutch physiologists, led by Saris, conducted an extensive study of the **Tour de France,** a race of 22 days covering more than 4000 km including thirty mountain passes up to 2700 m altitude. Five cyclists of one of the leading professional teams were evaluated. Daily energy expenditure was estimated, with the cost of each day's cycling being calculated from the detailed descriptions of each stage. Body weight and body fat was checked over the period, and cyclists kept a record of all food and fluid intake during the race. The first remarkable result was the total energy expenditure estimated for the race which was an average daily energy expenditure of **25 400 kJ (6 060 kcal)**. The heaviest day of exercise was estimated to cost **32 700 kJ (7800 kcal)**, and on the one rest day, energy expenditure was estimated to drop below **13 000 kJ (3100 kcal)**. Despite this energy output, there were only minor changes reported in body-weight and body fat over the three – week period. The estimated energy intake from food, drinks, and supplements was reported at a *daily average* of **24 700 kJ (5 9000 kcal)** (Saris *et al.*, 1989).

The riders did very well in balancing their energy intake and expenditure during this period of intensive endurance cycling. The **carbohydrate** intake was **60 %** of the total food intake. The cyclists consumed **12 – 13 g** of carbohydrate per kilogram of body mass per day, which indicate the remarkable energy expenditure during the race. **Protein** intake was more than adequate, supplying about **15 %** of total energy during the period, or an intake of over **3g/kg** of body weight/day. **Fat** intake, supplied about **23%** of energy intake, and was well below the 36 % fat intake of the average young adult (Nicklas *et al.*, 1995).

Vitamin and Mineral intakes were above requirements, both on the basis of recommended dietary intake levels and from blood measurements of micronutrient status. Fortified liquid formulas (such as high-carbohydrate) and liquid meal supplements also supplied additional minerals and vitamins. As would be expected from sweat loss needs, fluid intake was high – an average of 6,7 litres per day per cyclist (Burke, 1998).

Westerterp *et al.* (1986) also reported isotope data from four professional cyclists participating in the Tour de France. The riders' average daily intake was **24 700 kJ (5880 kcal)** consisting of (% total dietary energy): **protein 15, carbohydrate 62 and fat 23 (Table 2.1).**

An interesting aspect of the results of Garcia-Roves *et al.* (1998) of a similar study is the high protein intake (**3.0/kg** body weight) as well as the high fat intake of 25.5 %. This high protein intake is similar to that observed in the study of Saris *et al.* (1989), which exceeded **2.5g/kg** body weight. The amount of protein required for endurance athletes is within the range of **1.2 – 1.4/kg** body weight per day according to studies done by Lemon *et al.* (1995). The fat intake of these cyclists provided **25.5%** of the total energy (Garcia-Roves *et al.*, 1998). This intake is relatively high with respect to the **20%** recommended by Costill & Miller, (1980).

The information obtained from these studies **(Table 2.1)** can be added to the pool of limited information on nutritional intake during endurance events of top cyclists and may be used to review the future nutrition guidelines for cyclists. Cyclists who engage in intensive training programs need these guidelines for proper nutrition management.

The diet analysis of the subjects **(Table 2.1)** reflects a relatively high carbohydrate diet in comparison with the **average** dietary intake of young adults which consist of **49 %** carbohydrate, **13 %** protein and **36 %** fat, with an average calorie intake of **2346 calories/day** (Nicklas *et al.*, 1995).

Table 2.1: Nutritional intake of competitive cyclists

Authors	**Event/training**	**Protein intake %**	**Fat intake %**	**CHO intake %**	**Total energy kcal/day**
1. Garcia-Roves *et al.* (1998)	"Vuelta Ciclista a Espana" Tour of Spain	14.5	25.5	60	5595
2. Saris *et al.* (1989)	"Tour de France"	16	23	60	5880.9
3. Westerterp *et al.* (1986)	"Tour de France"	15	23	62	5880.9
4. Burke *et al.* (1995(a))	Training and racing	15	23	62	3000 – 7000
5. Gabel *et al.* (1995)	Endurance race 3299 km	10	27	63	7125

The advantages of the combination between **endurance training** and **correct dietary** habits are greater muscle (Ness *et al.*, 1975; Taylor, 1979) and hepatic glycogen stores. The higher muscle glycogen levels of trained athletes can be partly explained by changes that may occur in **eating patterns,** as people become more aware of their bodies' needs. The trend is to eat a **higher carbohydrate** diet as fitness increases, causing an increase in muscle glycogen stores that would occur regardless of any training effects. The concentration of glycogen in the leg muscles of **untrained** people consuming a normal diet varies from about **80 – 120 mM/kg** of wet muscle mass (Ren *et al.*, 1990; Bangsbo *et al.*, 1992), whereas average muscle glycogen concentrations of trained athletes consuming a high carbohydrate diet is approximately **130 mmol/Kg** of wet muscle mass (Sahlin *et al.*, 1990).

The effect of dietary changes alone, however, can be established from studies by Jardine *et al.* (1988) in which untrained people eating a high (70 %) carbohydrate diet had muscle glycogen levels of up to 100 mmol/kg of wet muscle mass. Thus it appears that the remaining increase in muscle glycogen (from 100 to 130 mmol/kg) in athletes occur as a consequence of **training**. The mechanism for this may be explained by the finding in rats that training increases glycogen syntheses and phosphorylase activities 60 – 150 %, and glycogen content in the soleus by 50 – 70%, the increase being proportional to the level of training (James & Kraegen, 1984). Other studies indicated glycogen levels of around **144 – 200 mM/kg** in trained athletes who have not exercised for 24 – 48 hr and who have consumed a high carbohydrate diet (Spencer *et al.*, 1992; Widrick *et al.*, 1993).

2.1.3 Nutritional issues of endurance events and training.

Distance races or training sessions should be tackled with full muscle glycogen stores as well as the **correct** feeding patterns. If a weekly programme of road racing or intensive training is followed, it is not possible to undertake a carbo-loading schedule three days **prior** to each race. Good **recovery nutrition** will help to replenish carbohydrate stores throughout the training week, but there may not be adequate time to fully restore muscle glycogen before the race. This place more emphasis on carbohydrate intake practices **during** the race. The following paragraphs will supply more information on how careful planning and correct choices of food can contribute to optimal performance (Burke, 1995(a)).

2.1.3.1 Nutritional intake prior to a race or training session

Pre-exercise carbohydrate intake has the potential to increase liver (Costill *et al.*, 1986; Coyle *et al.*,1986) and muscle (Ahlborg & Bjorkman., 1987) glycogen concentrations during the hours before exercise. Several studies reported ergogenic effects of pre-exercise carbohydrate feedings on performance (Sherman *et al.*, 1989; MacLaren *et al.*, 1994).

Blom *et al.* (1986) reported that during exercise at 65 – 75% of VO_{2max}, time to fatigue correlated with **pre-exercise muscle glycogen** content, and exhaustion coincided with depletion of muscle glycogen stores. As carbohydrate ingestion does not slow the rate of glycogen utilization in working muscle, it is advisable for endurance athletes to start exercise with an adequate supply of muscle glycogen (Dennis *et al.*, 1997). This emphasizes the importance of a high carbohydrate diet prior to endurance events and intensive training. Hawley *et al.* (1997) demonstrated that elevated starting muscle glycogen content will postpone fatigue by approximately 20 % in endurance events lasting more than 90 minutes. Cyclists often train and compete after an overnight fast and consume less-than-optimal quantities of dietary carbohydrate. This may cause body carbohydrate reserves (liver and muscle glycogen) to be less than normal during subsequent exercise.

Some studies demonstrate that pre-exercise carbohydrate feedings **decrease** (Foster *et al.*, 1979) or have no effect on (Hargreaves *et al.*, 1987) exercise performance.

The study of Langenfeld *et al.* (1994) demonstrated a **5 %** improvement in non-fasted subjects after the ingestion of carbohydrate prior to prolonged exercise. Other studies indicated an improvement of performance. These studies included a 10 – 16 hour fasting period before exercise which is not realistic when realizing that few competitors will compete in such conditions (Coyle *et al.*, 1986).

The inconsistency within the literature may be related to the **rate of absorption** and **oxidation** of the ingested CHO (carbohydrate). Glucose and fructose which are frequently used to examine the effect of pre-exercise CHO ingestion, are absorbed at different rates and consequently have different effects on levels of circulating hormones and blood glucose levels. Pre-exercise ingestion of glucose results in hyperglycemia followed by a large rise in plasma insulin (Hargreaves *et al.*, 1985). This results in rebound hypoglycemia, lower circulating free fatty acids (Sherman *et al.*, 1989), and increased CHO oxidation and muscle glycogen utilization (Hargreaves *et al.*, 1985). This may have a negative effect on exercise performance.

(a) Studies on the amount of CHO ingestion before exercise

El-Sayed *et al.* (1997) had 8 cyclists ingest 40 g of carbohydrate 25 minutes before a 1 h simulated time trial. They reported that carbohydrate ingestion enabled subjects to ride at a significantly **higher average power output** (277 vs. 269 W; $p < 0.05$) and cover a **greater distance** (41.5 vs. 41.0 km; $p < 0.05$) compared to the placebo.

Several researchers have shown an improvement in cycling performance, with an CHO intake providing **4.5 – 5.0 g/kg** body weight, **3-4 h** before exercise (Sherman *et al.*, 1989) **(Table 2.2)**. Coyle, (1995) recommended a carbohydrate intake between **200 to 300 g 4h** before exercise.

Coyle, (1995) and Burke (1998) demonstrated that the pre-exercise meal should be low in **fat** and **protein** and, of course, should not cause **gastrointestinal discomfort**. Most people suppose that cyclists are not bothered by a full stomach of food to the same extent as runners because they don't experience the same mechanical forces. However a full stomach can be uncomfortable and can interfere with your breathing if you sit in a crouched position over the handlebars (Burke, 1998).

Table 2.2: Nutritional intake prior to the race

Author	Type of food	Amount	Time period before exercise	Type of exercise
Gleeson *et al.* (1986)	Carbohydrate	1 g/kg body mass	60 minutes	Steady state cycling.
Sherman *et al.* (1989)	Carbohydrate	4.5 – 5.0 g/kg body mass	3 - 4 hours	Time trial.
Sherman *et al.* (1991)	Carbohydrate	1.1 g/kg body mass	60 minutes	90 min submaximal cycling.
Wright *et al.* (1991)	Carbohydrate	5 g/kg body mass	3 hours	Steady state cycling.
Singh *et al.* (1994)	Carbohydrate	4.5 g/kg body mass	4 hours	Endurance exercise.
Coyle, (1995)	Carbohydrate	200 – 300 g	4 hours	Submaximal cycling.

(b) The Glycemic Index and the pre-exercise meal

Earlier studies by Foster *et al.* (1979) and Costill *et al.* (1986) suggested that pre-exercise carbohydrate feedings may **impair** exercise performance by causing a sudden **drop** in blood glucose (hypoglycemia), and an accompanying acceleration of muscle glycogenolysis and glucose oxidation. It is often ignored that there are different **types** of carbohydrates, which are capable of producing different **glycemic** and **insulinemic** responses. The wide variety of metabolic responses to different types of carbohydrates and their influence on metabolism during subsequent exercise is often ignored in the pre-exercise-feeding literature.

The physiological and biochemical effects of the ingestion of various forms of carbohydrate, either before or during prolonged exercise, have received some experimental investigation. Most of the attention has been on five major issues: a) the **time** at which carbohydrate should be ingested; b) the **amount** that should be ingested; c) the ideal **type** and **form** (solid or liquid) to be ingested; d) the effect of exercise **duration** (Wright *et al.*, 1991; Wilber & Moffat, 1992); and e) the influence of the percentage of **VO_{2max}** at which exercise is performed on the utilization of exogenous carbohydrate . All of the above mentioned factors may have an influence on the duration and magnitude of the **insulin response** to a meal, which may influence **substrate metabolism** as well as performance during subsequent exercise (Bergstrom, 1967(a)).

Performance during prolonged exercise has been related to the ability to **maintain** blood glucose levels late in exercise when glycogen stores are low. Furthermore, the ingestion of complex forms of carbohydrate **prior** to exercise, such as starch have been shown to **maintain higher blood glucose levels** during exercise than the ingestion of simpler carbohydrates such as glucose. Goodpaster *et al.* (1996) hypothesized that the ingestion of a more complex CHO in the form of either **waxy** or **resistant** starch **prior** to exercise may provide a slower release of blood glucose than would glucose. A higher blood glucose level can then be maintained towards the **end** of strenuous exercise when **liver and muscle glycogen** are low, thus enhancing performance (Goodpaster *et al.*, 1996).

It is suggested that the **Glycemic Index** may be an important resource when selecting the **ideal carbohydrate** according to the blood glucose response that it elicits. Carbohydrate foods evoking the greatest responses are considered to be **High Glycemic Index** foods, while those producing a relatively smaller response are categorized as **Low Glycemic Index** foods. Athletes wishing to consume carbohydrates 30 to 60 minutes before exercise should be encouraged to ingest **Low Glycemic Index** foods. Consuming these types of foods will decrease the likelihood of creating **hyperglycemia** and **hyperinsulinemia** at the onset of exercise, while providing exogenous carbohydrate throughout exercise. It is recommended that **High Glycemic Index** foods be consumed during exercise *(Refer to chapter 2.1.3.2)*. These foods will ensure rapid digestion and absorption, which will lead to elevated blood glucose levels during exercise. Post exercise meals should consist of **High Glycemic Index** carbohydrates. **Low Glycemic Index** foods do not induce adequate muscle glycogen resynthesis compared with high glycemic index foods (Walton & Rhodes, 1997) *(Refer to chapter 2.1.3.3)*.

Glucose, a **High Glycemic Index food**, consumed in the hour **before** prolonged, strenuous exercise has been shown to be **disadvantageous**, although the evidence is conflicting. Some studies have found an increased use of muscle glycogen (Hargreaves, 1985; Costill *et al.*, 1986), a rapid rise in plasma insulin, and **shorter endurance times** when glucose is administered **15 to 60 minutes** before exercise. The increase in glycogen use may be related to the insulin surge inhibiting FFA mobilisation (Costill *et al.*, 1986). However, it is important **not to eat** foods with too high a glycemic index **one to two hours before** an event or right before a competition that might last longer than that. This will cause too much insulin to be stimulated and blood- sugar levels will drop below normal during the critical stages of the event (Hargreaves, 1985; Costill *et al.*, 1986). It may also lead too fatigue and hunger towards the end of the competition or workout. However, High Glycemic Index foods may be beneficial in the middle of an event when one needs a quick burst of energy (Coyle *et al.* 1986) *(Refer to chapter 2.1.3.2).*

In the study of Thomas *et al.* (1991), trained cyclists ingested foods with different **Glycemic Index** values 1 hour before they cycled until exhaustion. They ingested either lentils **(Low Glycemic Index food)**, potato **(High Glycemic Index),** glucose, or water. The **Low Glycemic Index meal** of lentils prolonged endurance at 67 % VO_{2max} by 20 minutes compared to the **High Glycemic Index meal** of potato. This suggest that a Low Glycemic Index pre-exercise meal may prolong endurance during strenuous exercise by inducing **less** post-prandial hyperglycemia, lower levels of plasma lactate before and during exercise, and by maintaining plasma glucose and FFA (free fatty acids) at higher levels during critical periods of exercise. They also demonstrate that a **High Glycemic Index food** causes higher rates of **CHO oxidation** (higher RER measurements) during the first 90 min of exercise than does **Low Glycemic Index** foods. It seems that muscle glycogen which is the primary fuel source in the **early stages** of training is being more rapidly depleted after the ingestion of High Glycemic Index foods.

Thomas *et al.* (1994) did a further study on the ingestion of Low Glycemic Index foods before prolonged exercise and demonstrated that these foods increase the blood glucose concentration toward the **end** of exercise. Plasma glucose levels after more than 90 min of exercise was found to correlate **inversely** with the observed Glycemic Index of the foods. Free fatty acid levels during the last hour of training also correlated inversely with the Glycemic Index. The findings suggest that the **slow digestion** of carbohydrate in the pre-event food favours higher concentrations of fuels in the blood toward the end of exercise.

Low Glycemic Index foods may have advantages for cyclists when eaten before prolonged strenuous exercise by providing a **slow–release** source of glucose to the blood. This may prevent hypoglycemia or rapid insulin responses. Varying blood glucose levels may lead to poor performance and the cyclist aim should be to **maintain steady blood glucose levels** during submaximal exercise (65 – 70 % of $VO_{2\ max}$) (Thomas *et al.*, 1991). The correct **choice** and **timing** of pre-exercise meals will also have advantages for endurance cyclists.

2.1.3.2 Intake during the race

The intake of carbohydrates during exercise can elevate and maintain blood glucose levels. The maintenance of high blood glucose levels is believed to cause a sparing of muscle glycogen (Hargreaves *et al.*, 1984) or to allow maintained carbohydrate oxidation near the end of exercise when the body's endogenous stores are depleted (Coggan & Coyle, 1989).

A very important practical nutritional problem for cycling in long events such as the "Tour de France", "Giro de Italia" or "Vuelta Ciclista a Espana" is the difficulty of eating enough food **in between** sessions in order to obtain the amount of carbohydrate needed for optimum performance (Brouns *et al.*, 1989(b)). The alternative is that a large part of the daily energy intake should take place while on the bike.

At the onset of exercise there is a marked increase in both the absolute and relative oxidation of **glucose** as a fuel. Glucose is made available to skeletal muscle by increased delivery from **plasma** (hepatic glycogenolysis and gluconeogenesis from plasma glycerol, lactate, and alanine precursors) and increased breakdown of **intramuscular glycogen**. During the early part of moderate-intensity exercise, plasma glucose provides approximately **one-third** and muscle glycogen approximately **two-thirds** of the carbohydrate oxidized (Coggan & Coyle, 1991). However, as exercise continues the relative contribution from plasma glucose **increases** and that from muscle glycogen **decreases** (Coyle *et al.*, 1986; Romijn *et al.* 1993). Thus, after prolonged exercise virtually all carbohydrate oxidized is derived from **plasma glucose**. The decline in plasma glucose and muscle glycogen content that occur with continued exercise, contribute to the onset of fatigue.

Carbohydrate feeding during exercise can **delay fatigue** and permit continued exercise by preventing hypoglycemia (Coyle *et al.*, 1986). It is important to start ingesting CHO **early** in exercise before the cyclist experience a hunger sensation, and perhaps even from the **start** of the ride. The muscles oxidize a small amount of CHO from outside sources in the first 30 – 60 minutes of exercise, but after this it becomes quite dependent on carbohydrate consumed during exercise.

Cyclists are more self-reliant than other athletes are, in that food and drinks can be carried on the bike or in the pockets of the cycling jersey. New research indicates that carbohydrate intake will enhance performance over events as short as **40 km**, and fluid needs will vary both with the distance and the weather conditions (Burke, 1998).

Carbohydrate intake during prolonged strenuous exercise result in the **maintenance** of a sufficiently high rate of carbohydrate oxidation and the postponement of fatigue (Coyle *et al.*, 1986). To ensure that this will occur, consumption of **30 – 60 g/h** starting **early** in exercise has been suggested (Coggan & Coyle, 1988). The type of carbohydrate ingested at this time is critical, and in the study of Garcia-Roves *et al.* (1998) it was maltodextrine, sugar, fructose and oligosacharides. These carbohydrates have shown to improve endurance capacity.

A study by Mason *et al.* (1993) demonstrated that liquid and solid carbohydrate diet with equal carbohydrate content produces similar blood glucose and insulin response during exercise: the administration of carbohydrate during the race was both solid food and sports drinks. Murdoch *et al.* (1993) examined the metabolic and performance effects of ingesting solid compared to mashed bananas between two prolonged exhaustive exercise bouts. Cyclists cycled to exhaustion at 70 % $V_{O2\ max}$. The mean glucose concentration did not differ significantly between the two treatments. These data demonstrate that solid bananas are as effective as mashed bananas in maintaining plasma glucose during exercise.

The ingestion of **High Glycemic Index foods** during an event may be beneficial when one needs a quick burst of energy (Coyle *et al.*, 1986). **High Glycemic Index foods** quickly enter the bloodstream, and are best to eat **during** or **after** exercise (Burke, 1995(b)).

Athletes can increase their stamina by eating 100 to 300 calories of carbohydrates per hour of endurance exercise (Murray *et al.*, 1991). When cyclists decide to take food in the form of candy bars it is important to make sure that the majority of **calories** come from **carbohydrates** and not from fat or protein (Burke, 1995(a)). Through experimentation of liquid and solid foods the cyclist can decide on the best food to consume during the event.

(a) The onset of fatigue during cycling events

Not all studies, however, have shown that **muscle glycogen depletion** is the cause of fatigue **during** prolonged exercise (Blom *et al.*, 1986; Coyle *et al.*, 1986). One challenge to the "glycogen depletion causes exhaustion" theory came from Coyle *et al.* (1986) who demonstrated that exercise could be continued even when muscle glycogen content was low, provided that the **blood glucose** concentration remained **high**. Cyclist ingested either a glucose polymer solution or water placebo while cycling at 70 % of $VO_{2\,max}$. The subjects ingesting the glucose solution were able to exercise for **an hour longer** than subjects ingesting the placebo were. They concluded that it could not have been muscle glycogen depletion that stopped the subjects from continuing to exercise, but rather an **inadequate supply of plasma glucose** for oxidation and thus emphasizing the importance of maintaining high blood glucose levels during the event through the ingestion of carbohydrates.

The 'bonk' or hunger flat that cyclist sometimes experience near to the end of a race is probably the result of blood sugar decline (Coyle *et al.*, 1986), – notice how quickly the cyclists recover after eating some carbohydrate. Cyclists seem more susceptible to low blood sugar levels than other distance athletes such as runners do.

On the other hand the heavy **'dead'** legs that some cyclists experience are probably due to **low muscle glycogen** levels in the quadriceps muscles.

McConell *et al.* (1996) compared the effects of carbohydrate ingestion *throughout* exercise with ingestion of an equal amount of carbohydrate *late* in exercise. Performance improved with the ingestion of carbohydrate **throughout** exercise. It has been previously suggested that the key to improved performance during sustained high-intensity exercise is the relative **carbohydrate availability** in the form of circulating blood glucose (Coggan & Coyle, 1991). Carbohydrate ingestion during prolonged exercise results in improved performance by increasing blood glucose oxidation when intramuscular glycogen stores become compromised. **Table 2.3** represents some recommendations of different authors on the amount of CHO intake **during** events. According to **Table 2.3**, **50 grams** of CHO/ hour during exercise will provide enough energy for submaximal endurance exercise. **Table 2.4** demonstrates the amount of food needed to provide **50** gram of **CHO/hour**.

Table 2.3: Carbohydrate intake during a race

Author	**Amount of CHO**
Burke, 1998	50 g/hour
Coggan, 1988	30 – 60 g/hour
Murray, 1991	25 – 75 g/hour

Carbohydrates can also be ingested through liquids. Some products available on the **South African market** with a **CHO concentration of less than 8.5 %** are represented in **Table 2.5**. The amounts indicate the recommended intake to provide **50 g** of **CHO/hour.**

Table 2.4: Amount of food needed to provide 50 g of CHO during a race

Food / Fluid	**Amount**
Banana	2 large
Choc chip cookies	4 – 8
Chocolate bar	1½ x 50 – 60 gram bar = 80 g
Cola drink e.g. Coke	500 ml
Dried fruit e.g. sultanas, raisins	75 g
Fruit Juice	500 ml
Jam sandwich	2 thick slices + 4 teaspoons jam
Jelly beans, sweets, nougat	60 g
Muesli bar	2
Orange	3 medium
Sports bar e.g. Power Bar	1 – 1½
Sports drink e.g. Energade	600 – 1000 ml
Sports gels e.g. Power Gel	1 sachet

(Burke, 1998)

Table 2.5: South African products

Carbohydrate drink	**Amount to provide 50 gram CHO**
Cyber Quench	± 600 ml
Energade	± 700 ml
Game	± 650 ml
Gatorade	± 850 ml
Lucozade isotonic	± 650 ml
Powerade	± 625 ml
Quest	± 1000 ml

(Burke, 1998)

2.1.3.3 Intake after the race (Glycogen replenishment)

The rapid restoration of muscle glycogen stores is a critical issue for cyclists competing in endurance events over successive days or during intensive training periods. Post exercise feeding programs which promote glycogen storage has been studied intensively by sport physiologists (Costill & Miller, 1980; Kiens *et al*, 1990).

Replenishment of daily glycogen stores can be a challenge considering the amounts of carbohydrates that should be ingested (8 – 10 g/kg of body weight) (Burke, 1998). Costill & Miller, (1980) illustrates in **Figure 2.1** the importance of a high carbohydrate diet (70% of energy intake) to replenish glycogen stores. The carbohydrate content of the average western diet is insufficient for proper recovery of the glycogen stores in between intensive training sessions or during a cycle tour (Costill & Miller, 1980). Bergstrom *et al*. (1967(a)) indicated that subjects on a high-protein and high-fat diet remained glycogen depleted for **five days** whereas the subjects on the **high-carbohydrate** diet replenished their muscle glycogen in **two days**.

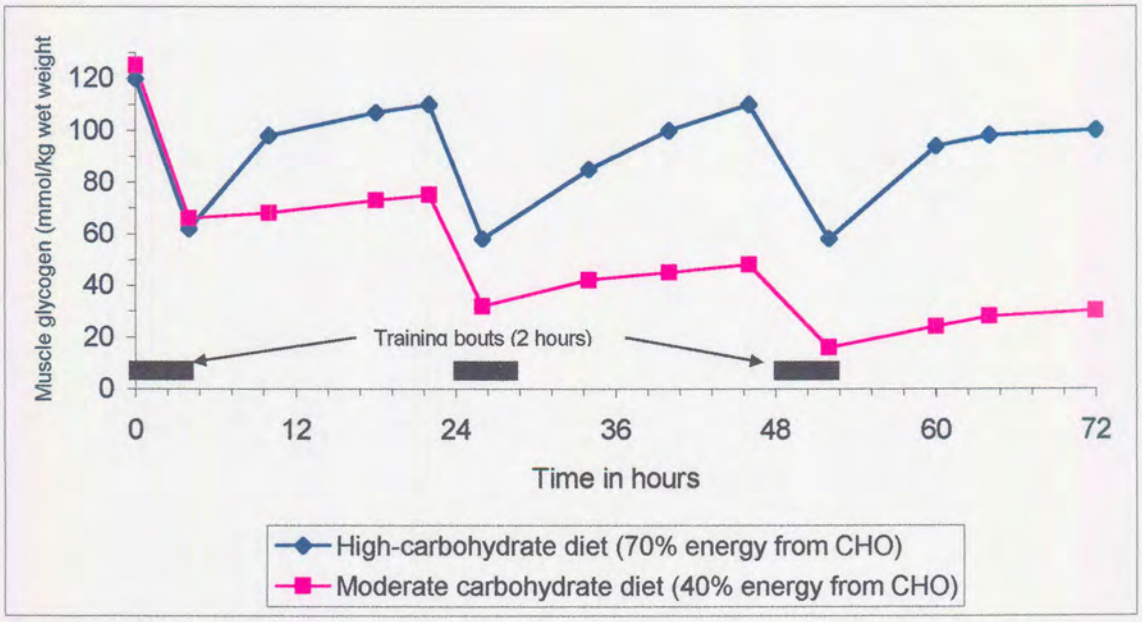


Figure 2.1 Rate of glycogen replenishment after a 70% CHO diet and a 40% CHO diet

Daily recovery between heavy training sessions or competition stages requires a high total carbohydrate intake, but also clever **timing** of meals and snacks to enhance muscle glycogen restoration. Ivy *et al.* (1988(a)) demonstrated the advantages of the **immediate intake** of carbohydrate after the completion of the race **(Figure 2.2)**. Immediate intake of carbohydrate causes **rapid glycogen synthesis**. A possible explanation (Burke, 1998) for this quick recovery is that the muscles are still active after the completion of a race which means that there is a high blood supply to the cells. Muscle cells will take up glucose across their walls at a higher rate than during rest. It seems that this accelerated glycogen synthesis only lasts for **2 hours** (Burke, 1998). **Table 2.6** illustrates the recommended CHO intake by several authors for glycogen replenishment after endurance events.

In the study of Garcia – Roves *et al.* (1998), carbohydrate intake of cyclists was **1.1 g/kg** body weight per hour during the first **6 hours** after the race **(Table 2.6)**. The recommendations for muscle glycogen resynthesis are well established with respect to the quantity of carbohydrate intake. Ivy et al. (1988(b)) recommends an immediate post-exercise carbohydrate intake of 0.7 to 1.5 g/kg body weight. Burke, (1998) recommends a carbohydrate intake of **8 – 10 g/kg** of body weight per day to optimize muscle glycogen stores within **24 h** after strenuous exercise. Brouns *et al.* (1989(a)) demonstrated that carbohydrate intake of **12 – 13 g/kg** of body weight per day during extreme endurance exercise is the range of maximal contribution of carbohydrate to energy metabolism **(Table 2.6).**

Another interesting factor for muscle glycogen resynthesis is the addition of **protein** immediately after exercise in a ratio of **3:1** to a carbohydrate meal. This produces higher rate of glycogen resynthesis over the first **4 hours** of recovery (Zawadzki *et al.*, 1992). The study of Garcia – Roves *et al.* (1998) of the intake of carbohydrate/protein ratio (1.1 per 0.35 g/kg body weight per hour) agrees with this statement.

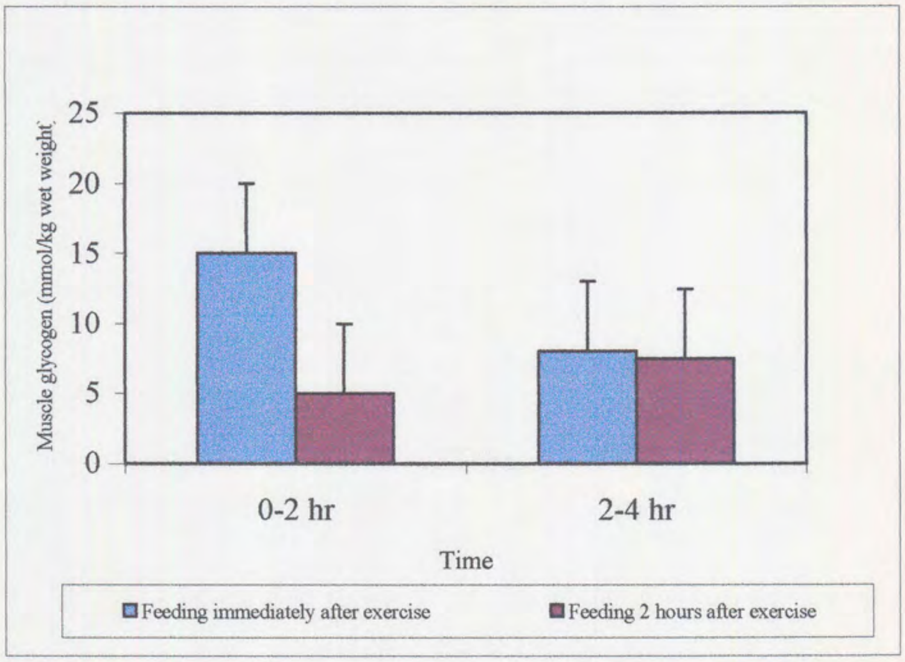
Table 2.6: Previous studies on glycogen repletion after endurance exercise

Authors	**Type of exercise**	**Amount of CHO/kg body weight**	**Starting time of CHO ingestion and total period of ingestion**
Ivy *et al.* (1988(b))	Endurance cycling events	0.7 – 1.5 gram	Directly after race
Brouns *et al.*(1989(a))	Extreme endurance events	12 – 13 gram	Within next 24 hours.
Burke, (1998)	Laboratory endurance cycling	10 gram	Within next 24 hours.
Garcia-Roves *et al.* (1998)	Stage race Tour of Spain	1.1 gram./hour	For the next 6 hours.

Several authors recommend an ingestion of **High Glycemic Index** foods for muscle glycogen replenishment (Burke, 1998; Garcia-Roves *et al.*, 1998). Garcia-Roves' study includes both **high and medium glycemic index** foods. In the study of Burke *et al*, (1993), glycogen storage after 24h was greater with **High Glycemic Index** food (106.1 ±117) than with Low Glycemic Index food (71.5 ±6.5). Research of the effect which different carbohydrate foods has on glycogen storage has taken a simplistic approach to carbohydrate nutrition, dividing foods into **"simple"** - or **"complex"** carbohydrate foods on the basis of their chemical composition (Costill *et al.*, 1981). It has been suggested that ingestion of simple-carbohydrate foods will elicit a large, rapid, and short-lived rise in blood glucose, whereas the response to complex-carbohydrate foods will be more sustained. In other areas of carbohydrate research, it has been found that this simplistic model is quite **incorrect** and that each carbohydrate food elicits its own individual effect on blood glucose quite separately and unpredictably from its chemical composition. These different responses of CHO foods is represented in **Table 2.9 (The Glycemic Index)**.

The **glycemic index** concept has been developed to define carbohydrate foods (and meals) **(Table 2.8)** according to their actual postprandial glycemic impact (Jenkins *et al.*, 1981). With a more physiologically based classification of foods, researchers have been able to manipulate the metabolic responses of diets to improve glucose control in diabetics and reduce hyperlipedemia (Jenkins *et al.*, 1985).

This research may be important for athletes to establish feeding patterns which may improve endurance performance.



Ivy *et al.* (1988)

Figure 2.2 Rate of glycogen replenishment after immediate and after 2 hours CHO feeding

A pattern of frequent meals and snacks may also be handy for making sure that total energy and carbohydrate needs are attended to. CHO snacks immediately following a long training session will kick-start muscle glycogen synthesis and prepare fuel stores for the next training session.

2.1.3.4 Special nutritional needs of cyclists

Good nutrition is important at every stage of training and competition. It is not just the amount of CHO, protein and fat, which need attention in the diet of endurance athletes. Other nutritional issues include specific vitamin and mineral needs.

Hard-training cyclists must maintain a proper level of **iron** in order to compete in top form. Iron helps the hemoglobin molecule carry oxygen to your exercising muscles and plays a key role in energy production in the working muscles. If the body's iron stores are not adequate, an individual can develop anaemia, a condition that can be identified by low haemoglobin and/or serum ferritin. The normal value for iron in males is 14 to 18 grams per 100 millilitres of blood and for women 12 to 16. Iron status is particularly an issue for female cyclists. Above the normal iron loss of 0.9 milligrams every day during training, women loose an additional 15 to 45 milligrams each time they menstruate. High intakes of lean meat, beans, spinach, broccoli, prunes, and dried apricots will prevent iron deficiency (Burke, 1998).

Dietary interventions or nutrition management may have benefits for endurance athletes such as cyclists. Frentsos *&* Baer (1997) examined the dietary habits of 6 elite triathletes (4 male, 2 female) over a period of 7 days. The diet records showed mean daily energy and carbohydrate intake to be **insufficient** to support estimated requirements. They used individualised **nutrition intervention** by using the Diabetic Good Exchange System to support performance during training and competition. Follow-up 7-day diet records showed that average energy intake and percentage of **energy from carbohydrate increased**, as did intakes of zinc and chromium. The subjects' performance in a short course triathlon **improved** compared to a similar competition completed prior to the nutrition intervention.

Diet can affect both muscle glycogen content and exercise performance. Possibly the best study is that of Bergstrom *et al.* (1967(a)) in which initial muscle glycogen concentrations were manipulated through various combinations of diet and exercise. In this study Bergstrom *et al.* (1967(a)) demonstrated that initial glycogen levels influenced subsequent exercise time to exhaustion, but also that muscle glycogen concentration could be influenced by dietary manipulation. Other studies also reported that muscle glycogen depletion is the cause of fatigue (Bangsbo *et al.*, 1992; Costill & Hargreaves, 1992). Blom *et al.* (1986) reported that during exercise at 65 – 75 % of $VO_{2\ max}$, time to fatigue correlated with pre-exercise muscle glycogen content and exhaustion coincided with depletion of muscle glycogen stores. Karlsson & Saltin (1971) are the only researchers who have tested the glycogen- depletion theory in the field. Using well-trained subjects, they found that after following the carbohydrate-loading regimen of Bergstrom *et al.* (1967(a)) subjects ran a faster time in a 30 km road race than those who followed a normal diet. Of particular interest was the finding that loading did not result in a faster initial running speed. Rather, it allowed the athletes to maintain their initial speed for longer.

Muscle glycogen depletion has other **detrimental effects**. Exercise for 60 min at 60% of VO_{2max} after either carbohydrate – loading or depletion (Lemon & Mullin., 1980), caused serum and sweat urea nitrogen concentration to increase up to 154-fold in **glycogen depleted** subjects compared to a 66-fold increase in carbohydrate-loaded subjects. This corresponds to a **protein breakdown** of 13.7 g/hr, or 10.4 % of the total caloric cost in the glycogen depleted group (Lemon & Mullin., 1980) and contradicts the data of Wagenmakers *et al.* (1989), which showed that amino acids and protein did not contribute substantially as an energy source during exercise.

It appears that protein requirements of endurance athletes increase as the **duration** and **intensity** of exercise increases. However, factors such as total calorie intake and protein quality should be considered when determining protein needs.

During training , females reported protein intake of 1.1 to 1.5 g/kg/day for aerobic sports and 1.1 to 2.0 g/kg/day for anaerobic sports. Expressed as a percentage of calories, the intakes were **13.0** to **15.8%** for aerobic sport and **17** to **30%** for anaerobic sport. For some endurance athletes, protein requirements may be as high as **1.6** g/kg/day (Brouns *et al.*, 1989(a)).

There are certain groups of endurance athletes who may be at risk for low protein intake. Cyclists who want to maintain a low bodyweight for competition as well as vegetarian athletes may have a protein deficient diet.

Many athletes are concerned about **vitamin and mineral** intake and often use nutritional supplements both for "insurance" as well as performance reasons. The supplements taken most often include **vitamin C, the B-complex, and iron**. Vitamins and minerals in excess of the RDA (Recommended Daily Allowance) do not improve performance and can be **toxic** when consumed in large amounts. On the other hand, vegetarians and cyclists with low-calorie intakes may benefit from a multivitamin or mineral supplement (Grandjean & Ruud, 1994).

2.2 THE GLYCEMIC INDEX

2.2.1 History of the Glycemic index.

In 1981 Jenkins *et al.* (1981) published the first list of Glycemic Index values for 62 foods. Despite early controversy, most studies have found the Glycemic Index concept to be reproducible and predictable within the context of mixed meals **(Table 2.8)**, and clinically useful in the dietary management of diabetes and hyperlipidemia (Leeds *et al.*, 1998).

The **Glycemic Index** was developed to classify the metabolism of carbohydrates more accurately. This index ranks carbohydrates according to the degree that they raise blood sugar concentration according to a reference food. The Glycemic Value of the reference food *(glucose or white bread)* is **100** (Jenkins *et al.*, 1981) and the glycemic value for the food is then calculated as a percentage of an equivalent amount of the reference food.

The **Glycemic Index** is not only used in diabetes research but is successfully applied in research to enhance sport performance. Previous research indicated an increase in performance and higher concentrations of plasma fuels towards the end of exercise when **Low Glycemic Index** food were ingested prior to an event (Thomas *et al.* 1991). Costill., (1988), examined the advantages of the avoidance of High Glycemic Index foods 30 – 60 min before exercise, and indicated that this procedure can prevent hypoglycemia.

2.2.2 Factors which influence the glycemic index

The right **kind** and **amount** of carbohydrate can make a significant difference in sport performance as well as the well being of people with diabetes.

Recent studies revealed that the physiological responses to food (how food acts in the body) are far more complex than was previously appreciated. What is true is that different carbohydrate containing foods do have different effects on blood sugar levels. This research lead to the conclusion that many starchy foods (bread, potatoes and rice) are digested and absorbed very **quickly**, not **slowly** as had always been assumed. Moderate amounts of most sugary foods (confectionery) did not produce dramatic raises in blood sugar as had always been thought (Jenkins *et al.*, 1984).

Researchers cannot still make use of the old distinction between **starchy** and **sugary** food or **simple** and **complex** carbohydrates. These distinctions are based on the chemical analysis of the food, which does not totally reflect the effects of these foods on the body.

The wide variety of metabolic responses to different **types** of carbohydrates and their influence on metabolism during subsequent exercise need to be addressed in exercise –feeding literature. The metabolic responses during exercise after the ingestion of **simple carbohydrate** have been studied by Hargreaves *et al.* (1987) but the responses to different **complex carbohydrate** meals need further research in the exercise literature (Thomas *et al.*, 1991). Further in practice as well as in preference, carbohydrates are generally not the sole component of a pre-exercise meal.

Horowitz *et al.* (1993) studied the differences among complex carbohydrates. Rice, like potato, is a complex carbohydrate with different influences on blood glucose. We observe the glycemic and insulinemic responses to the potato meal to be significantly **greater** than those for the rice meal (Horowitz *et al.*, 1993). This finding is consistent with previous work (Jenkins *et al.*, 1984). The difference in metabolic responses observed between these two complex carbohydrates may be attributed to several factors including differences in **preparation** (mashed vs. boiled), **hydration,** or differences in the **polymeric structure** (amylose vs. amylopectin) (Behall *et al.*, 1988) of the specific carbohydrate. These factors alter the *digestion and absorption* characteristics of the meals. The physical form of the food consumed affects the surface area of the starch molecule, which in turn dictates the magnitude of the carbohydrate-enzyme interaction within the intestine and thus the glycemic response to the food (O'Dea *et al.*, 1980). The following paragraphs elaborate more on these glycemic responses to the different properties of carbohydrates.

2.2.2.1 Rate of ingestion and digestion

The **rate** of carbohydrate digestion in the gastro intestinal tract has important implications for athletes. Differences in glycemic responses to various carbohydrate-rich foods are related to differences in the rate at which the carbohydrate is digested and absorbed. Carbohydrates, which break down quickly during digestion, have the highest **Glycemic Index** factors. The blood sugar response is fast and high. In other words the glucose (or sugar) in the bloodstream increases rapidly. Conversely, carbohydrates, which break down slowly, releasing glucose gradually into the bloodstream, have low Glycemic Index factors (Leeds et al., 1998).

The slow digestion and gradual rise and fall in blood sugar responses after the ingestion of a Low Glycemic Index food helps to control blood sugar levels in people with **diabetes**. This effect may also benefit healthy people and athletes because it reduces the release of the hormone insulin and ensures controlled blood glucose levels. Slowly ingested foods tend to result in a lower **Glycemic Index** than the same foods when rapidly ingested (Leeds *et al.*, 1998).

2.2.2.2 Starch gelatinization and particle size

Differences in particle size and gelatinization help to explain the wide differences in the composition of the starch granule (Behal *et al.,* 1988). The less gelatinized (swolen) the starch, the slower the rate of digestion resulting in a lower insulin response. Thus the greater the degree of gelatinization of the starch granules, the higher the Glycemic Index value of the starch (Ross *et al.*,1987). The starch in raw food is stored in hard compact granules that make it difficult to digest. Most starchy foods need to be cooked for this reason. During cooking, water and heat expand the starch granules to different degrees, some granules burst open and set the individual starch molecules free. The swollen granules and free starch molecules are very easy to digest because the starch-digesting enzymes results in a rapid and high blood sugar rise after consumption of the food. A food containing starch which is fully gelatinised will therefore have a very High Glycemic Index factor (Heaton *et al.*, 1988; Leeds *et al.*, 1998).

The particle size of starch foods has a marked effect on the insulin response: as particle size decreases, the Glycemic Index increases (Heaton *et al.*, 1988). Grinding or milling of cereals reduces the particle size and makes it easier for water to be absorbed and enzymes to attack. The fibrous coat around **beans** and **seeds** and intact plant cell walls act as a physical barrier, slowing down access of enzymes to the starch inside. Cereal foods such as white bread (GI = 70) made from fine flours tend to have High Glycemic Index factors. Jarvi *et al.* (1999) compared the effects of a Low Glycemic Index and a High Glycemic Index diet on blood glucose levels. The study demonstrated the large impact which particle size and degree of processing has on the Glycemic Index of foods **(Table 2.7).** Note how the same type of foods were used, but with different degrees of processing.

Table 2.7: Influence of the degree of processing on the Glycemic Index of foods

Low Glycemic Index diet	High Glycemic Index diet
Durum pasta	*Bread* made from *durum wheat*
Bread made of *whole barley* seeds	Bread made of *ground barley* seeds
White beans, *whole*	White beans, *ground*
Parboiled rice	*Sticky* rice

(Jarvi *et al.*, 1999)

The larger the particle size, the lower the Glycemic Index factor. When starch is consumed in its **natural form** – whole intact grains which were softened by soaking and cooking – the food will have a low Glycemic Index factor. For example, cooked barley has a Glycemic Index factor of only 25. Most cooked legumes have a Glycemic Index factor between 30 and 40. Cooked whole wheat has a Glycemic Index factor of 41 (Leeds *et al.*, 1998). Powdered or ground foods tend to have a higher Glycemic Index than their whole counterparts. For example rice flour has a higher Glycemic Index than rice in its whole form. Also, foods consumed in a liquid form tend to have a higher Glycemic Index than foods in a solid form (Jarvi *et al.*, 1999).

By using the correct cooking methods and correct choice of carbohydrates the speed of carbohydrate digestion and the resulting effect on blood sugar levels can be altered.

2.2.2.3 High amylose to amylopectin ratio

There are two variations of starch in food – amylose and amylopectin. Amylose results in a slower rate of digestion and therefor a reduced blood glucose response because its straight chain structure allows hydrogen bonds to be formed. Amylopectin is unable to form hydrogen bonds (Behall *et al.*, 1988). The hydrogen bonding of amylose limits swelling and gelatinization of the starch granule upon cooking.

Researchers discovered that the ratio of one to the other has an effect on the **Glycemic Index** value of the food (Behall *et al.* 1988; Holt & Brand Miller 1995). Amylopectin molecules are larger and more open and the starch is easier to gelatinise and digest. Thus foods that have little amylose and plenty of amylopectin in their starch has higher Glycemic Index factors such as wheat flour. Foods with a higher ratio of amylose to amylopectin have lower Glycemic Index factors (Leeds *et al.*, 1998).

Rice is a good example of a food that varies markedly in its Glycemic Index depending on its amylose content (Leeds *et al.*, 1998). Processed foods such as packaged breakfast cereals that have been manufactured under standard conditions show less variation than does raw horticultural products which are prepared and cooked under varying conditions.

2.2.2.4 Fibre

The fibre content of carbohydrate foods may lessen the glucose response of the food (Wolever, 1990; Trout *et al.*, 1991). The effect of fibre on the Glycemic Index factor of food depends on the **type** of fibre. Viscous, soluble fibres such as **guar** and **pectin** have been found to reduce the Glycemic Index while insoluble fibre, such as that found in **wheat** and brown rice seems to have little effect on the Glycemic Index. If the fibre is still intact it can act as a physical barrier to digestion and then the Glycemic Index factor will tend to be lower. Soluble fibres increase the **viscosity** of the intestinal contents and this will **slow down** the interaction between the starch and enzymes in the small intestine. This result in a shorter contact time of the glucose with the brush border of the small intestine (Leeds *et al.*, 1998).

Finely ground cereal fibre, such as in wholemeal bread, has no effect whatsoever on the rate of starch digestion and subsequent blood sugar response (Leeds *et al.*, 1998).

2.2.2.5 Sugar

It was previously mentioned that most foods containing simple sugars do not raise blood sugar levels any more than that of most complex starchy foods like bread or potatoes. The digestion of sugar produces only half as many glucose molecules as the same amount of starch.

The presence of sugar also restricts gelatinization of the starch by binding water during food manufacture. Table sugar or refined sugar has a Glycemic Index factor of only **65** whereas baked potato has a Glycemic Index value of **85**. Table sugar is a disaccharide (double sugar), composed of one glucose molecule coupled to one fructose molecule. Fructose is absorbed and taken directly to the liver where much of it is slowly converted to glucose. The blood sugar response to pure fructose is very small (G.I factor of **23**). Many foods containing large amounts of refined sugar have Glycemic Index factors close to 60. This is lower than the ordinary soft bread with a Glycemic Index factor averaging around 70. Sugars that naturally occur in food include lactose, sucrose, glucose and fructose in variable proportions, depending on the food. The overall blood sugar response to a food is very hard to predict on theoretical grounds because gastric emptying is slowed by increasing concentration of the sugars, whatever their structure (Leeds *et al.*, 1998).

2.2.2.6 Protein-starch and fat-starch interactions

The total amount of **carbohydrate**, the **amount and type of fat**, the fibre and salt content of a food are important considerations in the dietary management concerning the Glycemic Index (Truswell, 1992). CHO foods usually contain a combination of nutrients, and are usually consumed before exercise. Different nutrients are oxidized and absorbed at different rates (Horowitz & Coyle, 1993). Meals usually consist of a variety of foods with different Glycemic Index factors. We can still apply the Glycemic Index factor to these meals. The total carbohydrate content and the contribution of each food to the total must be known to calculate the total Glycemic Index value of the meal **(Table 2.8).**

Carbohydrates are commonly eaten with fat. In addition to being affected by the **preparation** and **structure** of the carbohydrate, the metabolic response to a meal may be manipulated by consuming carbohydrate together with other nutrients (e.g. fat, protein). Fats in conjunction with carbohydrate will alter the glycemic and insulinemic response to the whole meal (Welch *et al.*, 1987).

Fat slows down the rate of stomach emptying thereby slowing the digestion of starch. The fat both increases the viscosity of the effluent through the gastrointestinal tract and interferes with the enzyme-carbohydrate interaction (Welch *et al.*, 1987) thus **reduces the glycemic** response of carbohydrates (Leeds *et al.*, 1998). It should however be noted that large quantities of protein and fat may be required to depress the glucose response of a meal (Ercan *et al.*, 1994).

2.2.2.7 Anti- nutrients

Some foods contain substances that inhibit digestion of starch e.g. phytates, tannins (Trout *et al.*, 1991).

Table 2.8: Determining the Glycemic Index values of meals

Meal	**CHO g**	**% total CHO**	**Glycemic Index value**	**Glycemic Index contribution to meal**
Orange Juice 150 ml	12.5	26	53	26% × 53 = 14
2 Weet bix 30 g	21	43	75	43% × 75 = 32
Milk 150 ml	7	15	27	15% × 27 = 4
1 slice toast	13	27	70	27% × 70 = 19
TOTAL	**48**	**100**		**GI of meal = 69**

(Leeds et al., 1998)

Recent recommendations by the joint Food and Agricultural Organization (FAO)/World Health Organization Expert Consultation in a report entitled "Carbohydrates in Human Nutrition" supports the choice of Low Glycemic Index foods in healthy individuals (Jarvi *et al.,* 1999). There is evidence that dietary changes that involve replacement of foods with a High Glycemic Index by those with lower Glycemic Index values result in improved glycemic control and reduces fasting serum lipids in diabetic subjects. (Brand *et al.,* 1991)

Table 2.9: Glycemic Index of some popular foods

Food	**GI**	**Food**	**GI**	**Food**	**GI**
Glucose	**100**	Muesli, toasted	**43**	All bran cereal	**42**
Potato, baked	**85**	Noodles, 2 minute	**46**	Spaghetti	**41**
Corn flakes	**84**	Muffin, bran	**60**	Apple	**36**
Rice Krispies	**82**	Orange Juice	**57**	Pear	**36**
Rice Cakes	**82**	Potato, boiled	**56**	Chocolate milk	**34**
Potato, microwaved	**82**			Fruit Yoghurt,low fat	**33**
Jelly beans	**80**	Rice,white long grain	**56**	Split peas	**32**
Honey	**73**	Rice, brown	**55**	Milk, skim	**32**
Bread, White	**70**	Popcorn	**55**	Apricots, dried	**31**
Bread, whole wheat	**65 – 75**	Corn	**55**	Green beans	**30**
Cornmeal (maizemeal),cooked	**68**	Sweet potato	**54**	Banana, underripe	**30**
Fanta	**68**	Banana, overripe	**52**	Milk, whole	**27**
Table sugar	**65**				
Raisins	**64**	Peas, green	**48**		
Oatmeal	**42 - 75**	Baked beans	**48**		
Ice Cream	**36 - 80**	Orange	**43**		

(Leeds et al., 1998)

2.3 ENERGY METABOLISM DURING EXERCISE

The multitude of misconceptions associated with sports nutrition is often the result of attempts to apply **traditional** dietary practices to the specialized dietary needs of the athlete. Such an approach ignores the unique **metabolic demands** imposed by prolonged muscular effort.

The purpose of this chapter is to discuss the different energy systems involved in sport as well as the extent to which the various substrates are used for energy throughout a wide range of intensities.

2.3.1 Energy storage in the body

The immediate form of human energy in the body is available from the energy-rich compound **adenosine triphosphate (ATP).** It is a complex molecule constructed with high-energy bonds which releases energy rapidly, when split by enzyme action. ATP is used for all the energy-requiring processes of the cell, including muscle contraction. ATP is classified as a high-energy compound and is stored in the tissues in small amounts (McArdle *et al.*, 1991; Williams 1992). Approximately 5 millimoles (mm) of ATP are stored within each kilogram of muscle (Hultman, 1967). The total amount of ATP in the body at any one time is approximately 85 g (McArdle *et al.*, 1991). This amount provides only enough energy to perform maximum exercise for several seconds. ATP cannot be supplied to the cells directly from the blood or other tissues; it must be synthesized continuously within each cell. Some of this energy for ATP resynthesis is supplied rapidly and without oxygen by the transfer of chemical energy from another high-energy phosphate compound called **creatine phosphate (CP)** of which 15 mM are stored within the muscles (Hultman,, 1967). The cell's concentration of **CP** is about three to five times greater than that of **ATP** (McArdle *et al.*, 1991).

ATP may be formed out of **carbohydrate, fat, or protein.** This will take place after some complex biochemical changes within the body. Because ATP and CP are found in very small amounts in the body and can be used up in a matter of seconds, it is important to have adequate energy stores as a backup system. Your body stores of **carbohydrate, fat** and **protein** can provide you with ample amounts of ATP, enough to last for many weeks even on a starvation diet. **Table 2.10** summarizes the distribution of stored energy in the human body.

Table 2.10: Distribution of the major energy stores in the human body.

Energy Source	**Major storage form**	**Total body calories**
ATP	Tissues	1
PC	Tissues	4
Carbohydrate	Serum Glucose Liver Glycogen Muscle Glycogen	20 400 1500
Fat	Serum free fatty acids Serum triglycerides Muscle triglycerides Adipose tissue triglycerides	7 75 2500 80 000
Protein	Muscle protein	30 000

(Williams, 1992)

Carbohydrate is stored in limited amounts as blood glucose, liver glycogen and muscle glycogen. Depending on the diet and activity pattern, ± 10 – 30 g glycogen are stored in each kilogram of skeletal muscle; thus ± 8400 kJ are available for exercise. Additionally ± 80 g glycogen is stored in the liver. Liver glycogen can be hydrolyzed back to glucose and transported via the blood to the muscles for oxidation (Coyle, 1995).

Fats form part of the largest form of **stored energy** in the body. It is stored as triglycerides in both the muscle tissue and adipose (fat) tissues. The supply of triglycerides and free fatty acids (FFA) in the blood are a limited supply. The protein of the body tissues, particularly the muscle tissue, is a large reservoir of energy but is **not** used under **normal circumstances** (Coyle, 1995).

2.3.2 The human energy systems

Stored energy must undergo certain **biochemical reactions** in order for this energy to be available as **ATP** for muscular contractions and movement. These biochemical reactions serve as a basis for classifying human energy expenditure by three systems: the 1) **ATP-CP system,** 2) **lactic acid system** and the 3) **oxygen system** (Williams,1992). **Figure 2.3** represents the three energy systems involved in the production of **ATP**.

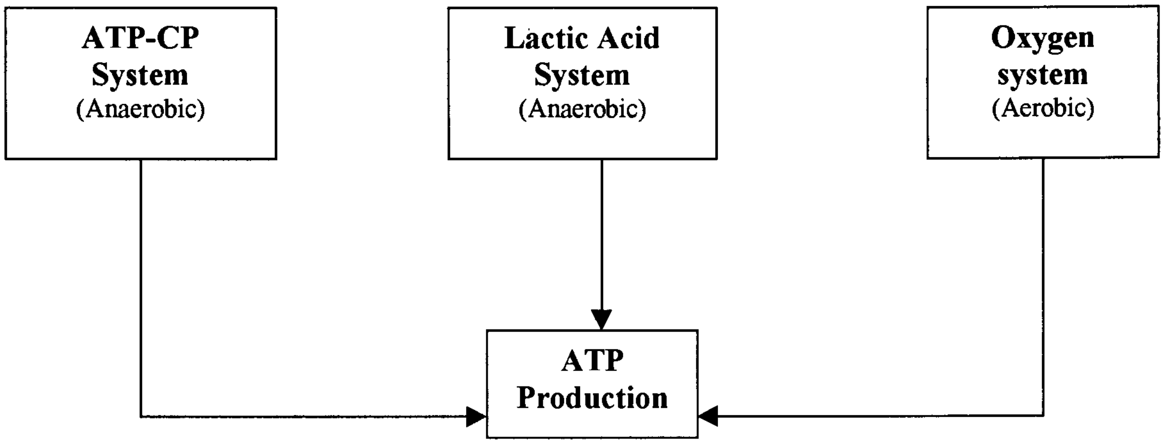


Figure 2.3 Three energy systems involved in ATP production.

2.3.2.1 Immediate energy: The ATP-CP System

High intensity exercise of short duration such as sprints, require an immediate and rapid supply of energy. This energy is provided almost exclusively from the high-energy phosphates **ATP** and **CP** stored within the specific muscles activated during exercise (McArdle *et al.*, 1991; Prentice, 1994). The **ATP-CP** system is also known as the **phosphagen system** because both adenosine triphosphate (ATP) and creatine phosphate (CP) contain phosphates (Williams, 1992). ATP is the immediate source of energy for almost all body processes, including muscle contraction (Volek et al., 1997).

As was previously mentioned this high-energy compound, stored in the muscles, rapidly releases energy when an electrical impulse arrives in the muscle (Williams, 1992). CP, a high-energy compound, present in the muscles, assist in the **forming** of ATP as it is used. CP is also in short supply and needs to be replenished if used (Hole, 1993).

All sports require the utilization of the high-energy phosphates, but many activities rely almost exclusively on this means for energy transfer. The ATP-CP system is critical to energy production. Because these phosphagens are in short supply, any all-out exercise for 5-6 seconds may deplete the supply in a given muscle (Williams, 1992).

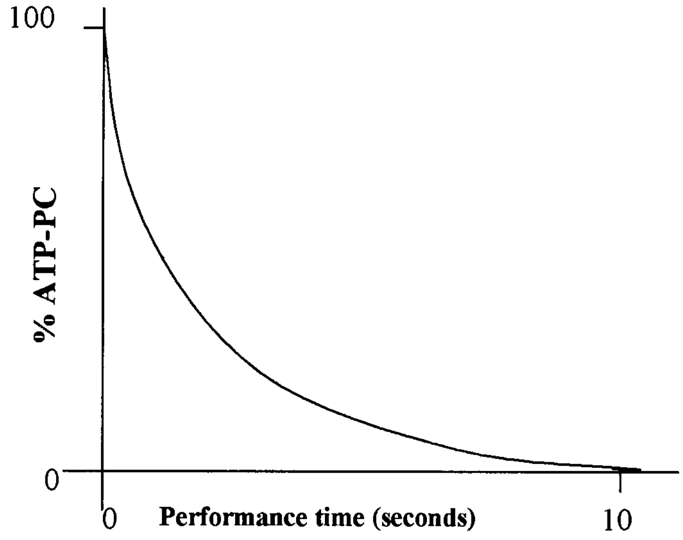


Figure 2.4 The percentage of energy (in the form of ATP) contributed by the ATP-CP system during physical activities (Burke, 1995).

For sustained exercise and for recovery from an all-out effort, additional energy must be generated for ATP replenishment. In such a situation stored carbohydrates, fats, and proteins are available to continually recharge the phosphate pool (McArdle, 1991). **Figure 2.4** demonstrates the contribution of the ATP-CP system during intensive exercise lasting 10 seconds.

2.3.2.2 Short term energy: The Lactic Acid system

The lactic acid system cannot be used directly as a source of energy for muscular contraction, but it can help **replace** ATP rapidly when necessary (Williams, 1992). The high-energy phosphates must continually be resynthesized at a rapid rate for **strenuous exercise** to continue beyond a brief time period (McArdle *et al.*, 1991). During strenuous exercise, the energy to phosphorylate ADP comes mainly from **glucose** and **stored muscle glycogen**. To be used for energy, muscle glycogen must be broken down in a series of reactions to eventually form ATP. This process is called **glycolysis.**

One of the major factors controlling the metabolic fate of muscle glycogen is the availability of **oxygen** in the muscle cell. If oxygen is available, a large amount of ATP is formed. This is known as **aerobic** glycolysis. If little or no oxygen is available, then little ATP is formed and **lactic acid** is a **by-product**. This is known as **anaerobic**, or without oxygen glycolysis.

The mechanism of lactic acid formation is efficient in a way that it allows time for the rapid production of ATP through substrate-level phosphorylation, even though the oxygen supply is inadequate or the energy demands outstrip the capacity for ATP resynthesis aerobically. This anaerobic energy for ATP resynthesis can be thought of as reserve fuel that is brought into use by the cyclist to "jump" for the last 300 meters to the line. It is also of critical importance in supplying the rapid energy above that available from the stored phoshagens during a 500 to 800 meter sprinting exercise. The most rapidly accumulated and highest lactic acid levels are reached during exercise that can be sustained for 60 to 180 seconds. As the intensity of "all-out" exercise decreases, thereby extending the work period, there is a corresponding decrease in both the rate of build-up, and the final level of lactic acid (McArdle *et al.*, 1991).

The **ATP-CP** system as well as the **lactic acid** systems are able to produce ATP rapidly and are used in events characterized by **high intensity levels** occurring for short periods.

The lactic acid system has the advantage of producing ATP rapidly. Its capacity is however limited in comparison to **aerobic glycolysis**, because only about 5 % of the total ATP production from muscle glycogen can be released. Lactic acid is also produced as a **by-product** and may be involved in the onset of **fatigue**. Lactic acid releases hydrogen, which cause an increase in the acidity within the muscle cell and thus disturbing the normal cell environment. The functions of enzymes which are responsible for muscle contraction in the muscle cell may be impaired as a result of lactic acid formation (Williams, 1992). **Figure 2.5** demonstrates the energy contribution of the Lactic Acid system for physical activities.

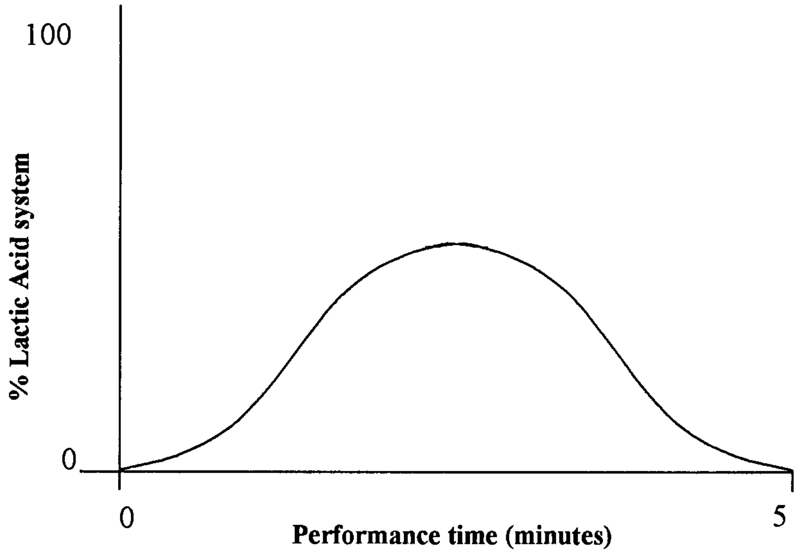


Figure 2.5 The percentage of energy (in the form of ATP) contributed by the lactic acid system for physical activities. (Burke, 1995)

2.3.2.3 Long-term energy: The aerobic system.

Although the energy released in glycolysis is rapid and does not require oxygen, relatively little ATP is resynthesized in this manner. Consequently, aerobic reactions provide the important final stage for energy transfer, especially if intensive training proceed beyond several minutes (McArdle *et al.*, 1991).

The aerobic system (O_2 system) makes the most significant contribution to energy production during **long-distance events** such as **road races** and long **time trials**. The aerobic system also uses muscle glycogen as fuel. During events that last more than 20 minutes, it uses fat. This system requires oxygen to function and goes through more than 20 steps within the muscle cell before ATP is produced. For this reason, the aerobic system is a **slower producer of ATP** during exercise although it produces a greater amount (Burke, 1995(a)). **Figure 2.6** represents the contribution of the O_2 system for ATP production.

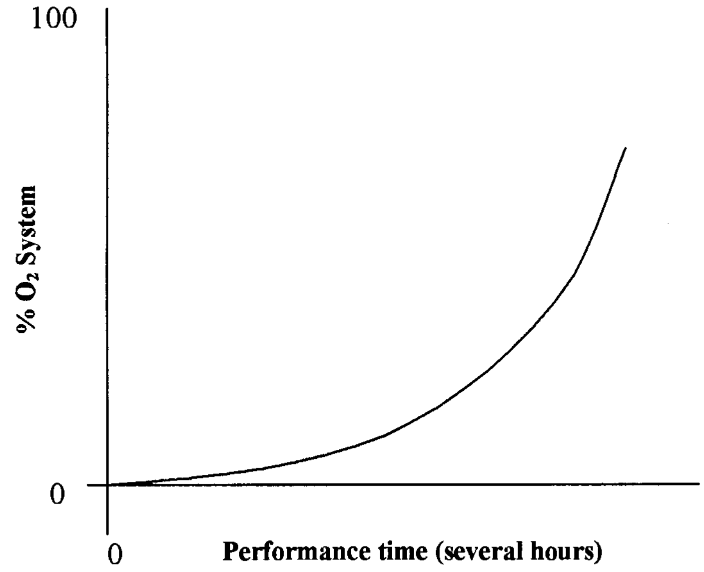


Figure 2.6 The percentage of energy (in the form of ATP) contributed by the aerobic (O_2) system for physical activities. (Burke, 1995)

It should be noted that all three energy systems – **ATP-CP, lactic acid,** and **oxygen – systems** are used in one way or another during most cycling events. The most important factor determining which energy system will be the dominant one is the **intensity** of the exercise, which is the **rate, speed** or **tempo** at which the cyclist compete. In general, the faster you do something, the higher your rate of energy expenditure and the more rapidly you must produce **ATP** for muscular contraction. Very rapid muscular movements are characterized by high rates of power production (Williams, 1992). **Table 2.11** represents different cycling events which relies on different energy systems (Burke, 1986).

Table 2.11: Various cycling events and their predominant energy sources.

Event	Performance time	Speed (ATP-PC strength) (%)	Anaerobic capacity (ATP-PC and lactic acid systems) (%)	Aerobic capacity
	Hours and minutes			
100-mile road race	3:55 – 4:10	-	5	95
100K criterium	2:05 – 2:15	5	10	85
100K team time trial	2:10 – 2:20	-	15	85
25-mile time trial	0:52 – 0:60	-	10	90
25-mile criterium	0:50 – 0:60	5	15	80
	Minutes and seconds			
10 mile points race (track)	20:00 – 25:00	10	20	70
4000-meter individual pursuit	4:45 – 5:05	20	55	25
Kilometer	1:07 – 1:13	80	15	5
Match sprints	0:11 – 0:13	98	2	-

(Burke, 1986)

2.3.3 Muscle fibres of the human body

The human body possesses several different types of muscle fibres, and their primary differences are in the **ability to produce energy**. By means of surgical biopsy, which extracts about 20 to 40 mg of tissue (the size of a grain of rice) biochemists and exercise physiologists have studied the functional and structural characteristics of human skeletal muscle. This study has led to the identification of two distinct type of muscle fibres **(Type I and Type II)**, the proportion of which probably remains fairly constant throughout life (Karlsson & Jacobs, 1982).

Type I is called a slow-twitch red fibre, and it can produce energy primarily by aerobic processes (the oxygen system). This fibre is also referred to as the slow-oxidative **(SO)** fibre (Williams, 1992). This fibre has a relatively slow contraction speed. The capacity of Type I fibres to generate ATP aerobically is intimately related to their numerous and large mitochondria and to the high levels of enzymes required to sustain aerobic energy transfer. Fatigue associated with long distance cycling, usually occurs in the **slow-twitch (Type I)** fibres.

Type II is called a **fast-twitch (FT)** fibre. This fast-contracting fibre has two basic subdivisions **(Type IIa and IIb)** and possesses a high capability for the anaerobic production of **ATP** during **glycolysis**. These fibres are activated during change-of – pace activities such as sprinting for the line (McArdle *et al.*, 1991). **Type IIa** is known as a fast-twitch **red fibre**; it also can produce energy anaerobically via the **lactic acid system**. It is also known as the fast oxidative glycolytic **(FOG)** fibre. **Type IIb fibre,** is a fast-twitch white fibre that produces energy primarily by anaerobic processes and is also known as the fast glycolytic **(FG)** fibre. **Type II fibres** also may use the **ATP-CP system** at a faster rate than **type I** fibres (Williams, 1992).

It should be noted that the demands placed on **muscle glycogen** are not equally shared by all the different types of **fibres** in an exercising muscle. It has been shown that during prolonged exercise at **less** than **70%** to **80% of** $\mathbf{V_{O2\ max}}$, glycogen depletion is greatest in the **slow twitch (type 1)** fibres and therefor these fibres are given the greatest responsibility for fatigue which develops in this type of activity (Costill *et al.*, 1973).

The contribution of the four major substrates (muscle glycogen, muscle triglyceride, plasma FFA and plasma glucose) to total energy expenditure during exercise at a wide range of intensities is shown in **Figure 2.7**. This data represents recent studies using stable isotope infusion to quantify substrate turnover (Romijn *et al.*, 1993). These measures were taken after 30 min of exercise in the fasted state in endurance-trained people. Exercise duration, diet, and state of training has an influence these responses.

Plasma triglycerides are a potential source of energy for muscle. However, triglyceride entry into muscle is catalyzed by lipoprotein lipase, which is not capable of meeting more than a small percentage of the energy needs of strenuous exercise (Oasci *et al.*, 1990).

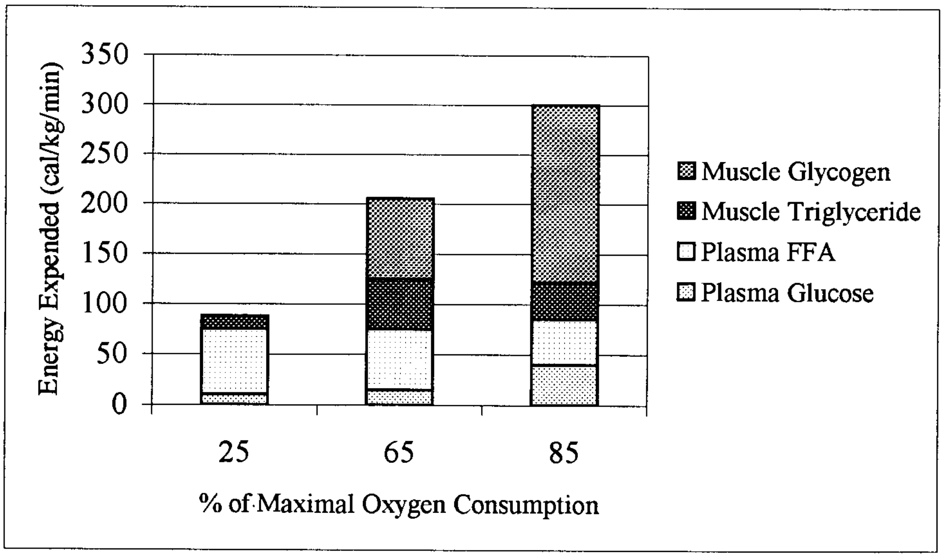


Figure 2.7. Contribution of the four major substrates to total energy expenditure.

2.3.4 Low intensity exercise

During prolonged exercise, the fuel reserves of the body are mobilized to provide the energy required for muscular contraction. Almost all the energy for exercise at a **low intensity** (25% VO_{2max}), comparable to walking, is derived from **plasma fatty acids,** with an additional small contribution from blood glucose when performed in the fasted state (Coyle, 1995). **Protein** is not metabolized during muscular contraction in substantial amounts unless the person is starved or bodily carbohydrate reserves are maintained at low levels (Sherman & Lamb, 1988).

Adipose tissue is the largest fuel reserve in the body. A person weighing 70-kg with 15% body fat has approximately **390 MJ** energy as stored fat. Stored fat has significant energy potential for exercise. Fat oxidation **cannot** typically support energy demands which is **higher** than 60% of VO_{2max} because of the slow rate of mobilization and the slow diffusion of fat from blood into muscle during exercise (Sherman, 1995).

The amount of energy stored in the form of **triglycerides** within adipocytes throughout the body is large, totalling 200 – 625 MJ (±50 000 – 150 000 kcal) in men and women with a normal body composition of 10 and 30% body fat (Sherman, 1995).

Triglycerides which is stored in adipocytes can be hydrolyzed (i.e., lypolysis) into glycerol and **free fatty acids**, the latter must bind to the protein carrier albumin for transport via the blood circulation (i.e.; **plasma fatty acids**) to the exercising muscles. Additional triglyceride, amounting to ±12 000 – 20 000 kJ, is stored in droplets within the **muscle fibres** and is available for oxidation following intramuscular lipolysis. Therefore, the two forms of fat for oxidation by muscle during exercise are **plasma fatty acids** and **intramuscular triglycerides** (Coyle, 1995).

In addition to the FFA that can be generated by the breakdown of **triglyceride** in **adipose tissue**, a portion of the lipids oxidized during prolonged exercise is derived from plasma and **intramuscular triglyceride hydrolysis**. While the direct contribution of plasma triglyceride is relatively small during exercise, intramuscular lipid stores have been shown to decrease **30%** and **50%** during **30** and **100 km** races, respectively (Costill & Miller, 1980). Thus it appears that optimal endurance sports performance is strongly influenced by the **availability** of **CHO** and **fats.**

Despite the large amount of potential energy in body fat stores, the rate at which they can be oxidized is limited and thus carbohydrate metabolism is needed to provide the additional substrate for oxidation as the intensity of exercise is increased. Fat oxidation can only provide about **one-half** of the energy needed for exercise at **70%** **VO_{2max}** and no more than **one-third** of the energy needed for more strenuous exercise lasting 10 – 30 min (**i.e., > 85% of VO2max**). This emphasizes the need for adequate muscle glycogen and blood glucose concentrations for more strenuous exercise. (Coyle, 1995). The reason for the muscle's limited ability to oxidize fat, and thus its dependence on carbohydrate, is still not clear. One line of thinking is that the limitation is in the transport of fatty acids into the mitochondria (Coyle *et al.,* 1986).

When carbohydrate oxidation declines as the result of depletion of muscle glycogen and hypoglycemia, people are unable to oxidize fat at rates sufficient to meet the energy requirements of even moderate-intensity exercise (60 – 75% VO_{2max}). As people fatigue, they must **reduce** the work rate to the lowest intensity (i.e., **30 – 50%** VO_{2max}) that matches their ability to predominantly oxidize fat (Coyle *et al.*, 1983).

2.3.5 Moderate intensity exercise

When exercising at **moderate intensities** (i.e.; 65% VO_{2max}), comparable to the pace chosen when cycling for 2 – 3 h, total fat oxidation increases despite the reduction in the rate of appearance of fatty acids. The substantially higher rate of total fat oxidation compared with entry of fatty acids into plasma reflects an increased oxidation of intramuscular triglycerides. In fact, during moderate-intensity exercise in endurance-trained people, plasma fatty acids and intramuscular triglyceride contribute equally to total fat oxidation (McArdle *et al.*, 1991).

One of the major and most important adaptations to endurance training is the increased ability to metabolize fat. Costill *et al.* (1980) have studied marathon runners who derived over **75%** of their energy from **fat metabolism** during 60 minutes of treadmill running at 70% of $VO_{2max.}$ This data was based on the respiratory exchange ratios of the subjects. Although skeletal muscle demonstrates an enhanced capacity for free fatty acid (FFA) oxidation following endurance training, the rate of FFA utilization is controlled, in part, by its **concentration in plasma** (Havel *et al.*, 1966). The increase of FFA **mobilization** from adipose tissue elevates **plasma FFA**, which subsequently accelerates the rate of FFA oxidation in the exercising muscle. This mechanism of elevated plasma FFA may result in the sparing of muscle glycogen and generally improve endurance performance (Costill *et al.*, 1978).

The energy used to power steady-state aerobic exercise in people is derived predominantly from the oxidation of **carbohydrate** and **fat**. During light and moderate exercise, carbohydrates supply about one-half of the body's energy requirements (Coyle, 1995).

2.3.6 High-intensity exercise

Most cyclists often train and compete at intensities higher than **70% VO_{2max}**, a source of fuel other than fat or protein must be available. That source of fuel is **carbohydrate** (Sherman & Lamb, 1988). As was previously mentioned carbohydrate is stored as **blood glucose, liver glycogen** and **muscle glycogen.** The average person has approximately 5 MJ of **carbohydrate** stored as energy. Stored carbohydrate is located in **muscle** (**79%** of the total) and **liver** (**14%** of the total) in the form of **glycogen**, or in the **blood** (**7%** of the total) in the form of **glucose** (Sherman., 1995). In normal circumstances, oxidation of bodily protein does not contribute significantly to energy production. (Coyle, 1995).

High-intensity exercise (**85%** of VO_{2max}) is performed at a level that promotes relatively high rates of muscle glycogen breakdown and thus carbohydrate oxidation (Coyle, 1995). When the flow of oxygen to the working muscle does not adequately meet the demands for oxidative metabolism especially during the early minutes of exercise, there is greater reliance on **CHO** for energy (Sherman & Lamb, 1988). Carbohydrate is the only nutrient whose stored energy can be used to generate ATP **anaerobically**. This is important in vigorous exercise that requires rapid release above levels supplied by aerobic metabolic reactions. In this case, stored glycogen and blood glucose must supply the main portion of energy for ATP resynthesis.

High-intensity exercise represents the greatest intensity that a person can maintain for a **30 – 60 min** period, with great effort and with the sensation of fatigue in the exercising muscles. The high exercise intensity results in accelerated rates of **lactic acid** production, which accumulates in the blood and muscles. At high intensities, carbohydrate oxidation provides more than **two-thirds** of the needed energy with the remainder coming from **plasma fatty acids** and **intramuscular triglycerides** (Coyle, 1995).

If carbohydrate was the only fuel metabolized during moderate intensity exercise, it would be depleted in **2 hours**. Thus, because of the limited stores of stored carbohydrate and because carbohydrate appears to be the **preferred fuel** that is metabolized to support exercise at intensities **higher than 65% VO_{2max}** , it is imperative that bodily stores of carbohydrate be preserved or maintained by consuming adequate amounts of carbohydrate before, during , and immediately after exercise *(Refer to chapter 2)*. If exercise is undertaken at intensities **higher than 65% of VO_{2max}** for 60 min or more, **muscle glycogen** depletion have a negative effect on exercise performance, whereas if the exercise duration is 90 – 120 min, **liver glycogen** and a **lowering of blood glucose** may limit the quality of exercise (Sherman., 1995).

Blood borne glucose is another important contributor to the metabolic **CHO pool.** At rest the uptake of glucose accounts for **less than 10 %** of the total oxygen consumption by muscle. During moderate to strenuous exercise, however, the net glucose uptake by the leg muscles increases **10- to 20-fold** above the resting values (Wahren *et al.*, 1971). If the exercise time is extended, the amount of energy derived from blood glucose increases and may account for 75 % of the muscle's carbohydrate metabolism (Wahren et al., 1971).

The large drain on blood glucose necessitates an increase in **hepatic glucose output**, to prevent exertional hypoglycemia. Since the liver is the major contributor of glucose to blood, the increased demands imposed by muscular activity result in a rapid reduction in liver glycogen stores and a reliance on **gluconeogenesis** (Sherman & Lamb, 1988).

CHAPTER 3 - METHODS AND PROCEDURES

3.1 SUBJECTS

Twelve healthy, male and female cyclists, whose individual characteristics appear in **Table 3.1**, participated in the study. The data of 11 of the 12 original subjects were recorded since mechanical problems prevented accurate data recording of one of the subjects.

The Department of Human Movement Science of the University of Pretoria (South Africa) approved the protocol. Subjects were well informed about the test procedures and signed a form of consent of the University of Pretoria *(See appendix A).*

The subjects were selected according to their training distances and level of participation in competitions. The subjects cycled an average of 340 km/week before the start of the study. All of the subjects competed on national and provincial level in the year of the study. The study wasn't conducted in peak cycling season. This ensured minimal interference with the testing procedures due to cycling events.

Trained cyclists were used as subjects and a specific requirement was that their training schedule should be constant throughout the **two weeks** of the research period. Each subject received a record sheet to assist them in the accurate recording of their daily training during the first week *(See appendix B).* This data sheet included daily training hours, training intensity, sleeping hours and resting heart rate. The subjects took their resting heart rates in the mornings before getting out of bed. The recording of the first week's training ensured that the second week's training was the same intensity and duration.

Trained subjects oxidise more fat and less carbohydrate than **untrained** subjects when performing submaximal work at the same absolute intensity (Askew, 1984). This increased capacity to utilise energy from fat conserves crucial muscle and hepatic glycogen stores and can contribute to increased endurance (Askew, 1984) which **motivates** the use of **trained cyclists** instead of sedentary subjects.

Active athletes tend to be more sensitive to **insulin** than sedentary people (Heathe *et al.*, 1983). This was considered to be an important variable since the blood glucose response was constantly measured throughout the study procedures.

Table 3.1: Individual characteristics of subjects

Gender	AGE	LENGTH	MASS kg	FAT %	$VO_{2\,max}$	Somatotype	Resting Blood glucose
Male	27	179.5	73	9.37	53.8	1.8 – 5.8 – 3.1	5.3
Male	29	174	78	10.14	51.2	2.1 – 6.1 – 1.2	5.6
Male	25	175.5	70	7	60.2	1.5 – 4.6 – 2.8	5
Male	28	167.5	71	14.33	46.5	3.8 – 6.3 – 1.2	6
Male	26	179	76	12.17	61	3.1 – 5.0 – 2.6	4.1
Male	21	178	74	9.5	53.6	2.2 – 4.8 – 2.7	4.4
Male	19	193.7	79.8	10.5	57.9	2.1 – 3.8 –4.6	4.7
Male	20	176	65	7.74	59	1.6 – 5.2 – 3.7	4.5
Male	26	184	83.6	7.86	53.6	1.9 – 6.4 – 2.4	4.1
Male	21	182	81.1	9.16	52.6	2.1 – 5.8 – 2.4	5.2
Female	36	169.5	69.5	14	46.1	3.4 – 4.1 – 1.8	4.5
Average	25.27	178.06	74.64	10.16	54.14	2.33-5.26-2.59	4.85
SD	4.94	7.14	5.65	2.44	5.06	0.76-0.89-1.01	0.62

In view of the purpose of the study, all the subjects' **eating habits** were assessed before deciding on the contents of the test meal. This excluded possible **allergic** reactions or digestive problems which could occur. Complete diet analysis of each subject occurred before the onset of the study *(See Table 3.3 & 4.2).* Daily training was recorded before the onset of the study for the purpose of calculating the energy demands of the subjects to ensure the correct dietary prescription.

3.2 PROCEDURES

The total test period consisted of 14 days which included **two different dietary interventions** of 7 days each. Each subject performed **three** exercise trials during the test period.

3.2.1 VO_{2max} exercise trial

The **first** trial consisted of a complete $VO_{2\ max}$ evaluation and was followed by two submaximal exercise (65 – 70 %) trials which were performed at a set target heart rate. Subjects abstained from any physical activity 24 hours before each trial to ensure homogeneity amongst all the trials.

Subjects reported at the laboratory one hour before the test and weren't allowed to eat or drink anything except water for at least 2 hours. The exercise trial consisted of a complete $VO_{2\ max}$ evaluation on a **Technogym CPR Spintrainer (Photo 2)**. Two different cycle simulators (manually adjustable - and an automatic Technogym spintrainer) were compared before the start of the study **(Table 3.2).** This comparison was done to determine the suitability of the equipment for the specific needs of the testing procedures. It was decided that the **Technogym CPR Spintrainer** should be used for the study. It allowed the laboratory assistants to continue with the procedures without interference such as the manual adjustment of the resistance every 3 minutes.

Table 3.2: Comparison between manual and automatic cycling simulators.

Manually adjustable cycling simulator.	**Automatic cycling simulator.**
1. Cannot be calibrated. Use prescribed tyre pressure.	1. Can be calibrated for weight, bicycle type and tyre pressure.
2. Manual adjusting of resistance.	2. Automatic adjusting of resistance according to target heart rate.
3. No heart rate monitor connected to apparatus.	3. Heart rate monitor connected to apparatus.
4. Adjust resistance to own protocol.	4. Programmed with various protocols.
5. Built in fan.	5. Built in fan.

Anthropometrical data of the subjects were gathered before the $VO_{2\ max}$ trial **(Table 3.1).** Weight and height were measured with a **SECA** scale and length meter. Skinfold measurements were taken with a **Harpenden skinfold caliper.** The anatomical points of measurement are shown in Appendix C and the data collection form in Appendix B. A standard data collection protocol was used in all the trials which included a 10 minute resting **RER** recording (Respiratory exchange ratio) **(Medgraphics Cardiopulmonary Diagnostic system)** , resting heart rate, blood pressure, blood lactate and blood glucose. Lactate blood sampling were recorded with an **Accusport Lactate Monitor.** Glucose blood sampling were measured with an **Accutrend Glucose Monitor**. The blood samples were gathered from a single prick wound on the finger. Care was taken to allow only a single drop of blood to come into contact with the lactate and glucose strips.

Subjects used their own bicycles, which were mounted on the **Technogym spintrainer (Photo 1)**. The spintrainer was calibrated for each individual subject's weight as well as bicycle type and tyre pressure. The calibration of the spintrainer is a standard procedure which was repeated with all the subjects.

The Conconi (Conconi *et al.*, 1996) protocol was used for the first exercise trial (complete VO_{2max} test). Subjects started to cycle at a speed of **20 km/h** after which the speed was automatically increased every **3 minutes** with **2 km/h** until **36 km/h** and then with **1 km/hour** until exhaustion. Cycling continued until the subjects couldn't maintain the required speed for longer than **15 seconds**. Blood samples were taken with 3 minute intervals.

The first test determined the resting and training RER, heart rate, blood glucose response, $VO_{2\ max}$, lactic threshold and maximum heart rate. These data were used to determine the **Target Heart rate** for the following two trials which were performed at **65 – 70 %** of $VO_{2\ max}$. The data collection form can be seen in **Appendix B** *(See Table 3.6 for a summary of the testing procedures).*

The **$VO_{2\ max}$** trial was used for initial data collection and also served the purpose of **familiarising** the subjects with the equipment, especially the mouthpiece of the oxygen analyser.

3.2.2 Post-dietary intervention trials.

The first dietary intervention started directly after the $VO_{2\,max}$ trial. The next two trials can be described as the **post dietary intervention trials** and are referred to as **Test 1 and Test 2** in this study. The $VO_{2\,max}$ trial is a separate and independent test because it was used only for the purpose initial data collection.

Test 1 and **Test 2** were separated by 7 days. The two dietary periods **(7 days each)** had the same amount of **kcal, carbohydrates, proteins** and **fats** according to each subject's **weight** and **energy expenditure (Table 3.3)**. This ensured homogeneity of muscle glycogen for all the subjects. The diets differed in their Glycemic Index values of the pre-exercise meals **(Table 3.4, 3.5)**.

The response of the subjects to the **pre-exercise meal** provided the most significant data. It reflected a competition situation in which the subjects prepared themselves accordingly. It is not uncommon for endurance athletes to follow a high carbohydrate diet **(70% of total energy)** as part of the preparation for events. Most researchers are in no doubts that adaptation to a high carbohydrate diet before exercise (Karlsson & Saltin, 1971) can enhance exercise performance. The amount of carbohydrate ingested before the exercise trial was equal to **2.1 g** of **available carbohydrate** for each kilogram of body mass.

Table 3.3: Contents of the 7 day preparation diets

Carbohydrates	Proteins	Fats
75.9 %	15.7 %	8.35 %

Table 3.4: Test 1 - pre-exercise meal

Food	**Carbohydrate /100 gram**	**Glycemic Index /50 gram of CHO**
1. Corn flakes	83	84
2. Skimmed milk	4.9	32
3. Raisins	73.8	64
4. Honey	77.2	73
5. Orange Juice	12.8	57

Table 3.5: Test 2 - pre-exercise meal

Food	**Carbohydrate /100 gram**	**Glycemic Index /50 gram of CHO**
1. Oats (instant)	63.3	66
2. Dates	75	50
3. Bananas (underripe)	22.7	52
4. Grape Juice	16	48

During the **first dietary intervention** subjects followed a prescribed diet, which provided the same amount of carbohydrates **(g/kg of body weight)** for all the subjects. This ensured homogeneity amongst all the subjects. The diets reflected common eating patterns of endurance athletes as part of the preparation for events. The high carbohydrate diet **(Table 3.4)** included a pre test meal with a **High Glycemic Index (Table 3.5)** which was consumed 60 minutes before **Test 1**.

Subjects reported at the laboratory 30 minutes before the test. Pre test data collection simulated the $VO_{2\ max}$ procedure except for the anthropometrical measurements **(Table 3.6).** Subjects started to cycle at a set target heart rate (65 – 70 % of $VO_{2\ max}$) which was calculated during the $VO_{2\ max}$ evaluation. The subjects were allowed to **self-select gears** and **cadence** throughout the exercise trial. The Spintrainer automatically adjusted the resistance to keep the subjects at their prescribed target heart rates.

Blood samples were taken every 10 minutes **(Photo 3)** for the measurement of blood glucose and blood lactate levels. The subjects were encouraged to drink small amounts of water after each blood sampling to prevent heat stress and dehydration. The temperature of the laboratory was maintained at **22 °C**. Further cooling effect was created by the fan of the Technogym spintrainer. The subjects indicated RPE **(Rate of Perceived Exertion)** every 10 minutes after the blood sampling *(See **Appendix B** for RPE scale).*

The second dietary intervention started directly after this **Test 1.** The diet contained the exact same amount of carbohydrates/kg body weight as the first diet, but the **Glycemic Index factors** of the pre test meal were lower **(Table 3.5)**. The test procedures and data collection of Test 2 was an exact replica of Test 1. Each subject's response to the second dietary intervention was compared with the response to the first dietary intervention. It was therefor very important to ensure that Test 1 and Test 2 follow the same procedures.

In a number of studies, subjects have ingested carbohydrates prior to the commencement of exercise. These have ranged from 5 min (Winder et al., 1985), 20 min (Coyle *et al.*, 1983), 30 min (Alberici *et al.*, 1993; Horowitz *et al.*, 1993), 40 min (Ahlborg & Bjorkman., 1987), 45 min (Hargreaves 1985; Gleeson *et al.*, 1986), 60 min (Sherman *et al.*, 1991; Guezennec *et al.*, 1993), 180 min (Jandrain *et al.*, 1984) to 240 min (Sherman *et al.*, 1989) before exercise. Of these studies, a number measured oxidation of the ingested carbohydrate (Guesennec *et al.*, 1989). In this study 60 min were allowed after the pre-exercise meal to allow sufficient time for absorption.

The most common variables measured have been **exercise time** to exhaustion, the **respiratory exchange ratio (RER)** (Bonen *et al.*, 1981; Wilber & Moffat, 1992), blood glucose concentration, ratings of perceived exertion (RPE) and changes in muscle glycogen content. More specific variables are needed to indicate the influence on performance. Trained cyclists were used in this study and specific performance indicators included: total **distance** covered, average **speed** and **rate of perceived exertion (RPE).** Previous studies didn't use exercise **performance** as variables (Horowitz & Coyle, 1993).

3.2.3 Subject Reports

Each subject received a detailed report on his performance after completing the study *(See Appendix D).* The following reports were included: a) Anthropometrical data, b) Physiological changes, c)VO_{2max} report and d) Lactic Threshold report.

Photo 1: Patient setup

Photo 2: Oxygen analyzer and cycle simulator

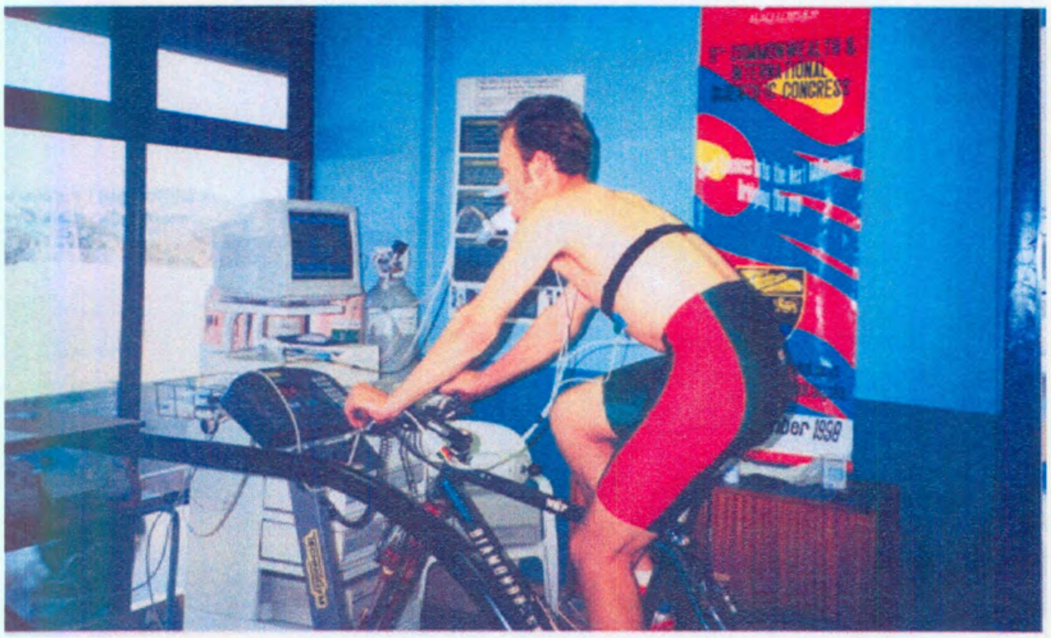


Photo 3: Blood Glucose Measurement

Table 3.6: Study procedures

VO_{2max} Trial	First Dietary Intervention	Test 1: Exercise at 65 – 70% of VO_{2max}	Second Dietary Intervention	Test 2: Exercise at 65 – 70% of VO_{2max}
• **Data collection:** Somatotype Fat % Resting Blood Pressure Resting RER Resting Heart Rate Resting Blood Glucose Resting Blood Lactate • **Complete VO_{2max} (Conconi protocol)** Maximum Heart Rate Blood Glucose (3min intervals) Blood Lactate (3min intervals) - Determine Lactic Threshold.	• **7 day diet intervention** High Glycemic Index foods 2.1g/CHO/kg of body weight for all the subjects. **Diet consist of:** 75.9 % CHO, 15.7 % protein, 8.35 % fat Preparation methods of the food include: Steam, Boil, Microwave and Dry Roast	• **Pre-exercise meal** Ingestion of test meal 60min before the test. • **Data collection** Resting Blood Pressure Resting RER Resting HR Resting Blood Glucose Resting Lactate • **Steady state exercise at 65 – 70% of VO_{2max}** Blood Glucose and Lactate measurements every 10 minutes. RPE every 10 minutes Exercise below Lactic Threshold.	• **7 day diet intervention** Low Glycemic Index foods 2.1g/CHO/kg of body weight for all the subjects. **Diet consist of:** 75.9 % CHO, 15.7 % protein, 8.35 % fat Preparation methods of the food include: Steam, Boil, Microwave and Dry Roast	• **Pre-exercise meal** Ingestion of test meal 60min before the test. • **Data collection** Resting Blood Pressure Resting RER Resting HR Resting Blood Glucose Resting Lactate • **Steady state exercise at 65 – 70% of VO_{2max}** Blood Glucose and Lactate measurements every 10 minutes. RPE every 10 minutes • Exercise below Lactic Threshold

CHAPTER 4 – RESULTS

4.1 DIET ANALYSIS

The diet **(Table 4.1)** analysis shows a similarity to a previous study done by Garcia – Roves *et al.* (1998) who found that cyclists consume approximately **60.0%** carbohydrates, **25.5 %** protein and **14.5 %** fat during extreme endurance competition periods such as the "Tour de France" *(Refer to chapter 2* ***Table 2.1****).*

Results of the 7 – day diet analysis shows that there is an overall insufficient intake of calories **(Table 4.2)** as well as the following vitamins: **B1, B2, B3, B6, B8, B9, B12, C and E**. The following minerals were also below the recommended daily allowance: **copper, iodine, selenium, chromium, iron and potassium (Table 4.2).** Note that these intakes are not deficient, but rather below the optimal amount/day which is recommended for endurance athletes.

Table 4.1: Dietary information of subjects

	Carbohydrate intake Gram	**Protein intake gram**	**Fat intake gram**	**Total Kcal Intake**
Average for all subjects.	477.55	118.60	108.05	3495.67
Percentage of total Kcal intake.	67.8	16.8	15.4	100
SD	83.91	33.53	17.75	

Table 4.2 Diet analysis for Minerals and Vitamins

	Subjects											
Nutrient	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Vit A	▨	▨	▨	▨	▨	▨	▨	▨	✓	▨	▨	▨
Vit C	✓	✓	✓	✓	✓	✓	✓	✓	▨	✓	✓	✓
Vit D	✓	▨	▨	✓	▨	▨	✓	✓	▨	✓	▨	✓
Vit E	✓	✓	✓	✓	▨	✓	✓	✓	▨	▨	✓	✓
Vit B1	✓	✓	✓	✓	▨	✓	▨	✓	✓	✓	✓	✓
Vit B2	✓	✓	✓	▨	✓	✓	✓	▨	✓	✓	✓	✓
Vit B3	✓	✓	✓	▨	✓	✓	✓	✓	▨	✓	✓	✓
Vit B5	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨
Vit B6	✓	✓	▨	✓	▨	✓	✓	▨	✓	▨	✓	▨
Vit B8	✓	✓	▨	✓	✓	✓	✓	✓	✓	▨	▨	✓
Vit B9	✓	✓	✓	✓	▨	✓	✓	▨	✓	▨	✓	▨
Vit B12	✓	▨	✓	▨	▨	✓	✓	✓	✓	✓	✓	✓
Calcium	✓	✓	✓	▨	✓	✓	▨	✓	▨	✓	✓	✓
Copper		✓	✓	✓	✓	✓	▨	✓	✓	✓	✓	✓
Chromium	✓	✓	✓	▨	✓	✓	▨	✓	▨	✓	✓	✓
Iodine	✓	✓	✓	▨	✓	✓	✓		▨	✓	✓	✓
Iron	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Magnesium	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Manganese	✓	✓	▨	▨	✓	▨	✓	✓	▨	▨		✓
Potassium		✓	✓	✓	✓	▨	▨	✓	▨	▨	✓	✓
Sodium	✓	✓	▨	✓	▨	▨	▨	▨	▨	▨	✓	✓
Zinc	✓	▨	✓	▨	✓	✓	✓	▨	▨	▨	▨	▨

✓ Represents an insufficient intake of the specified nutrient by the subject.

▨ Represents adequate intake of the specified nutrient.

4.2 RATE OF PERCEIVED EXERTION (RPE)

The subjects indicated the RPE every 10 minutes after the blood sampling. **Appendix B** represents the RPE scale. The RPE values which were indicated by the subjects during Test 1 and Test 2 are represented in **Figure 4.1**. Subjects indicated that they experienced more physical strain in Test 1 **(High Glycemic Index food)** than in Test 2 **(Low Glycemic Index food)** and the average RPE values were significantly higher ($p<0.05$) throughout Test 1.

Table 4.3: RPE values for five different time intervals

Time	N	Lower RPE in Test 2	Higher RPE in Test 2	Same RPE as in Test 1	p-value
10 minutes	**11**	**10**	**0**	**1**	**p = .004**
20 minutes	**11**	**8**	**1**	**2**	**p = .020**
30 minutes	**11**	**6**	**0**	**5**	**p = .023**
40 minutes	**11**	**5**	**0**	**6**	**p = .041**
50 minutes	**11**	**7**	**1**	**3**	**p = .023**

The RPE values were recorded every 10 minutes while the cyclists maintained the same intensity. At all the time intervals the RPE values were significantly higher in Test 1 ($p < 0.05$).

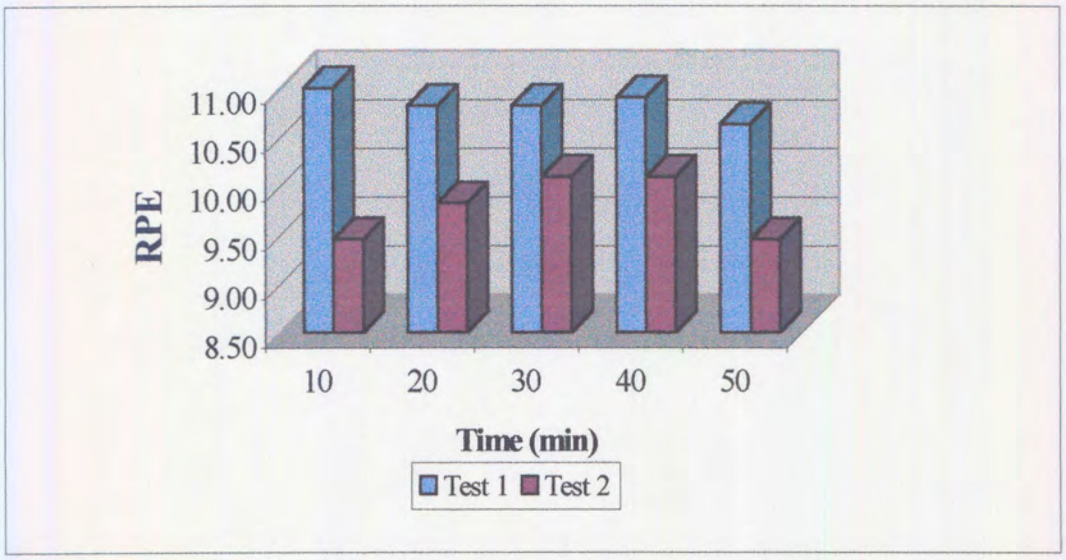


Figure 4.1 RPE values of Test 1 and Test 2

4.3 BLOOD GLUCOSE LEVELS

After the first dietary intervention **(High glycemic Index food)** – blood glucose levels dropped an average of **1.92 mmol/L** ± 0.62 after **10 minutes** of cycling **(Figure 4.2)**. After the second dietary intervention blood glucose dropped **1.15 mmol/ L** ± 0.44 **(Low glycemic Index food) (Figure 4.2).** The drop in blood glucose levels significantly differed ($p<0.05$) with an average of **0.68 mmol/L** between the two tests after **10 minutes** of cycling. It took 20 minutes for the blood sugar level of the **first test** to reach the same level of the blood sugar level of the **second test.**

The starting glucose values of both tests at 0 min are the same ($p<0.05$). There is however a clear and significant ($p<0.05$) difference between the blood glucose values measured at 10min of cycling between the two tests **(Table 4.4)**. Blood glucose declined from 5.86 mmol/L blood to 3.94 mmol/L blood after 10 minutes of cycling after the ingestion of a **High Glycemic Index** food. After the ingestion of the **Low Glycemic Index** food the blood glucose declined from 5.77 mmol/L blood to 4.62 mmol/L blood. The values are represented in Table 4.4. In each separate Test there is a significant difference between the blood glucose value at 0 min and 10 min ($p<0.05$).

Table 4.4: Glucose values at 0 min and 10 min of cycling

	0 min	10 min	Difference
Test 1	5.86 mmol/L	3.94 mmol/L	1.92 mmol/L
Test 2	5.77 mmol/L	4.62 mmol/L	1.15 mmol/L
Level of significance	$p< 0.05$	$p< 0.05$	

Table 4.5 Descriptive data of glucose response

Glucose	N	Minimum	Maximum	Mean	Standard Deviation
Test 1 - 0 min	11	5.20	6.80	5.83	.46
Test 2 - 0 min	11	5.20	7.10	5.78	.51
Test 1 -10 min	11	3.00	6.00	3.93	.86
Test 2 - 10 min	11	3.90	6.00	4.61	.63

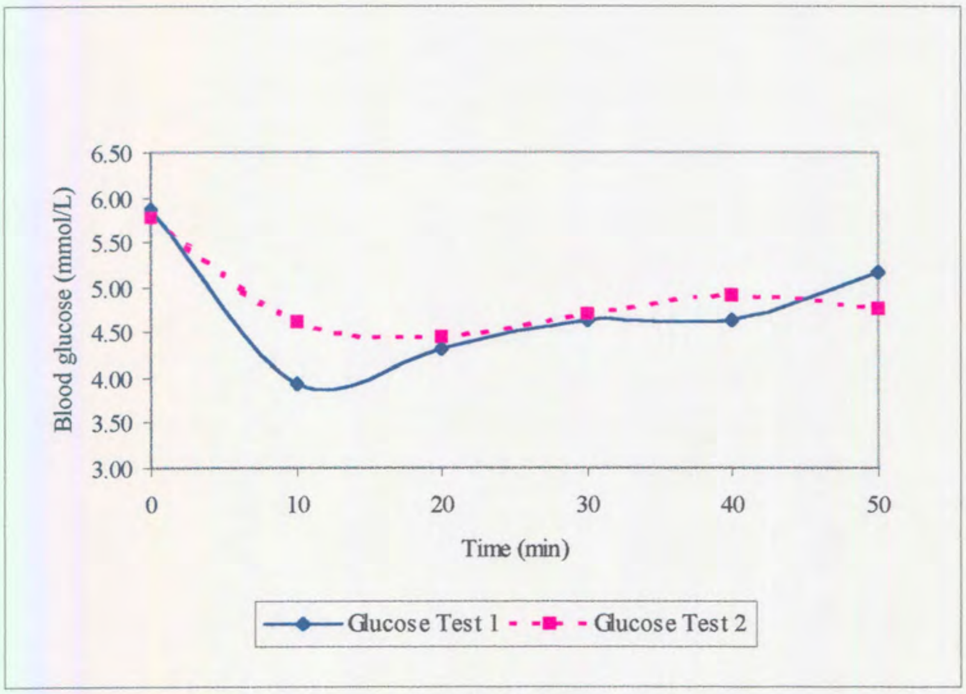


Figure 4.2 Blood Glucose response of Test 1 and Test 2

4.4 BLOOD LACTATE LEVELS

After the ingestion of the High Glycemic Index meal in Test 1, the blood lactate levels were significantly higher ($p<0.05$) during the first 15 minutes. The average lactic acid value for all the subjects after 15 minutes of cycling in the Test 1 was 3.03 mmol/L blood. In Test 2 the average lactic acid value was 2.79 mmol/L blood. Eight of the eleven subjects had a higher blood lactate level in the first 15 minutes after ingestion of the High Glycemic Index diet. Two subjects had lower lactate levels and in one subject there was no difference. The average lactate value for all the subjects after the High Glycemic Index meal was 2.84 mmol/L blood **(Figure 4.3).**

4.5 DISTANCE AND SPEED

The average speed maintained by all the subjects at 65 – 70% of VO_{2max} was ***24.19 km/h*** after the first dietary intervention **(High glycemic Index food)** and *28.11* **km/h** after the second dietary intervention **(Low glycemic Index food).** The difference in the average speed maintained by the subjects during both tests is not statistical significant due to the small sample size.

The total distance covered by the subjects in 50 minutes was ***22.86 km*** after the first dietary intervention **(High glycemic Index food)** and ***27.43 km*** after the second dietary intervention **(Low glycemic Index food).** The difference in the distance covered of the two tests is **4.57 km** in a period of 50 minutes **(Figure 4.4).**

There is no significant difference ($p>0.05$) between the total distances of Test 1 and Test 2 although 8 of the 11 subjects cycled a longer total distance in Test 2 **(Table 4.6).** The reason for this may be due to the small sample size. If a larger sample size were used there might have been a statistical difference between the total distances. Another reason may be the differences between the total distances done by each individual participant since one of them was female.

Table 4.6 Descriptive data of total distance

	N	**Maximum**	**Mean**	**Standard Deviation**
Distance test 1	11	29.27 km	20.75	4.74
Distance test 2	11	31.63 km	23.26	5.9

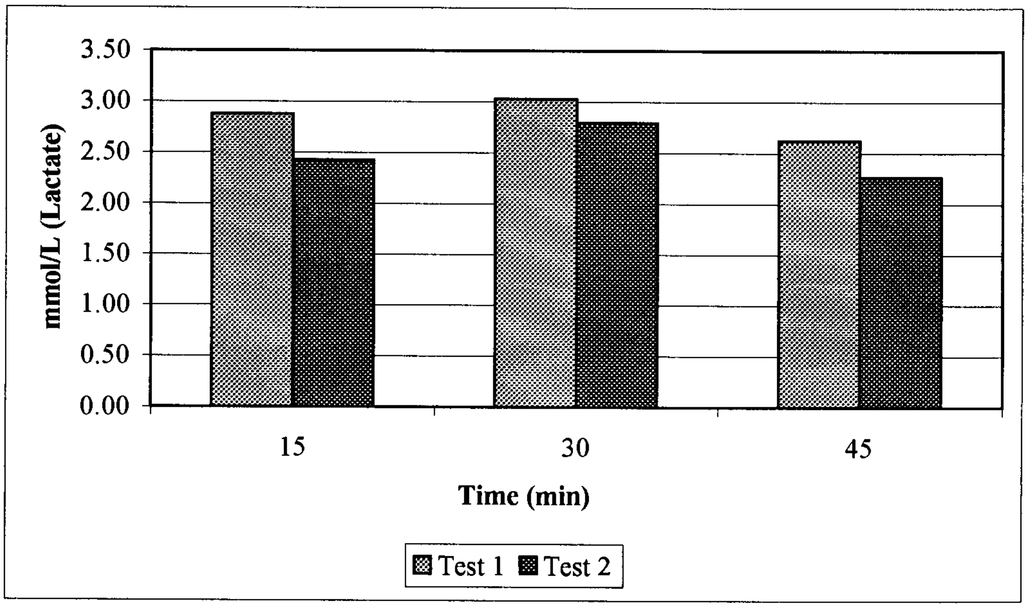


Figure 4.3 Blood Lactate levels of Test 1 and Test 2

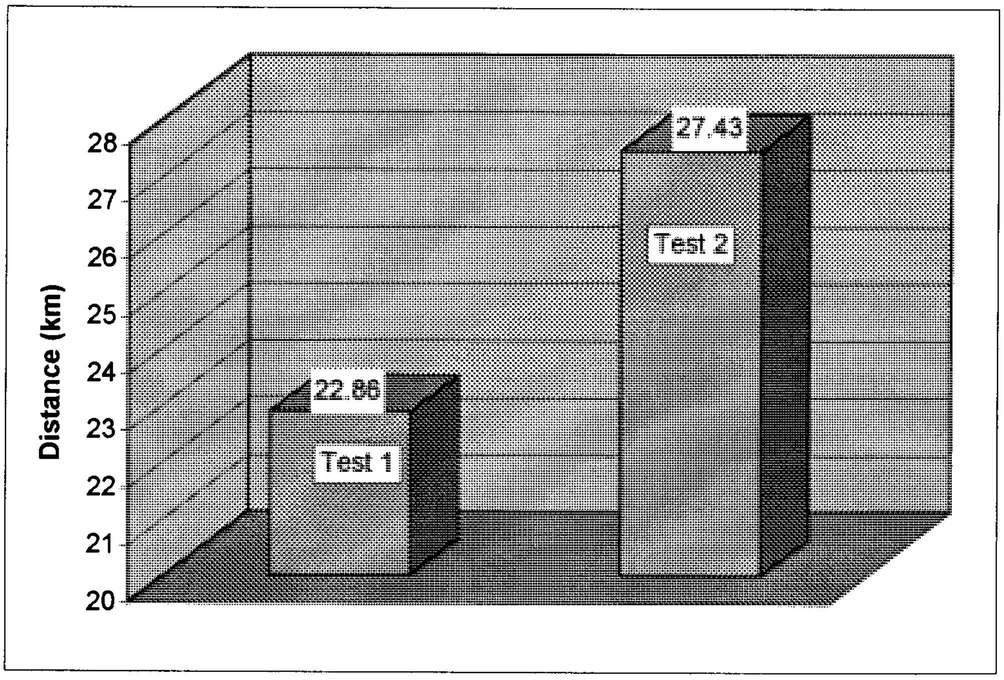


Figure 4.4 Comparison between two Tests - Average distance covered

CHAPTER 5 - DISCUSSION

5.1 INTRODUCTION

The nutrition and fluid requirements of an endurance athlete should be tailored not only to the sport, with endurance being the most important variable, but also to the individual competitor and the physical environment at the time of the event. Proper assessment of the athlete's nutritional needs, training program and type of event is essential before nutritional adjustments can occur. Previous studies didn't use this assessment method before deciding on the test meals (Sherman *et al.*, 1989; MacLaren *et al.*, 1994). Dietary manipulations should be aimed at optimising glycogen stores by ingesting the correct **amount** of CHO, at the right **time** in conjunction with the applicable **Glycemic Index factor**.

Endurance events should be tackled with full muscle glycogen stores as well as the correct feeding patterns. This doesn't imply that a carbohydrate loading regimen should be followed prior to each race or training session. Nutritional planning should rather include a consistent **high carbohydrate intake** as well as the correct **choice** and **timing** of CHO ingestion. Good recovery nutrition will help to replenish carbohydrate stores throughout training periods, but a lack of time makes it difficult to meet the required levels of glycogen. This emphasizes the intake of carbohydrate during races *(Refer to chapter 2).*

The major object of the study was to indicate the importance of using the **Glycemic Index** as part of the nutritional preparation for endurance events. First a thorough literature survey was conducted to **a)** gather and evaluate all existing data on the dietary intakes of competitive cyclists, **b)** develop useful nutritional guidelines concerning the use of the Glycemic Index in event preparation, and **c)** understand human energy metabolism.

Chapter 4 provides feedback on the results obtained from the study, identifying the areas where statistically significant changes were noted as well as changes with

practical importance after the dietary interventions. This chapter will therefor discuss the aspects that are of **statistical** and **practical** importance.

5.2 SUBJECTS

The subjects were selected according to their training distances and level of participation in competitions. The subjects cycled an average of 340 km/week before the start of the study. The study was conducted after the peak cycling season. This ensured minimal interference with the testing procedures.

In view of the purposes of the study, all the subjects' **eating** and **training** habits were assessed before deciding on the contents of the test meals **(Table 4.1)**. This excluded possible allergic reactions or digestive problems which might have occurred. This method also included the assessment of each subject's energy requirements and – expenditure. Previous studies didn't use these techniques and are not representative of any normal behaviours of endurance athlete (Costill, 1988; Thomas *et al.*, 1991).

The secondary aim was to establish effective nutritional guidelines to ensure that the subjects will implement the nutritional methods of the study in their daily training and event preparation. In this respect it was important that the test meals reflected their own eating habits. Test meals should be palatable in order to give the study significant value. The ingredients of the meals were selected in a way to accommodate all the subjects. The ingredients of the meals are common products which can be purchased on the markets of South Africa *(See table 4.4 & 4.5).* The products are also closely related to products available on the international markets. A study by Jenkins *et al.*, (1981) demonstrated that the variation of the Glycemic Index factor amongst specific foods does not differ that much between different countries.

Trained subjects were used for the purpose of establishing nutritional guidelines for endurance athletes. Trained subjects have higher levels of muscle glycogen than sedentary subjects. The concentration of glycogen in the leg muscles of untrained people consuming a normal diet varies from about **80 – 120 mmol/kg** of wet muscle mass (Ren *et al.*, 1990; Bangsbo *et al.*, 1992), whereas average muscle glycogen concentrations of trained athletes consuming a high carbohydrate diet is approximately **130 mmol/kg** of wet muscle mass (Sahlin *et al.*, 1990).

The higher muscle glycogen levels of trained athletes can be partly explained by changes that may occur in eating patterns, as people become more aware of their bodies' needs. This is evident in the diet analysis of the study population *(See table 4.1)*. The trend is to eat a higher carbohydrate diet as fitness increases, causing an increase in muscle glycogen stores which will occur regardless of any training effects. The subjects were adapted to ingesting high CHO diets and didn't experience any discomfort due to the high CHO content of the diets used in the study.

The increased muscle glycogen due to dietary changes alone, however, can be established from studies by Jardine *et al.* (1988) in which untrained people eating a high (70 %) carbohydrate diet had muscle glycogen levels of up to **100 mmol/kg** of wet muscle mass. Thus it appears that the remaining increase in muscle glycogen (from **100** to **130 mmol/kg**) in athletes occur as a consequence of **training** (Spencer *et al.*, 1992; Widrick *et al.*, 1993).

Trained subjects also oxidise more fat and less carbohydrate than untrained subjects when performing submaximal (65% of VO_{2max}) work at the same absolute intensity (Askew, 1984). This increased capacity to utilise energy from fat conserves crucial muscle and hepatic glycogen stores and can contribute to increased endurance (Askew, 1984) which contributes to the motivation of using **trained cyclists** instead of sedentary subjects. The ability to cycle for 50 min at the same intensity was also a precondition for participating in the study. All of the subjects competed on national or provincial level in the same year as the study.

Active athletes tend to be more sensitive to **insulin** than sedentary people (Heathe *et al.*, 1983) which was considered as an important variable in the study since the blood glucose response was constantly measured.

5.3 DIET ANALYSIS AND NUTRITIONAL GUIDELINES

Previous studies **(Table 2.1)** demonstrated similar results concerning the dietary content of cyclists. This demonstrates that competitive cyclists have a higher daily carbohydrate intake than their sedentary counterparts.

The average dietary intake of young adults consist of **49 %** carbohydrate, **13 %** protein and **36 %** fat, with an average calorie intake of **2346** calories/day (Nicklas *et al.*, 1995). The subjects in this study had a high percentage of daily **CHO (67.8%)** intake, but the total calorie intake was still insufficient **(Table 4.1)** to meet the reccomended daily intake. Frentsos & Baer, (1997) examined the dietary habits of 6 elite triathletes (4 male, 2 female) over a period of 7 days and found similar results. The results indicated the mean daily energy and carbohydrate intake to be **insufficient** to support estimated requirements. This may result in weight loss, glycogen depletion, dehydration, (Grandjean & Ruud, 1994) and **poor performance**. Vitamin and mineral intakes were also below the recommended daily allowance in the present study **(Table 4.2)**.

Costill & Miller, (1980) and Bergstrom *et al.* (1967(a)) demonstrated the advantages of a high CHO intake throughout the course of endurance training. These researchers indicated that subjects on a high-protein and high-fat diet remained glycogen depleted for five days whereas subjects on a high-carbohydrate diet replenished their muscle glycogen in two days during periods of endurance training. However the protein requirements of endurance athletes should not be neglected. The protein requirements for some endurance athletes may be as high as **1.6** g/kg/day (Brouns *et al.*, 1989(a)).

Results of the 7–day diet analysis demonstrate an overall insufficient intake of calories **(Table 4.1)** as well as the vitamins **B, C** and **E (Table 4.2).** The following minerals were below the recommended daily allowance: copper, iodine, selenium, chromium, **iron** and potassium **(Table 4.2).** Note that these intakes are not deficient, but rather below the optimal amount/day which is recommended for endurance athletes. It is essential for endurance athletes to ingest the desired amounts of iron.

Iron assists the hemoglobin molecule to carry oxygen to the exercising muscles and plays a key role in energy production.

The diet inventory of the subjects is a contribution to the limited pool of data which is currently available on the nutritional intakes of top level athletes during periods of intensive training and competition (Saris *et al.*, 1989) **(Table 2.1)**.

5.4 CHO INGESTION BEFORE EXERCISE (INFLUENCE OF THE GLYCEMIC INDEX FACTOR)

Pre-exercise carbohydrate intake has the potential to increase liver (Costill *et al.*, 1986; Coyle *et al.*,1986) and muscle (Ahlborg & Bjorkman., 1987) glycogen concentrations during the hours before exercise. Several studies reported ergogenic effects of pre-exercise carbohydrate feedings on performance (Sherman *et al.*, 1989; MacLaren *et al.*, 1994).

Leeds *et al.* (1998) suggested that the **Glycemic Index** will only benefit those who train for longer than 90 minutes at more than 65% of VO_{2max}. The present study contradicts this statement. The test results confirmed the advantages of applying the **Glycemic Index** in the preparation for shorter periods of training (50 min at 65% of VO_{2max}).

The results of the study as well as the literature research emphasizes the advantages of using the **Glycemic Index (Table 2.9)** as part of the dietary planning of endurance athletes. The Glycemic Index does what the glycemic response is unable to do; it standardizes the glycemic response areas to each individual response to a standard food. By doing this, it greatly reduces variability amongst individuals.

5.4.1 Blood glucose response to High Glycemic Index and Low Glycemic Index foods

The results on the blood glucose response correlate with previous findings by Foster *et al.* (1979) and Costill *et al.* (1986). They suggested that the ingestion of **High**

Glycemic Index food as part of the pre-exercise meal impair exercise performance by causing a sudden drop in blood glucose (hypoglycemia), and an accompanying acceleration of muscle glycogenolysis and glucose oxidation. Gleeson *et al.* (1986) and Sherman *et al.* (1989) also noted a drop in blood glucose during the first 15 min of exercise.

The pre test meal of Test 1 was a **high glycemic index** meal. The test results clearly indicate the advantages of ingesting a **Low Glycemic Index** meal before prolonged submaximal exercise. After the first dietary intervention **(High Glycemic Index food)** – blood glucose levels dropped an average of **1.92 mmol/L** ± 0.62 ($p< 0.05$) after 10 minutes of cycling **(Figure 4.2)**. Blood glucose dropped **1.15 mmol/L** ± 0.44 ($p< 0.05$) after the second dietary intervention **(Low Glycemic Index food) (Figure 4.2)**. The drop in blood glucose levels differed with an average of 0.68 mmol/L between the two tests after 10 minutes of cycling. It took 20 minutes for the blood sugar level of Test 1 to reach the same level of the blood sugar level of Test 2.

Low Glycemic Index pre-exercise meals may provide a slowly releasing source of blood glucose for the working muscles, thus preventing hypoglycemia or sugar high-lows. Foods such as legumes and pasta provide a slow but sustained release of glucose to the blood without an accompanying insulin surge. In comparison, food such as potato, bread and many breakfast cereals give glycemic and insulin responses almost as high as an equivalent amount of glucose (Thomas *et al.,* 1991). Glucose, a **High Glycemic Index** food, consumed in the hour before prolonged, strenuous exercise has been shown to be disadvantageous. Some studies have found increased use of muscle glycogen (Costill *et al.*, 1986; Hargreaves 1985), a rapid rise in **plasma insulin** and shorter endurance times when glucose is administered 15 to 60 minutes before exercise.

According to Costill *et al.* (1986) and Hargreaves *et al.* (1985) the intake of High Glycemic Index food shortly before endurance will stimulate too much insulin to be released and blood- sugar levels will drop below normal during the critical stages of the event which is usually the first 20 minutes in shorter cycle races. However, High Glycemic Index foods may be beneficial in the middle of an event (Coyle *et al.,* 1986) when one needs a quick burst of energy *(Refer to chapter2.1.3.2).* Foods with a **High**

Glycemic Index must be avoided one to two hours before an event or right before a competition *(Refer to chapter 2).* Controlled blood sugar levels in the early stages of endurance events may confer a glycogen sparing effect.

5.4.2 Speed and Distance

The performance advantages of the ingestion of a Low Glycemic Index pre-exercise meal instead of a High Glycemic Index pre-exercise meal include the average speed which were maintained by the subjects as well as the total distance in the current study. In the second post dietary test the cyclists maintained a higher pedalling speed. The average pedalling speed of the first test was *24.19 km/h* and in the second test *28.11 km/h* with a difference of *3.92 km/h.* The speed and distance results are not statistical significant due to several factors.

The total distance covered by the subjects in 50 minutes was **22.86 km** after the first dietary intervention **(High Glycemic Index food),** and **27.43 km** after the second dietary **intervention (Low Glycemic Index) (Figure 4.4)**. The difference in the distance covered between the two tests is 4.57 km in a period of 50 minutes.

There is however no significant difference ($p>0.05$) between the total distances of Test 1 and Test 2 although **8** of the **11** subjects cycled a longer total distance in Test 2. The explanation for this may be the fact that a small sample size was used and one of the subjects was female. If a larger sample size were used there might have been a statistical difference between the total distances.

In the study of Horowitz & Coyle, (1993) exercise performance was not measured. Thomas *et al.*, (1991) indicated performance advantages through the ingestion of Low Glycemic Index food instead of High Glycemic Index food before exercise.

5.4.3 Rate of perceived exertion

Fatigue involves complex interactions between the processes associated with muscle contraction and the metabolic processes associated with purine nucleotide metabolism and their interactions with the hormonal milieu, neural drive, and sensory feedback, and direct influences on and from the central nervous system (Sherman & Lamb, 1988).

The intensity of perceived exertion (perception of fatigue) during exercise is thought to be mediated by underlying physiological cues that involve alterations in contractile properties of peripheral and system changes. Factors such as blood **pH**, blood and/or muscle **lactate** concentration, muscle blood flow, muscle fibre type, and energy substrates have been proposed as physiological contributors to peripheral signals of perceived exertion. A previous study by Robertson *et al.* (1990) indicated that both **blood glucose** and **muscle glycogen** content are thought to influence perceptual signal strength. The decrease in circulating levels of **blood glucose** have been shown to be an important determinant of fatigue during moderate intense exercise (± 70% VO_{2max}) (Slentz *et al.*, 1990). After the High Glycemic Index meal circulating blood glucose levels dropped to hypoglycemic values and the subjects indicated higher RPE values than after the Low Glycemic Index meal. Fatigue in some individuals occur when blood glucose declines to hypoglycemic concentrations (<2.5 mmol/L) (Felig *et al.*, 1982).

Researchers don't often include the RPE values in their data collection. The **RPE** values recorded in both of the post dietary trials in the present study indicate that subjects experienced more discomfort and fatigue after the ingestion of the **High Glycemic Index** food than after the ingestion of **Low Glycemic Index** foods ($p<0.05$) **(Figure 4.1).** The discomfort which was experienced during the first **10 – 15 minutes** of training in **Test 1** occur concurrently with the drop of the blood glucose. The high RPE values may be the result of hypoglycemia and an increase in muscle glycogen use. The increase in glycogen use can possibly be related to the high levels of insulin which tend to inhibit the mobilization of free fatty acids (Costill *et al.*,1986). This finding contradicts previous studies done by Horowitz *et al.* (1993) in which the subjects experienced equivalent sensations of discomfort in both the **High Glycemic Index** and the **Medium Glycemic Index** trials. These subjects performed a 60 minute exercise task with equivalent sensations of discomfort or fatigue independently of the Glycemic Index of the test meal. A possible explanation for this may be that Horowitz *et al.* (1993) used a **High Glycemic Index** food and a **Moderate Glycemic Index** food instead of a **High Glycemic Index** and a **Low Glycemic Index** food.

The Glycemic Index has to be used in conjunction with the correct amounts of carbohydrates, protein and fat to have performance advantages. Ingesting the correct amounts of CHO before, during and after a competition must be accompanied with the correct Glycemic Index factor at the time *(Refer to chapter 2)*. **Table 5.1** represents food with a Low Glycemic Index which can be ingested as part of the pre-exercise meal.

5.4.4 Blood lactate levels

The results indicate that blood lactate levels during exercise may be influenced by the glycemic index of the pre-exercise meal. This is presumably a result of increased glycolysis in muscle tissues. After the ingestion of the **High Glycemic Index** meal the blood lactate levels during subsequent exercise were higher. The average lactate value for all the subjects after the **High Glycemic Index** meal was 2.84 mmol/L blood. The blood lactate value after the Low Glycemic Index meal was 2.49 mmol/L blood with a difference of *0.44* mmol/L blood *($p < 0.05$)* **(Figure 4.3)**. These results are a further indication that high glycemic index foods may be undesirable in the hour before exercise.

Similar results were found in the study of Horowitz & Coyle, (1993). They compared a High Glycemic Index pre-exercise meal with a Moderate Glycemic Index pre-exercise meal. The plasma lactate concentration was significantly higher ($p<0.05$) after the ingestion of the High Glycemic Index meal. This data was collected during exercise at 60% of VO_{2max}. Other studies observed plasma lactate levels to be either elevated (Thomas *et al.*, 1991), or unchanged (Sherman *et al.*, 1991).

5.4.5 Dietary changes and performance

Cyclists can experience the benefits of steady blood sugar levels during endurance events with minimal changes in their normal eating patterns. This is demonstrated by the blood glucose response of **Test 2**. **Figure 4.2** represents the blood glucose responses of both of the pre-exercise meals. The blood glucose response of Test 1 appears to have a **steep down slope** whereas the response of Test 2 is gradual. Similar results were indicated by Horowitz & Coyle (1993). This effect can be achieved by the ingestion of a **Low Glycemic Index** food prior to exercise. Sugar high–lows is something which an endurance athlete should try to avoid. This is especially important in the first stage of an event when hypoglycemia may occur as a result of the ingestion of a **High Glycemic Index** meal prior to the event. The occurrence of hypoglycemia during the first stages of an event is confirmed by the results of this study as well as those of Foster *et al.* (1979) and Costill *et al.* (1986).

Foods which were part of the **second** pre test meal **(Low Glycemic Index)** such as oats, dates and grape juice gave slow but sustained release of glucose to the blood without an accompanying insulin surge. Skimmed milk was used in both of the test meals to prevent the lowering effect which fat has on the Glycemic Index *(Refer to chapter 2.2.2.7).*

Food such as corn flakes, raisins and orange juice, which were part of the **first** pre test meal, resulted in a rapid release of glucose in the blood. This lead to an accompanying insulin release which lowered the blood sugar levels to a lower level than the start of the exercise. **Table 5.1** represents the Low Glycemic Index foods which can be ingested prior to exercise.

Table 5.1: Serving sizes of Low Glycemic Index foods to eat 1 to 2 hours before the event

Food	**G.I.**	**Serving size = 50 grams CHO**	**Serving size =75grams CHO**
Heavy grain breads	46	100 g (3 slices)	150 g (4 to 5 slices)
Spaghetti, cooked	37	200 g	300 g
Porridge	42	600 g	900 g
Baked beans	48	450 g (medium can)	670 g (1½ medium can)
Fruit salad	±50	500 g	750 g
Yoghurt	33	400 g	600 g
Apples	38	400 g (3 small medium)	600 g (4 medium)
Oranges	44	600 g (5 small)	900 g (7 small)
Dried apricots	31	105 g	160 g

(Leeds *et al.*, 1996)

5.4.6 The Glycemic Index and Carbohydrate metabolism

Dietary manipulations that elevate the **pre-exercise** concentration of liver glycogen (e.g., increased dietary carbohydrate intake) have the potential to favourably influence athletic training and performance capabilities. The current study evaluated the influences of a Low Glycemic Index pre-exercise meal and a High Glycemic Index meal on exercise performance in conjunction with a 7-day(high carbohydrate) diet which preceded each test.

The pattern of muscle glycogen metabolism during exercise at 75% VO_{2max} is curvilinear. The most rapid glycogenolysis occurs during the first 20 – 30 minutes, which is followed by a slower decline in muscle glycogen until fatigue occurs that is related to muscle glycogen depletion after 60 min in untrained subjects (Sherman & Lamb, 1988). The possible advantages of the ingestion of a **Low Glycemic Index** is demonstrated by Thomas *et al.,* (1994). He found that Low Glycemic Index foods increase the blood glucose concentration toward the **end** of exercise. Plasma glucose levels after more than 90 min of exercise was found to correlate inversely with the observed Glycemic Index of the foods. Free fatty acid levels during the last hour of training also correlated inversely with the GI. The findings suggest that the **slow digestion of carbohydrate** in the pre-event food favours higher concentrations of fuels in the blood toward the end of exercise. The subjects in the current study cycled for **50 minutes**, but the results indicated that the above mentioned statement may be true for shorter periods of exercise. The slow digestion of the Low Glycemic Index meal not only has advantages towards the end of exercise, but also during the first stages of exercise.

There has been much debate as to whether the ingestion of High Glycemic Index foods will alter muscle glycogen use. Theoretically muscle glycogen use would be increased if the decline in fat oxidation was not offset by a proportional increase in blood glucose uptake and oxidation by muscle. Two studies which found that pre-exercise feedings slightly increase muscle glycogen use also indicated a decline in blood glucose concentration, which may have limited muscle glucose uptake (Costill *et al.*, 1993; Hargreaves *et al.*, 1987). Other studies observed no significant effect after the ingestion of sugar (Hargreaves *et al.*, 1987; Okano *et al.*,1988; Devlin *et al.*, 1986).

5.5 CHO INTAKE DURING AND AFTER THE RACE

In order to accomplish the **secondary aim** of the study which was to establish dietary guidelines, some recommendations concerning the ingestion of High Glycemic Index food and Low Glycemic Index food should also be discussed. The blood glucose results clearly indicate the detrimental effect which the High Glycemic Index meal of Test 1 had on performance. The ingestion of a High Glycemic Index meal result in a rapid release of glucose in the blood and it is recommended that **High Glycemic Index** foods should rather be consumed **during** exercise. These foods will ensure rapid digestion and absorption, which will lead to elevated blood glucose levels during exercise. The maintenance of high blood glucose levels is believed to cause a sparing of muscle glycogen (Hargreaves *et al.*, 1984) or to allow maintained carbohydrate oxidation near the end of exercise when the body's endogenous stores are depleted (Coggan & Coyle, 1989).

The ingestion of High Glycemic Index carbohydrates such as the raisins in **Test 1** should start early in exercise before the cyclist experience a hunger sensation, and perhaps even from the start of the ride. The muscles oxidises a small amount of CHO from outside sources in the first 30 – 60 minutes of exercise, but after this it becomes quite dependent on carbohydrate consumed during exercise.

Foods that have a high glycemic index such as those found in **Test 1**, will increase glycogen stores, thus giving the cyclist much needed carbohydrates when eaten during exercise when glycogen stores in the muscle start to be consumed *(Refer to chapter 2).* During the early stages of moderate intensity exercise, plasma glucose provides approximately one-third, and muscle glycogen approximately two-thirds of the carbohydrate oxidised (Coggan & Coyle, 1987). However as exercise continues the relative contribution from plasma glucose increases and that from muscle glycogen decreases (Coyle *et al.*, 1986) *(Refer to chapter 2).* As the intensity of exercise increases, the rate of plasma fatty acid mobilization declines and thus the exercising muscles become dependent on carbohydrate as a source of energy. This is not due to simply limited availability of fatty acids, but also to a limited ability for fat oxidation in skeletal muscle. Carbohydrate ingestion **before** and **during** exercise exerts a large influence on fatty acid mobilization and oxidation, making muscles even more dependent on carbohydrate for energy during exercise (Sherman *& Lamb*, 1988).

Post-exercise meals should consist of **High Glycemic Index** carbohydrates. **Low Glycemic Index** foods do not induce adequate muscle glycogen resynthesis compared with high glycemic index foods (Walton & Rhodes, 1997) *(Refer to chapter 2).* The rapid restoration of muscle glycogen stores is a critical issue for cyclists competing in endurance events over successive days or during intensive training periods. Postexercise feeding programs which promote glycogen storage has been studied intensively by sport physiologists (Costill & Miller., 1980; Kiens *et al.,* 1990). Endurance athletes are advised to consume 65 – 70 % of their daily energy intake in the form of carbohydrate to allow for glycogen repletion (Costill, 1988) *(Refer to chapter 2.1.3.3 on glycogen replenishment after endurance events).* According to the dietary analysis of the subjects **(Table 4.1)**, the percentage of CHO intake is adequate but the total amount of calories is still insufficient.

Fatigue during intense endurance training is normally associated with the depletion of muscle and liver glycogen. Dietary practices should advocate high carbohydrate intake **before, during, and after** exercise. The aim should be to ensure that the carbohydrate stores in the body is as high as possible during the last stages of prolonged exercise. This theory is put into practice in chapter 2 by recommending that carbohydrate intake **after** exhaustive exercise should average **50g** per 2 hr of mostly moderate and high glycemic carbohydrate foods. The aim should be to ingest a total of approximately 600 g in 24 h (> 8g/kg body weight).

Not all studies, however, have shown that muscle glycogen depletion is the cause of fatigue during prolonged exercise (Blom *et al.,* 1986; Coyle *et al.*, 1986). One challenge to the "glycogen depletion causes exhaustion" theory came from Coyle *et al.* (1986) who demonstrated that exercise could be continued even when muscle glycogen content was low, provided that the **blood glucose concentration remained**

high. This can be achieved through the ingestion of High Glycemic Index foods during exercise.

Several authors recommend an ingestion of **High Glycemic Index** foods for muscle glycogen replenishment after training (Burke, 1998; Garcia-Roves *et al.*, 1998). Garcia-Roves' study includes both high and medium glycemic index foods. In the study of Burke (1993), glycogen storage after 24h was greater with **High Glycemic Index** foods (106.1 ±117) than with **Low Glycemic Index** foods (71.5 ±6.5) *(Refer to chapter 2.1.3.3).*

Table 5.2: Serving sizes of High Glycemic Index foods to eat during and after events

Food	**G.I.**	**Serving size = 50 grams CHO**	**Serving size =75grams CHO**
White or brown bread	70	100 g (3 slices)	150 g (4 to 5 slices)
Rice Krispies	89	45 g	65g
Scones	70	150 g (2 large)	200 g (3 large)
Rice cakes	82	60 g (5 rice cakes)	90 g (8 rice cakes)
Muffins (English style, oasted)	70	120 g (2 muffins)	180 g (3 muffins)
Baked potato (without fat)	85	330 g (3 small-medium)	580 g (5 small)
Rice (cooked)	83	180 g	270 g (4 medium)
Jelly beans	80	55 g (25 jelly beans)	85 g (38 jelly beans)

(Leeds *et al.*, 1998)

5.6 HORMONAL RESPONSES TO DIFFERENT CHARACTERISTICS OF CARBOHYDRATE FOODS

Different carbohydrate containing foods have different effects on blood sugar levels. The correct **type, amount** and **timing** of CHO ingestion don't always determine the subsequent influence on blood sugar levels. Differences in the **Glycemic Index** for the same food still exist. As was previously mentioned the **physical form** of the food consumed affects the surface area of the starch molecule, which in turn dictates the magnitude of the carbohydrate-enzyme interaction within the intestine and thus the glycemic response to the food (O'Dea *et al.*, 1980) **(Table2.7).** The physical characteristics of the test foods are mainly responsible for the differences in their Glycemic Indexes. Cornflakes (Glycemic Index = 84) were used in Test 1 and Oats in Test 2 (Glycemic Index = 66). These two carbohydrate foods have different characteristics. The surface area of the cornflakes are more exposed (manufacturing process – grinnding) and therefor rapid digestion can occur which result in a fast release of glucose into the blood. The oats are rolled and less exposed to digestion and elicit a lower insulin response. The **digestibility** of carbohydrates is the most important nutritional property concerning the Glycemic Index. The rate of absorption in the small intestine primarily determines the glycemic and hormonal responses after a meal and is expressed as the glycemic index, as defined by Jenkins *et al.* (1981).

It is evident that researchers cannot still make use of the old distinction between starchy and sugary food or simple and complex carbohydrates. These distinctions are based on the chemical analysis of the food, which does not totally reflect the effects of these foods on the body.

The difference in metabolic responses observed between complex carbohydrates may be attributed to several factors including differences in **preparation** (mashed vs. boiled), **hydration** (Gatti *et al.,* 1987), or differences in the **polymeric structure** (amylose vs. amylopectin) (Behall *et al.*, 1988) of the specific carbohydrate *(Refer to chapter 2.2.2).* These factors have an influence on the **digestion and absorption** characteristics of the meals. The extent of carbohydrate digestion in the small intestine (digestibility) determines the amount carbohydrates which will provide glucose to the organism and the amount of carbohydrate which will pass to the large bowel for subsequent fermentation.

Carbohydrates, which break down quickly during digestion, have high **Glycemic Index factors (Test 1 – meal).** The blood sugar response is rapid. Carbohydrates which digest slowly result in a gradual rise and fall in blood sugar responses and help control blood sugar levels **(Low Glycemic Index factors – Test 2 meal).** This effect can be beneficial for cyclists because it reduces the release of the hormone insulin and ensures controlled blood glucose levels throughout training (Leeds *et al.*, 1998).

Horowitz & Coyle, (1993) studied the differences among complex carbohydrates. Rice, like potato, is a complex carbohydrate with different influences on blood glucose. We observe the glycemic and insulinemic responses to the potato meal to be significantly greater than those for the rice meal (Horowitz & Coyle, 1993). This finding is consistent with previous work (Jenkins *et al.*, 1984).

5.7 CONCLUSION

The **Glycemic Index** sort food in a rank order on the basis of the measured blood sugar response to a specific reference food. The rate at which glucose enters the bloodstream affects the insulin response to that food and ultimately affects the fuels available to the exercising muscles. There are situations in which **Low Glycemic Index** foods provide an advantage and times when **High Glycemic Index** foods are better. For best performance, endurance athletes need to learn how to use the Glycemic Index in respect to the **choice** of CHO foods as well as the **time** and **amount** of ingestion.

High Glycemic Index foods such as cornflakes and raisins produce a rapid increase in glucose and insulin levels, something which is not desirable prior to a race when glycogen stores should already be fully charged. Low Glycemic Index foods, such as pasta, which are digested and absorbed much more slowly, are able to provide glucose to the working muscle towards the end of exercise when glycogen stores are declining. After the event, High Glycemic Index food have the most advantages because it stimulates more insulin, which is in turn responsible for putting glycogen back into the muscles.

Carbohydrate intake should **not** be avoided during the 4-h period before exercise. When the diet is not carefully planned according to the guidelines of chapter 2, endurance athletes tend to consume too little carbohydrate because they become satiated with **fat** and go through periods in the day when recovery of glycogen stores is suboptimal, thus wasting precious time (Coyle, 1995).

It's not just **pre**-and **post-event meals** that influence your performance. Consuming a high carbohydrate diet **every day** will help you reach peak performance. The Glycemic Index factor of the carbohydrate is not important here, only the **amount** of carbohydrate, It has been proven scientifically, unlike many other rumours involving dietary supplements, that eating lots of high carbohydrate foods will maximise muscle glycogen stores and thereby increase endurance (Frentsos *et al.*, 1997)

The Glycemic Index may have an important role in endurance events where the depletion of endogenous carbohydrate is a limiting factor. Utilizing the index as a reference guide in selecting carbohydrates for consumption **prior to, during** and **after** exercise may be a deciding factor in whether the carbohydrate will improve performance.

In conclusion this study support the fact that **Low glycemic index** food may confer an advantage when eaten **prior** to prolonged strenuous exercise by providing a **slow-release source of glucose** to the blood without causing extensive **hypoglycemia.** Proper preparation and the correct choice of the preevent meal can exclude the occurrence of sudden drops in the blood sugar levels. The Glycemic Index can also be successfully applied **during** and **after** events to improve performance.

The Biokineticist can play an important role in assisting athletes in their training and dietary practices. The combination of exercise physiology with correct nutritional guidelines may result in improved performance.

CHAPTER 6 –RECOMMENDATIONS AND FUTURE RESEARCH

6.1 RECOMMENDATIONS

This study gave very good and clear results concerning the use of Low Glycemic Index foods as part of the preparation for endurance events as well as the use of the Glycemic Index for optimising glycogen reserves. The following recommendations may be considered in order to increase the success of any future studies:

- Include more female participants in the study and devide the results into male and female or into age groups.

- Repeat the assessment of variables such as body weight, fat % etc. to determine the effect which the study diets had on non-performance related variables.

- The current study used a method of carbohydrate loading (super compensation) before the test procedures. To give the study more significance a higher fat and protein intake is suggested to simulate normal eating patterns. Carbohydrate loading is a method that should only be followed before serious competition events.

- The blood glucose levels later in exercise need more attention. The exercise time can be extended to 90 minutes. In this case the subjects must pass a fitness test before they can be considered for the study.

- In this study each subject ingested a High Glycemic Index and a Low Glycemic Index pre-exercise meal. Each subject's response were evaluated and compared with his own tests results to indicate the differences. Subjects were not compared with each other but to the average of the group. The inclusion of 2 groups of subjects to ingest either a **High Glycemic Index meal** and **Placebo** or a **Low Glycemic Index meal** and **Placebo** may lead to further findings. Due to the nature of the test population it is difficult to find subjects who are more or less homogenous

6.2 FUTURE RESEARCH

Areas for future research were identified from this study. Some of them may include aspects discussed under 6.1. It is therefor advisable to read these sections as a whole. The following are possibilities with respect to future studies:

- The effect of the Glycemic Index on physical activities which include strength and power sports.

- Investigate the long term advantages of following a every day diet which is planned according to the Glycemic Index.

- Research examining carbohydrate ingestion and its effects on performance has primarily concentrated on commercial drinks or some form of carbohydrate in solution Future research can include local products that one can buy from the shelf. These products can only be chosen after a proper inventory of popular food choices.

- Investigate the effect which carbohydrate fermentation has on energy metabolism during subsequent exercise.

- Determine whether Low Glycemic Index foods will be beneficial in respect to certain hypokinetic diseases such as Non-Insulin Dependent Diabetes Mellitus, high cholesterol, obesity, hypertension and hyperlipidemia.

- Research that employs “nutritional protocols more comparable to competitive feeding behaviour”.

APPENDIX A

Contents **Page**

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

University of Pretoria
Sportcentre Pretoria 0002 Tel 362-1574
Fax 362-0463 *http://www.up.ac.za*

Sports Research Institute

INDEMNIFICATION

____
(full name of prospective participant)

submit himself/herself herewith to the Sport Research Institute of the University of Pretoria (hereafter referred to as the UNIVERSITY), to the services and facilities of the said UNIVERSITY (ie. evaluation, rehabilitation and/or gymnasium programme).

And whereas I am aware of the fact that my health is such that it constitutes a potential risk to participate in the evaluation and training programme which I am about to commence, I therefore declare that I participate in the said training programme at my own risk and that I hereby indemnify the University, including its co-workers as well as the biokinetisist .... against any consequences which have a bearing on and/or ensure directly or indirectly as a result of the said training and evaluation programme.

I declare hereby that there is no information withheld that will exclude me from participating in an exercise programme.

I furthermore authorise Dr .... to furnish the Sports Research Laboratory of the University with relevant details regarding my state of health, with a view to compiling a suitable training programme for me.

Signed at .... on this .... day of .... 19 ....

____
Signature of prospective participant

Tel: ____________________ (h) ____________________ **(w)**
(code and number) **(code and number)**

■ **WITNESS**

1. ....

2. ....

APPENDIX B

RECORD SHEETS

Contents **Page**

Training Record Sheet

EUGENE TERBLANCHE
Training program for first week

Day	Resting Heart rate Morning	Hours of sleep.	Training (hours)	Intensity %	Description of training session
1.					
2.					
3.					
4.					
5.					
6.					
7.					

EUGENE TERBLANCHE
Training program for second week

Day	Resting heart rate morning	Hours of sleep.	Training (hours)	Intensity %	Description of training session
1.					
2.					
3.					
4.					
5.					
6.					
7.					

Data sheet for VO2max evaluation

Subject: Eugene Terblanche

Date: 28/09/1998

	Speed (km/h)	Time (min)	Heart rate (b/min)	Lactate level (mmol/L)	Blood Glucose (mmol/L)
1.	**20**	**0**	43	2.4	5.3
2.	**26**	**3**	100	2.5	5.0
3.	**32**	**6**	110	2.5	4.9
4.	**36**	**9**	129	2.4	5.2
5.	**39**	**12**	150	3.7	5.8
6.	**42**	**15**	170	6.7	5.9
7.	**45**	**18**	179	8.5	6.0

Somatotype Data Sheet

Subject: Eugene Terblanche

Date: 28/09/1998 (First Test)

Measurement	**Value**
Resting Heart Rate (b/min)	43
Blood Pressure (mm Hg)	124/78
Resting Lactic Acid (mmol/L)	2.4
Resting Blood Glucose (mmol/L)	5.3

Fat	9.7 Kg - 13.2 %
Lean body mass	63.3 Kg - 86.7 %
Weight	(71.8 – 77.1) kg
Total Body water	44.1 L - 60.4 %
REE	8121 kJ
EAR	4617 kJ
BMI	22.7

TANITA: 7.5 % VET

Test 1 – Post dietary test

Subject: Eugene Terblanche

Date: 5/10/98

Measurement	**Value**
Resting Heart Rate (b/min)	51
Resting Lactic Acid (mmol/L)	3.7
Resting Blood Glucose (mmol/L)	6.8
Resting Blood Pressure (mm Hg)	158/85

Time Min	**RPE**	**Speed km/h**	**Distance Km**	**HR beats/min**	**Glucose mmol/L**	**Lactic Acid**
0	0	0	0	51	6.8	3.7
10	11	24.2	5.5	138	4.3	3.0
20	12	23.5	9.17	141	3.0	2.7
30	12	24.2	12.94	141	4.1	3.3
40	13	23.8	17.4	137	4.8	2.6
50	12	28	21.09	139	5.6	3.5

Test 2 – Post dietary test

Subject: Eugene Terblanche

Date: 12/10/98

Measurement	**Value**
Resting Heart Rate	58
Resting Lactic Acid	3.3
Resting Blood Glucose	7.1
Resting Blood Pressure	135/73

Time Min	**RPE**	**Speed km/h**	**Distance Km**	**HR beats/min**	**Glucose mmol/L**	**Lactic Acid**
0	0	0	0	53	7.1	3.3
10	9	30.0	5.02	142	4.4	3.9
20	10	22.8	9.57	143	3.8	2.9
30	10	26.6	13.8	142	4.7	3.0
40	11	24.5	17.74	138	5.1	2.4
50	11	24.3	21.70	143	5.0	2.4

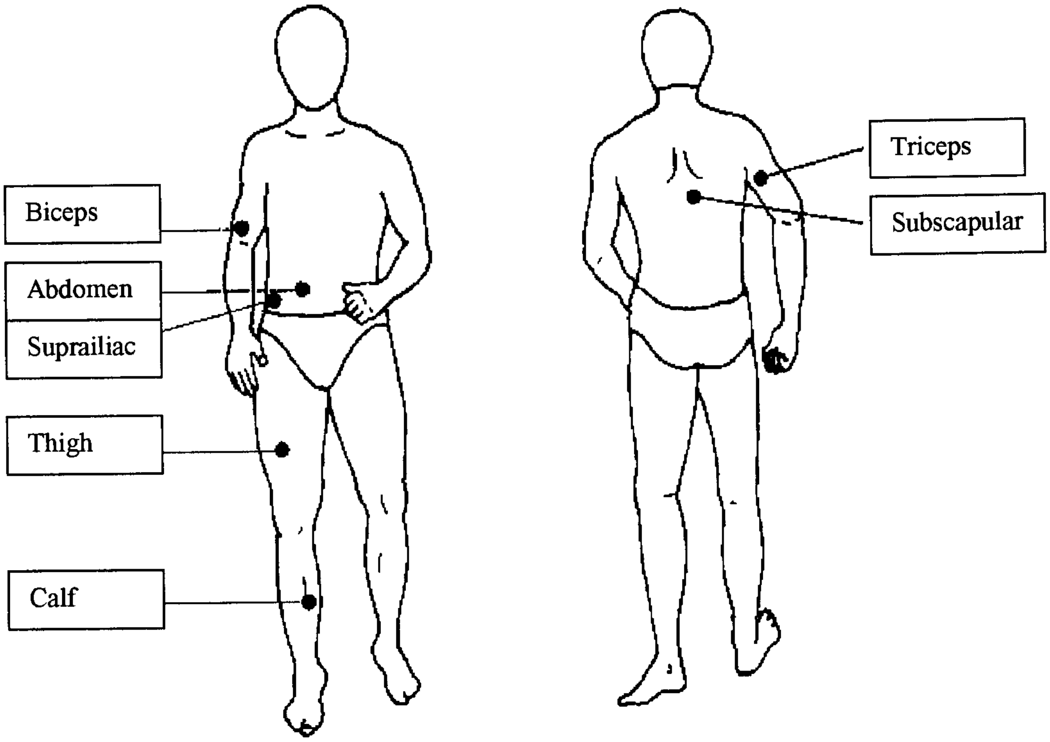
RPE scale

Category	RPE Scale
6	
7	very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

APPENDIX C

Contents **Page**

Anthropometrical measurements



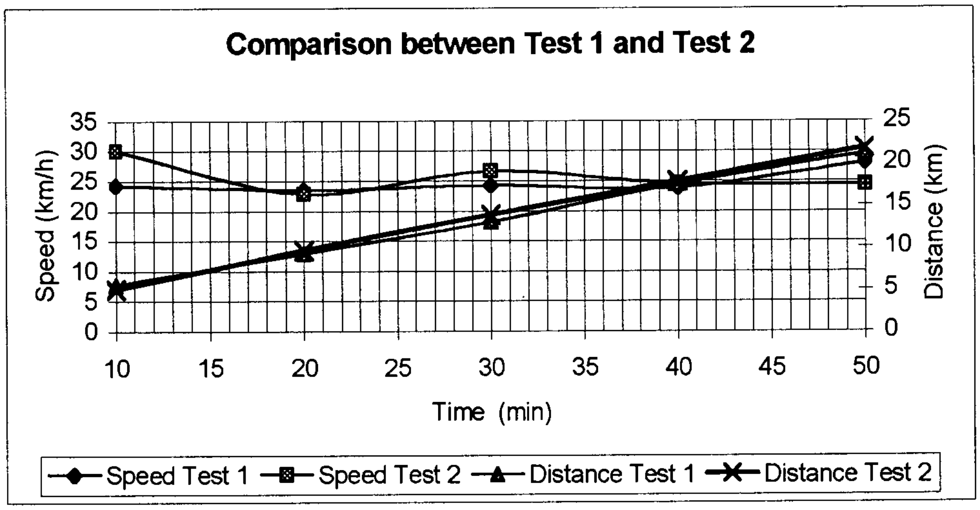
APPENDIX D

SUBJECT REPORTS

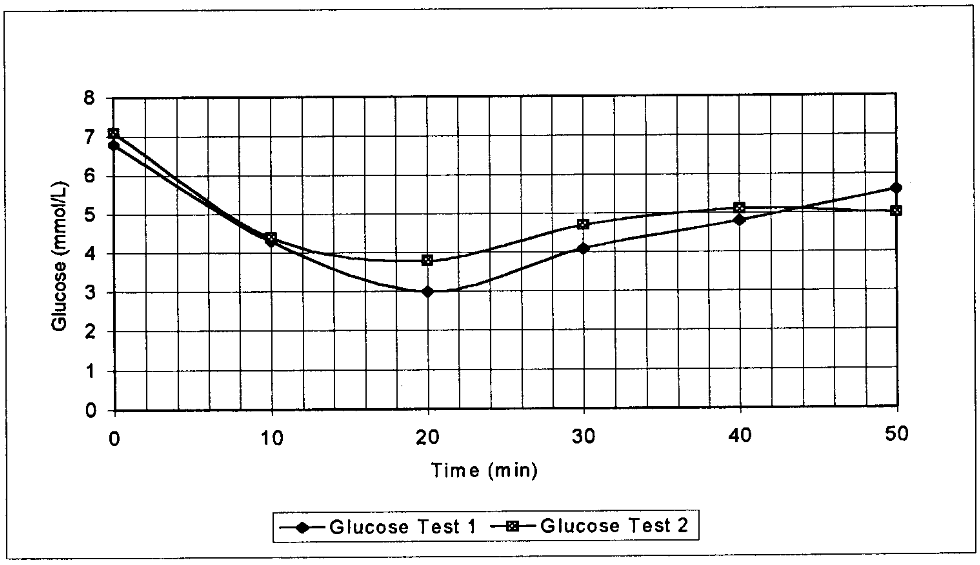
Contents **Page**

Physiological Changes

Total Distance and average speed improved after the second dietary intervention.



The blood glucose response after the second pre-exercise meal shows less variation. The glucose levels drops very low after the HGI pre-exercise meal after the first 10 – 15 minutes of exercise.



Anthropometry

Name: Eugene Terblanche

1. Length: 179.5
2. Mass: 73
3. Age: 27
4. % Fat: 9.37 kg Fat 6.84
5. % Bone: 18.42 kg. Bone 13.45
6. % Muscle:47.41 kg Muscle 34.61
7. Resting Heart Rate: 43
8. Blood pressure: 124/78
9. Resting Blood Lactate: 2.4 mmol/L
10. Resting Blood Glucose: 5.3 mmol/L
11. Somatotype: (Subject)

Fat Component	Muscle Component	Lean Component
I 1.8	II 5.8	III 3.1

IDEAL SOMATOTYPE: (Cyclists)

Fat Component	Muscle Component	Lean Component
I 1.8	II 5.0	III 2.7

12. **BMI** 22.7 kg\m2
13. **MIDDEL HIP CIRCUMFERENCE:** 0.84
14. **TOTAL BODY WATER:** 44.1 litre

> The average fat % for competitive cyclists lies between **8 – 12 %** for men and **10 – 15%** for ladies.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

VO2max Report

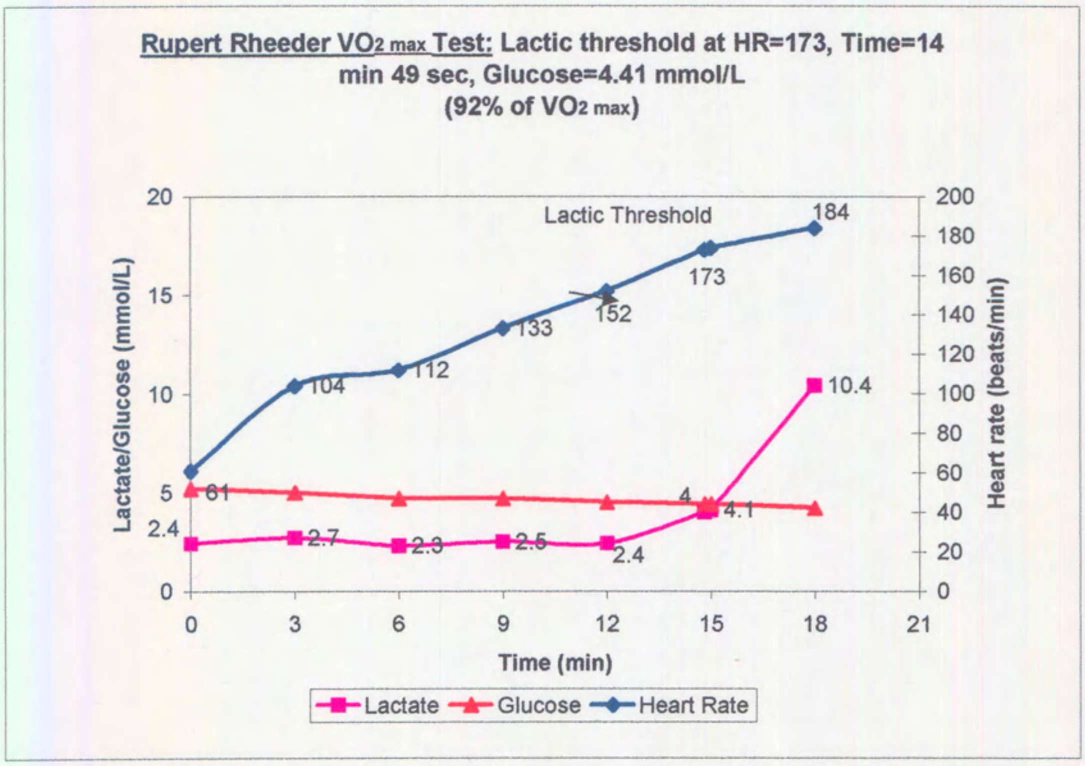
NORMS:

Age	Very low	Low	Average	High	Very High
Female					
20 – 29	28	29 – 34	35 – 34	44 – 48	49
30 – 39	27	28 – 33	34 – 41	42 – 47	48
40 – 49	25	26 – 31	32 – 40	41 – 45	46
50 – 65	21	22 – 28	29 – 36	37 – 41	42
Male					
20 – 29	38	39 - 43	44 – 51	52 – 56	57
30 – 39	34	35 – 39	40 – 47	48 – 51	52
40 – 49	30	31 – 35	36 – 43	44 – 47	48
50 – 59	25	26 – 31	32 – 39	40 – 43	44
60 – 69	21	22 – 26	27 – 35	36 – 39	40

TEST RESULT: 53.8 ml/min/kg

- The average $VO_{2\,max}$ for cyclists is 55,7 ml/min/kg.
- The highest $VO_{2\,max}$ ever recorded for a cyclist's is that of Miguel Endurain which is 88 ml/min/kg. His resting heart rate is 28 beats per minute.

Lactic Threshold



Rupert Rheeder $VO_{2\,max}$ Test: Lactic threshold at HR=173, Time=14 min 49 sec, Glucose=4.41 mmol/L (92% of $VO_{2\,max}$)

BIBLIOGRAPHY

Ahlborg, G. & Bjorkman, O. (1987). Carbohydrate utilization by exercising muscle following pre- exercise glucose ingestion. **Clinical Physiology,** 7: 181 – 195.

Alberici, J.C. Farrel, P.A. Kris-Etherton, P.M. Shiveley, C.A. (1993). Effects of pre-exercise candy bar ingestion on glycemic response, substrate utilization, and performance. **International Journal of Sport Nutrition,** 3: 323 – 333.

Askew, E.W. (1984). Role of fat metabolism in exercise. **Clinics in Sports Medicine,** 3: 605 – 621.

Baldwin, K.M. Fitts, R.H. Booth, F.W. Winder, W.W. Holloszy, J.O. (1975). Depletion of muscle and liver glycogen during exercise. Protective effect of training. **Pflugers Archives – European Journal of Physiology,** 354:203 – 212.

Bangsbo, J. Graham, T.E. Kiens, B. Saltin, B. (1992). Elevated muscle glycogen and anaerobic energy production during exhaustive exercise in man. **Journal of Physiology, – London** 451: 205 – 227.

Behall, K.M. Scholfield, D.J. Canary, J. (1988). Effect of starch structure on glucose and insulin responses to ingested rice. **American Journal of Clinical Nutrition,** 47:428 – 32.

Bergstrom, J. Hermansen, L. Hultman, E. Saltin B. (1967(a)). Diet, muscle glycogen and physical performance. **Acta Physiologica Scandinavica,** 71: 140 – 150.

Bergstrom, J. Hermansen, L. Hultman, E. Saltin, B. (1967(b)). Diet, Muscle glycogen, and physical performance. **Acta Physiologica Scandinavica,** 87S: 1 – 24.

Blom, P.C. Vollestad, N.K. Costill D.L. (1986). Factors affecting changes in muscle glycogen concentration during and after prolonged exercise. **Acta Physiologica Scandinavica,** Supplement 556: 67 – 74.

Bonen, A. Malcolm, S.A. Kilgour, K.P. MacIntyre, K.P Belcastro, A.N. (1981). Glucose ingestion before and during intense exercise. **Journal of Applied Physiology: Respiratory, Environmental & Exercise Physiology,** 50: 766 – 771.

Brand, J.C. Colaguiri, S. Crossman, S. Allen, A. Roberts, D.C.K. Truswell, A.S. (1991). Low-glycemic index foods improve long-term glycemic control in NIDDM. **Diabetes Care,** 14:95 – 101.

Brouns, F. Saris, W.H.M. Stroecken, J. Beckers, E. Thijssen, R. Rehrer, N.J. ten Hoor F. (1989(a)) Eating, drinking and Cycling. A controlled Tour de France simulation study, part I. **International Journal of Sports Medicine,** 10: S32 – 40.

Brouns, F. Saris, W.H.M. Stroecken, J. Beckers, E. Thijssen, R. Rehrer, N.J. ten Hoor F. (1989(b)) Eating, drinking and Cycling. A controlled Tour de France simulation study, part II. Effect of diet manipulation. **International Journal of Sports Medicine**, 10: S41 – 8.

Burke, E.R. (1986). **The Physiology of Cycling.** In Science of Cycling (p.2), Champaign, IL. Human Kinetics.

Burke, L.M. Collier, G.R. Hargreaves, M. (1993). Muscle glycogen storage after prolonged exercise: effect of the glycemic index of carbohydrate feedings. **Journal of Applied Physiology,** 75:1019 – 23.

Burke, E.R. (1995(a)) **Serious Cycling**., University of Colorado, P.O. Box 5076, Champaign, Human Kinetics.

Burke, L. (1995(b)). Practical issues in nutrition for athletes. **Journal of Sport Science,** 13:S83 – 90

Burke, L. (1998). **The complete South African guide to Sports Nutrition**, Cape Town, Oxford University Press.

Coggan, A.R. & Coyle, E.F. (1987). Reversal of fatique during prolonged exercise by carbohydrate infusion and or ingestion. **Journal of Applied Physiology,** 63: 2388 – 2395.

Coggan, A.R. Coyle, E.F. (1988). Effects of carbohydrate feedings during high intensity exercise. **Journal of Applied Physiology,** 65: 1703 – 09.

Coggan, A.R. & Coyle, E.F. (1989). Metabolism and performance following carbohydrate ingestion late in exercise. **Medicine & Science in Sports & Exercise,** 21:59 – 65.

Coggan, A.R. & Coyle, E.F. (1991). Carbohydrate ingestion during prolonged exercise: effects on metabolism and performance. **Exercise & Sports Science,** 19: 1 – 40.

Coggan, A.R. Swanson, S.C. (1992). Nutrition manipulation before and during endurance exercise: effects on performance. **Medicine & Science in Sports & Exercise,** 24:331 – 5.

Collings, P. Williams, C. Macdonald. (1981). Effects of cooking on serum glucose and insulin responses. **British Medical Journal,** 282: 1032.

Conconi, F. Grazzi, G. Casoni, I. Guglielmini, C. Borsetto, C. Mazzoni, G. Patracchini, M. Manfredini, F. (1996). The Conconi Test: Methodology after 12 years of application. **International Journal of Sports Medicine,** 17:509 – 519.

Costill, D.L. Gollnick, P.D. Jansson, E.C. (1973). Glycogen depletion pattern in human muscle fibres during distance running. **Acta Physiologica Scandinavica,** 89: 374 – 383.

Costill, D.L. Dalsky, G.P. Fink, W.J. (1978). Effects of caffeine ingesting on metabolism and exercise performance. **Medical Science in Sport,** 10:155 –158.

Costill, D.L. Miller, J.M. (1980). Nutrition for endurance sport: carbohydrate and fluid balance. **International Journal of Sports Medicine,** 1:2 – 14.

Costill, D.L. Sherman, W.M. Fink, W.J. Maresh, C. Witten, M. Miller, J.M. (1981). The role of dietary carbohydrates in muscle glycogen synthesis after strenuous running. **American Journal of Clinical Nutrition** ,34: 1821 – 1836.

Costill, D.L. Coyle, E. Dalsky, G. Evans, W. Fink, W. Hoopes, D. (1986). Effects of elevated plasma FFA and insulin on muscle glycogen usage during exercise. **Journal of Applied Physiology,** 61: 165 – 172.

Costill, D.L. (1988). Carbohydrates for exercise: dietary demands for optimal performance. **International Journal of Sports Medicine,** 9: 1 – 18.

Costill, D.L. & Hargreaves, M. (1992). Carbohydrate nutrition and fatigue. (Review) **Sports Medicine,** 13:86 – 92.

Coyle, E.F. Hagberg, J.M. Hurley, B.F. Martin, W.H. Ehsani, A.A. Holloszy, J.O. (1983). Muscle glycogen utilization during prolonged strenuous exercise when fed carbohydrate. **Journal of Applied Physiology,** 59: 429 – 433.

Coyle, E.F. Coggan, A.R. (1984). Effectiveness of carbohydrate feeding in delaying fatigue during prolonged exercise. **Sports Medicine,** 1: 446 – 58.

Coyle E.F., Coggan A.R., Hemmert, M. K., Ivy J.L. (1986). Muscle glycogen utilization during prolonged strenuous exercise when fed carbohydrate. **Journal of Applied Physiology,** 61 : 165 – 172.

Coyle, E.F. (1995) Substrate utilisation during exercise in active people. **American Journal of Clinical Nutrition,** 61(suppl): 968S – 79S.

Dennis, S.C. Noakes, T.D. Hawley, J.A. (1997). Nutritional strategies to minimize fatigue during prolonged exercise: fluid, electrolyte and energy replacement. **Journal of Sport Sciences,** 15(3): 305 – 313.

Devlin, J.T. Calles, J. Escandon, J. Horton, E.S. (1986) Effects of pre-exercise snack feeding on endurance cycle exercise. **Journal of Applied Physiology,** 60:980 – 5.

Economos, C.D. Bortz, S.S. Nelson, E. (1993). Nutritional Practices of Elite Athletes – Practical Recommendations. **Sports Medicine,** 16(6):381 – 399.

Edwards, C.A. Rowland, I.R. (1992). Bacterial fermentation in the colon and its measurement. In: Schweizer T.F, Edwards, C.A eds. **Dietary fibre – a component of food. Nutritional function in health and disease.** London: Springer – Verlag, 119 – 50.

El-Sayed, M.S. MacLaren, D. Rattu, A.J. (1997). Exogenous carbohydrate utilisation: effects on metabolism and exercise performance. **Comp Biochem Physiol A Physiol**. 118 (3): 789 – 803.

Ercan, N. Nutall, F.Q. Gannon, M.C. (1994). Effects of added fat on plasma glucose and insulin response to ingested potato given in various combinations as two meals in normal individuals. **Diabetes Care,** 17:1453 – 9.

Felig, P. Cherif, A. Minagawa, A. Wahren. (1982). Hypoglycemia during prolonged exercise in normal men. **Northern England Journal of Medicine**, 306:895 – 900.

Foster, C. Costill, D.L Fink, W.J. (1979). Effects of pre-exercise feedings on endurance performance. **Medicine and Science in Sports,** 11: 1 – 5.

Frentsos, J.A. & Baer, J.T. (1997). Increased energy and nutrient intake during training and competition improves elite triathletes' endurance performance. **International Journal of Sport Nutrition,** 7(1): 61 – 71.

Gabel, K.A. Aldous, A. Edgington, C. (1995). Dietary intake of two elite male cyclists during 10-day, 2050-mile ride. **International Journal of Sports Nutrition** 5(1): 56 – 61.

Garcia – Roves, R.M. Terrados, N. Patterson, A.M. (1998). Macronutrients intake of top level cyclists during continuous competition – change in feeding pattern. **International Journal of Sports Medicine,** 19(1): 61 – 7.

Gatti, E. Testolin, G. Noe, D. (1987) Plasma glucose and insulin responses to carbohydrate food (rice) in different thermal processing. **Annals of nutrition and metabolism.** 31:296 – 303.

Gleeson, M. Maughan, R.J. Greenhaff, P.L. (1986). Comparison of the effects of pre-exercise feeding of glucose, glycerol and placebo on endurance and fuel homeostasis in man. **European Journal of Applied Physiology & Occupational Physiology,** 55: 645 – 653.

Gollnick, P.D. Pernow, B. Essen, B. Jansson, E. Saltin, B. (1981). Availability of glycogen and plasma FFA for substrate utilization in leg muscle of man during exercise. **Clinical Physiology,** 1: 27 – 42.

Goodpaster, B.H. Costill, D.L. Fink, W.J. Trape, T.A. Jozsi, A.C. Starling, R.D. Trappe, S.W. (1996). The Effects of Pre-exercise Starch Ingestion on Endurance Performance. **International Journal of Sports Medicine,** 17:366 – 372.

Grandjean, A.C. & Ruud, J.S. (1994). Nutrition for cyclists. **Clinics in Sports Medicine** 13 (1): 235 – 47.

Guezennec, C.Y. Sabatin, P. Duforez, F. Merino, D. Peronnet, Koziet, J. (1989). Oxidation of corn starch, glucose and fructose ingested before exercise. **Medicine and Science in Sports and Exercise,** 21: 45 – 50.

Guezennec, C.Y. Sabatin, P. Duforez, F. Koziet, J. Antoine J.M. (1993). The role of type and structure of complex carbohydrates response to physical exercise. **International Journal of Sports Medicine,** 14: 224 – 231.

Hargreaves, M. Costill, D.L. Coggan, A. Fink, W.J. Nishibata, I. (1984). Effects of carbohydrate feedings on muscle glycogen utilization and exercise performance. **Medicine and Science in Sports and Exercise,** 16: 219 – 22.

Hargreaves, M. Costill, D.L. Katz, A. Fink, W.J. (1985). Effects of fructose ingestion on muscle glycogen usage during exercise. **Medicine and Science in Sports and Exercise 17,** 360 – 363.

Hargreaves, M. Costill, D.L. Fink, W.J. King, D.S. Fielding, R.A.: (1987). Effects of pre-exercise carbohydrate feedings on endurance cycling performance. **Medicine and Science in Sports and Exercise**, 19: 33 – 36.

Havel, R.J. Pernow, B. Jones, N.L (1966). Uptake and release of tree fatty acids and other metabolism in the legs of exercising man. **Journal of Applied Physiology,** 23: 90 – 96.

Hawley, J.A. Schabort, E.J. Noakes, T.D. Dennis, S.C. (1997). Carbohydrate loading and exercise performance: an update. **Sports Medicine,** 24(2): 73 – 81.

Heathe, G.W. Gavin, J.R. Hinderliter, J.M. Hagberg, J.M. Bloomfield, S.A. Holloszy J.O. (1983). Effects of exercise and lack of exercise on glucose tolerance and insulin sensitivity. **Journal of Applied Physiology.** 55: 512 – 517.

Heaton, K.W. Marcus, S.N. Emmett, P.M. Bolton, C.H. (1988). Particle size of wheat, maize, and oats test meals: effects on plasma glucose and insulin responses and on the rate of starch digestion in vitro. **American Journal of Clinical Nutrition,** 47: 675 – 82.

Holt, S.H.A. & Brand Miller, J. (1995). Increased insulin response to ingested foods associated with lessened satiety. **Appetite,** 24:43 – 54.

Hole, J.W. (1993). **Human Anatomy and Physiology**, sixth edition. Oxford England. Wm. C. Brown Publishers.

Horowitz, J.F. & Coyle, E.F. (1993). Metabolic responses to pre-exercise meals containing various carbohydrates and fat. **American Journal of Clinical Nutrition,** 58: 235 – 241.

Hultman, E. (1967). Studies on muscle metabolism of glycogen and active phosphate in man with special reference to exercise and diet. **Scandinavian Journal of Clinical Laboratory Investigation,** Supplement 94.

Ivy, J.L. Miller, W. Dover, V. Goodyear, L.G. Sherman, W.M Farrell, S. Williams, H. (1983). Endurance improved by ingestion of a glucose polymer supplement. **Medicine & Science in Sports & Exercise,** 15: 466 – 471.

Ivy, J.L. Katz, A.L. Cutler, C.L. Sherman, W.M. Coyle E.F. (1988(a)). Muscle glycogen synthesis after exercise: effect of time of carbohydrate ingestion**. Journal of Applied Physiology**, 64:1480 – 1485.

Ivy, J.L. Lee, M.C. Brozininck, J.K. Reed, M.J. (1988(b)). Muscle glycogen storage after different amounts of carbohydrate ingestion. **Journal of Applied Physiology,** 65:2018 – 23.

James, D.E. & Kraegen, E.W. (1984). The effect of exercise training on glycogen, glycogen synthase and phosphorylase in muscle and liver. **European Journal of Applied Physiology & Occupational Physiology,** 52: 276 – 281.

Jandrain, B.G. Krzentowski, G. Pirnay, F. Lacroix, A. Luyckx, A. Lebevre, P. (1984). Metabolic availability of glucose ingested 3 hours before prolonged exercise in humans. **Journal of Applied Physiology: Respiratory, Environmental & Exercise Physiology,** 56: 1314 – 1319.

Jardine, M.A. Wiggins, T.M. Myburgh, K.H. Noakes, T.D. (1988). Physiological characteristics of rugby players including muscle glycogen content and muscle fibre composition. **South African Medical Journal 73: 529 – 532.**

Jarvi, A.E. Karlstrom, B.E. Granfeldt, Y.E. Bjorck, I.E. Asp, N.L. Vessby, B.O.H. (1999). Improved Glycemic control and lipid profile and normalized fibrinolytic activity on a low-glycemic index diet in type 2 diabetic patients**. Diabetes Care**, 22: 10 – 18.

Jenkins, A.B. Chisholm, D.J. James, D.E. Ho, K.Y. Kraegen, E.W. (1985). Exercise induced hepatic glucose output is precisely sensitive to the rate of systemic glucose supply. **Metabolism**, 34: 431 - 436.

Jenkins, D.J.A. Thomas, D.M. Wolever, M.S. Taylor, R.H. Barker, H. Hasheim, Fielden, S.R.D. Baldwin, J.M. Bowling, A.C. Newman, H.C. Jenkins, A.L. Goff, D.V. (1981). Glycemic index of foods: a physiological basis for carbohydrate exchange. **American Journal of Clinical Nutrition,** 34: 362 – 366.

Jenkins, D.J.A. Wolever, T.M.S. Taylor, R.H. (1984). Glycemic Index of foods: a physiological basis for carbohydrate exchange. **Americal Journal of Clinical Nutrition,** 34:362 – 6.

Jenkins, D.J.A. Wolever, T.M.S. Kalmusky, J. Guidici, S. Giordano, C. Wong, G.S. Bird, J.N. Pattern, R. Hall. M. Buckley G. Little, J.A. (1985). Low glycaemic index carbohydrate foods in the management of hyperlipedemia. **American Journal of Clinical Nutrition,** 42:604 – 617.

Karlsson, J. & Saltin, B. (1971). Diet, muscle glycogen and endurance performance. **Journal of Applied Physiology,** 31:203 – 206.

Karlsson, J. & Jacobs, I. (1982). Onset of blood lactate accumulation during muscular exercise as a threshold concept. I. Theoretical considerations. **International Journal of Sports Medicine**, 3:190.

Kiens, B. Raben, A.K. Valeur, A.K. Richter, E.A. (1990). Benefits of dietary simple carbohydrates on the early post-exercise muscle glycogen repletion in male athletes (Abstract). **Medicine & Science in Sports & Exercercise,** 22, Suppl: S88.

Langenfeld, M.E Seifert, J.G. Rudge, S.R. Bucher, R.J. (1994). Effects of carbohydrate ingestion on performance of non-fasted cyclists during a simulated 80-mile time trial. **The Journal of Sports Medicine and Physical fitness,** 34:263 – 70.

Leeds, A. Brand Miller, J. Foster-Powell, K. Colagiuri, S. (1998). The **G.I. Factor – The Glycaemic Index solution**., Australia, Coronet Books.

Lemon, P.W.R. & Mullin, J.P. (1980). Effect of initial muscle glycogen levels on protein catabolism during exercise. **Journal of Applied Physiology: Respiratory, Environmental & Exercise Physiology,** 48:624 – 629.

Lemon, P.W.R. (1995). Do athletes need more dietary proteins and amino acids? **International Journal of Sport Nutrition,** 5:S39 – 61.

MacLaren, D.P.M. Reilly, M.T. Campbell, I.T. Frayn, K. (1994). Hormonal and metabolite responses to glucose maltodextrin ingestion with or without the addition of guar. **International Journal of Sports Medicine,** 15: 466 – 471.

Mason, W.L. McConnell, G. Hargreaves, M. (1993) Carbohydrate ingestion during exercise: liquid vs solid feedings. **Medicine & Science in Sports & Exercise,** 25: 966 – 9.

McArdle, W.D. Katch, F.I. Katch, V.L. (1991) **Exercise Physiology** – Energy, Nutrition, and Human Performance. USA. Lea & Febiger.

McConnel, G. Kloot, K. Hargreaves, M. (1996). Effects of timing of carbohydrate ingestion on endurance exercise performance. **Medicine & Science in Sports & Exercercise,** 28 (10): 1300 – 4

Mitchell, J.B. Costill, D. Houmard J.A., Flynn M.G., Fink W.J., Beltz J.D.: Effects of carbohydrate ingestion on gastric emptying and exercise performance. **Medicine & Science in Sports & Exercise,** 20: 110 - 115, 1988.

Murdoch, S.D. Bazarre, T.L. Snider, I.P. Goldfarb A.H (1993). Differences in the effects of carbohydrate food form on endurance performance to exhaustion. **International Journal of Sport Nutrition**, 3(1): 41 – 54.

Murray, B. Paul, G. Seifert, J. Eddy, D. (1991). Responses to varying rates of carbohydrate ingestion during exercise. **Medicine & Science in Sports & Exercise,** 23 (6): 713 – 718.

Ness, G.W Gardiner P.F. Secord, D.C Taylor, A.W. (1975) The effects of swimming and running regimens on skeletal muscle glycogen in the rat. **Revue Canadienne de Biologie** 34: 45 – 50.

Nicklas, T.A. Johnson, C.C. Myers, L. Webber, L.S. Berenson, G.S. (1995). Eating patterns,nutrient intakes, and alcohol consumption patterns of young adults: the **Boglusa Heart Study**. 4(5): 316 – 324

O'Dea, K. Nestel, P.J. Antonoff, L. (1980). Physical factors influencing postprandial glucose and insulin responses to starch. **American Journal of Clinical Nutrition**. 33: 760 – 5.

Oasci, L.B. Essig, D.A. Palmer, W.K. (1990). Lipase regulation of muscle triglyceride hydrolysis**. Journal of Applied Physiology,** 69:1571 – 7.

Okano, G. Takeda, H. Marita, I. Katch, M. Mu, Z. Miyake, S. (1988). Effects of pre-exercise fructose ingestion on endurance performance in fed men. **Medicine & Science in Sports & Exercise,** 20:105 - 9

Prentice, W. (1994) **Fitness for College and Life.** Fourth edition. St. Louis, USA. Wm. C. Brown Publishers.

Reed, M.T. Brozinick, J.R. Lee, M.C. Ivy, J.L. (1989). Muscle glycogen storage post-exercise: effect of mode of carbohydrate administration. **Journal of Applied Physiology,** 66:720 – 6.

Ren, J.M. Broberg S. Sahlin, K. Hultman, E. (1990). Influence of reduced glycogen level on glycogenolysis during short-term stimulation in man. **Acta Physiologica Scandinavica 139,** 467 – 474.

Robertson, R.J. Stanko, R.T. Goss, F.L. Spina, J.J. Reilly, J.J. Greenwalt, K.D. (1990). Blood glucose extraction as a mediator of perceived exertion during prolonged exercise. **European Journal of Applied Physiology,** 61:100 – 105.

Romijn, J.A. Coyle, E.F. Sidossis, L. Gastaldelli, A. Horowitz, J.F. Endert, E. Wolfe, R.R. (1993). Regulation of endogenous fat and carbohydrate metabolism in relation to exercise intensity**. American Journal of Physiology,** 265:E380 – 91.

Ross, S.W. Brand, J.C. Thornburn, A.W. Thruswell A.S. (1987). Glycemic index of processed wheat products. **American Journal of Clinical Nutrition,** 46: 631 – 5.

Sahlin, K. Katz, A and Broberg S. (1990) Tricarboxylic acid cycle intermediates in human muscle dufing prolonged exercise. **American Journal of Physiology,** 259: C834 – C841.

Saltin, B. Karlsson, J. (1971). Muscle glycogen utilization during work of different intensities. In: Pernow, B. Saltin, B. (eds): **Muscle Metabolism during Exercise,** New York, Plenum Press.

Saris, W.H.M. van Erp-Baart, M.A. Brouns, F. Westerterp, K.R. ten Hoof, F. (1989). Study on food intake and energy expenditure during extreme sustained exercise: Tour de France. **International Journal of Sports Medicine,** 10:S26 – 31.

Sherman, W.M. & Lamb, D.R. (1988). Nutrition and prolonged exercise. In: Lamb, D.R. Murray, R. eds. **Perspectives in exercise science and sports medicine.** Vol 1. Prolonged exercise. Indianapolis: Benchmark 213 – 80.

Sherman, W.M. Brodowicz, G. Wright, D.A. Allen, W.K. Simonsen, JC. Dernbach A. (1989). Effects of 4 hour pre-exercise carbohydrate feedings on cycling performance. **Medicine & Science in Sports & Exercise,** 21: 598 – 604.

Sherman, W.M. Peden, M.C. Wright, D.A. (1991). Carbohydrate feedings 1 hour before exercise improves cycling performance. **American Journal of Clinical Nutrition,** 54: 866 – 870.

Sherman, W.M. (1995). Metabolism of sugars and physical performance. **American Journal of Sports Medicine,** 62(suppl): 228S – 41S.

Slentz, C.A. Davis, J.M. Settles, D.L. Pate, R.R. (1990). Glucose feedings in rats: glycogen use, hormone responses and performance. **Journal of Applied Physiology**. 69: 989 – 994.

Spencer, M.K. Yan, Z. Katz A. (1992). Effect of low glycogen and carbohydrate and energy metabolism in human muscle endurance during exercise. **American Journal of Physiology** 262: C975 – C979.

Taylor, A.W (1979). The effects of different feeding regimens and endurance exercise programs on carbohydrate and lipid metabolism. **Canadian Journal of Applied Sport Sciences 4,** 126 – 130, 1979.

Thomas, D.E. Brotherhood, J.R. Brand, J.C. (1991). Carbohydrate feeding before exercise: Effect of the Glycemic Index. **International Journal of Sports Medicine,** 12:nr2 180 – 186.

Thomas, D.E. Brotherhood, J.R. Miller, J.B. (1994). Plasma glucose levels after prolonged strenuous exercise correlate inversely with glycemic response to food consumed before exercise. **International Journal of Sport Nutrition,** 4 (4): 361 – 373.

Trout, D.L. Behall, K.M. Oslesi, O. (1991). Prediction of Glycaemic Index for starchy foods. **American Journal of Clinical Nutrition,** 58:873 – 8.

Truswell, A.S. (1992). Glycaemic Index of foods. **European Journal of Clinical Nutrition**, 46: S91 – S101.

Uusitupa, M.I.J. (1994). Fructose in the diabetic diet. **American Journal of Clinical Nutrition,** 59(suppl): 753S – 7S.

Volek, J.S. Houseknecht, K. Kraemer, W.J. (1997). Nutritional strategies to enhance performance of high-intensity exercise. **Strength and Conditioning**. February: 11 – 17.

Wagenmakers, A.J. Brookes, J.H. Coakley, J.H. Reilly, T. Edwards, R.H. (1989). Exercise enduced activation of the branched-chain 2-oxo acid dehydrogenase in human muscle. **European Journal of Applied Physiology & Occupational Physiology,** 59: 159 – 167.

Wahren, J.P. Felig, P. Ahlborg, G. Jorfeldt, L. (1971). Glucose metabolism during leg exercise in man. **Journal of Clinical Investigation,** 50: 2715 – 2725.

Walton, P & Rhodes E.C. (1997) Glycaemic Index and optimal performance. **Sports Medicine**. 23(3): 164 – 172.

Welch, I.M. Bruce, C. Hill, S.E. Read, N.W. (1987). Duodenal and ileal lipid suppresses postprandial blood glucose and insulin responses in man. **Clinical Science,** 72: 209 – 16.

Westerterp, K.R. Saris, W.H.M. van Es, M. Ten Hoor, F. (1986). Use of the doubly labelled water technique in humans during heavy sustained exercise. **Journal of Applied Physiology**. 61:2162 – 2167.

Widrick, J.J., Costill, D.L., Fink W.J., Hickey M.S., McConnel G.K., H Tanaka (1993). Carbohydrate feedings and exercise performance: effects of initial muscle glycogen concentration. **Journal of Applied Physiology,** 74: 2998 – 3005.

Wilber, R.L & Moffat, R.J. (1992). Influence of carbohydrate ingestion on blood glucose and performance in runners. **International Journal of Sports Nutrition,** 2: 317 – 327.

Williams, M.H. (1992). **Nutrition for fitness and sport.** Third edition. USA. Wm. C Brown Publishers.

Winder, W.W. Terry, M.L. Mitchell, V.M. (1985). Role of plasma epinephrine in fasted exercising rats. **American Journal of Physiology.** 248: R302 – 307.

Wolever T.M.S. (1990). Relationship between dietary fibre and composition in food and the glycemic index. **American Journal of Clinical Nutrition,** 51:72 – 5.

Wright, D.A. Sherman, W.M Dernbach, A.R. (1991). Carbohydrate feedings before, during, or in combination ipmrove cycling endurance performance. **Journal of Applied Physiology,** 71: 1082 – 1088.

Zawadzki, K.M. Yaspelkis III B.B. Ivy, J.L. (1992). Carbohydrate – protein complex increases the rate of muscle glycogen storage after exercise. **Journal of Applied Physiology,** 72: 1845 – 9.