# Efficacy of Cellfood® and Switch™ as Ergogenic Aids in Endurance Athletes

by

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# DEDICATION

This dissertation is dedicated to my wife, Kim

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**THE ALMIGHTY:** In Him anything is possible.

# SYNOPSIS


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|---|---|
| **TITLE** | : Efficacy of Cellfood® and Switch™ as Ergogenic Aids in Endurance Athletes |
| **CANDIDATE** | : H.W. Nolte |
| **SUPERVISOR** | : Dr. H.J. van Heerden |
| **DEGREE** | : M.A. (HMS) |

The efficacy of Cellfood® and Switch™ as ergogenic aids for endurance runners was evaluated using a pre-test – post-test, double-blind cross-over, placebo controlled experimental design. Thirty marathon runners (19 males and 11 females) between the ages of 20-51 years (mean age = 38.4 ± 8.2 years), who could maintain a minimum running pace of 7.5 minutes per km, volunteered to take part in the study. Subjects were randomly assigned to either a placebo (n = 10), Cellfood® (n = 10) or Switch™ (n = 10) group. Each of the groups underwent a supplementation period comprising three four-week cycles of varying dosages, as recommended by the manufacturer. After each cycle the subjects stopped supplementation during a two-week washout period, prior to crossing-over to an alternative supplementation and dosage cycle.

In an analysis of significant changes ($p<0.05$) from baseline values within groups across the three cycles, Switch™ showed an ergogenic increases in red blood cell count (7.8%) and hematocrit (6.2%) during the first (low-dosage) cycle. Cellfood® showed a potentially ergolytic increase of 6.9% in lactate accumulation at 14 km/h treadmill speed during the second (intermediate-dosage) cycle. Switch™ showed an ergogenic decrease in lactate accumulation of 17.2% at 14 km/h during the third (high-dosage) cycle. Cellfood® showed an ergogenic decrease of 4% in $VE/V0_2$ during the first cycle, while Switch™ showed a similar decrease of 4.5% during the second cycle. During the third cycle Cellfood® showed an ergogenic increase of 5% in absolute $V0_2max$. In an analysis of significant differences ($p<0.05$) in changes between groups, across the three cycles, Switch™ showed an increase (5.7%) in haemoglobin (Hb) concentration after the first cycle, which differed significantly from an inverse decrease in Cellfood® (6.8%). During cycle two, Cellfood® showed an increase of 3.2% in haemoglobin concentration, which differed significantly from an

inverse decrease in Switch™ (3.3%). During the first cycle, Switch™ showed an increase in red blood cell count of 7.8%, which differed significantly from an inverse decrease of 1.2% in Cellfood®. The increase in hematocrit (6.2%) observed with Switch™ during cycle one, differed significantly from an inverse decrease of 11.8% observed in Cellfood®. During the second cycle, a reverse tendency was found in hematocrit, with Cellfood® showing an increase of 3.0%, which differed significantly from a decrease of 7.7% in Switch™. In the third cycle, Switch™ showed a potentially ergolytic decrease of 2.2% in haemoglobin saturation at 17 km/h, which differed significantly from an unchanged concentration in Cellfood®. During the third cycle, Cellfood® showed a significantly greater ergogenic decrease of 4.5% in heart rate at 10km/h, as compared to the corresponding 0.3% reduction observed in Switch™ .

In conclusion, when considering the relative efficacy of the two products with respect to potential ergogenic benefits throughout any of the cycles, Cellfood® (at the highest dosage) was the most superior, followed by Switch™ (at the lowest dosage), with both products either matching or being superior to placebo in any of the dosage cycles.

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**KEY WORDS**

Cellfood®; Switch™; Haemoglobin Concentration and Saturation; Hematocrit; Heart Rate; Blood Lactate Concentration; VE/$V0_2$; Absolute $V0_2$max.

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# SINOPSIS

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|---|---|
| **TITEL** | : Doeltreffendheid van Cellfood® en Switch™ as Ergogeniese Middels vir Uithouvermoë Atlete |
| **KANDIDAAT** | : H.W. Nolte |
| **STUDIELEIER** | : Dr. H.J. van Heerden |
| **GRAAD** | : M.A. (MBK) |

Die doeltreffendheid van Cellfood® en Switch™ as ergogeniese middels vir uithouvermoë atlete is ondersoek. 'n Voor-toets – na–toets, dubbel-blind oorkruis, plasebo beheerde eksperimentele ontwerp is vir die doel aangewend. Dertig maraton atlete (19 manlik en 11 vroulik) tussen die ouderdomme van 20 en 51 (gemiddelde ouderdom = 38.4 ± 8.2 jaar), wie 'n minimum hardloopspoed van 7.5 minute per kilometer kon handhaaf, het vrywillig aan die studie deelgeneem. Die proefpersone is lukraak na 'n plasebo (n = 10), Cellfood® (n = 10) of Switch™ groep (n = 10) toegewys. Elkeen van die groepe het 'n aanvullingstydperk van drie, vier-week siklusse met verskillende doserings, soos deur die vervaardigers aanbeveel, deurgemaak. Na die afloop van elke siklus het proefpersone die aanvullings vir 'n twee-week uitwas tydperk gestaak, waarna hulle met die volgende produk en dosis siklus begin het.

Met ontleding van beduidende veranderinge ($p<0.05$) tussen die voor- en na-toets waardes binne die groepe, oor die drie verskillende siklusse, het Switch™ 'n ergogeniese verhoging in rooi bloedseltelling (7.8%) en hematokrit (6.2%) na die eerste siklus (lae-dosering) getoon. Cellfood® het 'n potensïele ergolitiese toename van 6.9% in laktaat akkumulasie teen 14km/h tydens die tweede siklus (middel dosering) getoon. Switch™ het 'n ergogeniese afname van 17.2% in laktaat akkumulasie getoon teen 14km/h gedurende die derde siklus (hoë-dosering). Cellfood® het 'n ergogeniese afname van 4.0% in $VE/V0_2$ getoon tydens die eerste siklus terwyl Switch™ 'n soortgelyke afname van 4.5% getoon het tydens die tweede siklus. Tydens die derde siklus het Cellfood® 'n ergogeniese toename van 5% getoon in absolute $V0_2$ maks.

Met ontleding van beduidende verskille ($p<0.05$) in veranderings tussen groepe, oor die drie verskillende siklusse, het Switch™, tydens die eerste siklus 'n toename van (7.5%) in hemoglobien konsentrasie getoon wat beduidend verskil het van 'n omgekeerde afname in Cellfood® (6.8%). Tydens die tweede siklus het Cellfood® 'n toename van 3.2% in hemoglobien konsentrasie getoon, wat beduidend verskil het van 'n omgekeerde afname in Switch™ (3.3%). Tydens die eerste siklus het Switch™ 'n toename van 7.8% in rooibloedsel telling getoon wat beduidend verskil het van 'n omgekeerde afname van 1.2% in Cellfood®. Die toename in hematokrit (6.2%) in Switch™ tydens die eerste siklus, het beduidend verskil van 'n omgekeerde afname van 11.8% in Cellfood®. Tydens die tweede siklus was daar 'n omgekeerde tendens in die hematokrit waardes, met Cellfood® wat 'n toename van 3.0% getoon het wat beduidend verskil het van 'n afname van 7.7% in Switch™. Tydens die derde siklus het Switch™ 'n potensiële ergolitiese afname van 2.2% in hemoglobien versadiging getoon teen 17km/h. Hierdie afname het beduidend verskil van 'n onveranderde versadiging in Cellfood®. Tydens die derde siklus het Cellfood® 'n beduidend groter ergogeniese afname van 4.5% in harttempo getoon teen 10km/h teenoor die 0.3% afname wat in Switch™ waargeneem.

Wanneer die relatiewe doeltreffendheid van die twee produkte as ergogeniese middels deur alle siklusse samevattend in ag geneem word, was Cellfood® (teen die hoogste dosering) die mees doeltreffend, gevolg deur Switch™ (teen die laagste dosering), terwyl beide produkte tydens enige van die siklusse ten minste die gelyke of meer doeltreffend was as die plasebo.

**SLEUTELWOORDE**

Cellfood®; Switch™; Hemoglobien Konsentrasie en Versadiging; Hematokrit; Harttempo; Bloed Laktaat Konsentrasie; $VE/V0_2$; Absolute $V0_2$maks.

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# CHAPTER 1

# THE PROBLEM

## 1.1 INTRODUCTION

Athletes of various ages and levels of participation explore the use of ergogenic aids. Attempts to enhance athletic performance are not new. The Olympic games date back 2700 years, which means that seeking advantage in sport likely dates back just as far. The winner of the 1920 Olympic 100m dash, Charlie Paddock, drank sherry with raw eggs before the race. In 1960, the Danish cyclist Knut Jensen died during a road race from taking amphetamines (Voy and Deeter, 1991). The use of drugs to enhance performance is not limited to Olympic athletes only. Many adolescent athletes experiment with anabolic steroids. Caffeine is widely used as an ergogenic aid by runners, cyclists and tri-athletes and creatine is a popular supplement amongst university strength and power athletes (Eichner, 1993; Sinclair and Geiger, 2000). Considerable literature exists on the topic of ergogenic aids and athletic performance. It includes studies of the potential performance benefits of alcohol, amphetamines, epinephrine, aspartates, red cell reinfusion, caffeine, steroids, protein, phosphates, oxygen-rich breathing mixtures, gelatin, lecithin, wheat-germ oil, vitamins, sugar, ionized air, music, hypnosis, and even marijuana and cocaine (McArdle et al., 1991).

The ever-growing quest among sports participants to perform better and the abundance of ergogenic supplements makes it the responsibility of the scientific community to ensure that the public are well informed. Knowledge is necessary to lead us into the right direction. The health-related safety of these products is an obvious and urgent research concern. A prudent approach should also, however, focus on issues of efficacy in order to guide consumer spending and thus protect the public from exploitation.

## 1.2 STATEMENT OF THE PROBLEM

The industry of ergogenic supplementation has become a massive commercial enterprise. A series of products manufactured by Oxygen for Life (Pty) Limited are currently on the market for use as ergogenic aids in sport relying on aerobic energy provision. These include Cellfood® and Switch™. The efficacy of these products and their dosage response within the context of improved aerobic performance requires study.

## 1.3 AIM OF THE STUDY

In cognisance of the foregoing the purpose of the study was three-fold:

- Firstly, to determine whether Switch™ and Cellfood® have a beneficial effect on the physical performance of endurance athletes;
- Secondly, to determine whether either of the two products are a superior supplement when compared to the other; and
- Thirdly, to determine at which dosage these supplements tend to be most effective.

## 1.4 HYPOTHESES

In accordance with the stated purpose of the study the following hypotheses were formulated:

- The use of Cellfood® or Switch™ would improve the physiological performance of an endurance runner.
- There is no difference between the efficacy of Cellfood® or Switch™ as an ergogenic aid.
- The efficacy of both Cellfood® and Switch™ as an ergogenic aid for endurance runners, is dosage dependant.

## 1.5 DELIMITATION

The scope of the research undertaken was delimited to an experimental study. Within this context the products Cellfood® and Switch™ were interpreted as a form of ergogenic aid used by endurance athletes to improve their aerobic performance. Both male and female athletes of marathon clubs in the immediate geographical area of Pretoria, South Africa were used as subjects for the study. The subjects represented the average male and female marathon runner, which makes the results applicable to the general road running public living at a mild altitude elevation of 1369 meters above sea level.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 BIOENERGETICS

If one could select a single term that might be considered a common denominator for every aspect of physical activity the term energy is probably the most appropriate. It is through the release of energy that a muscle is able to contract. The manner in which this energy store is depleted essentially depends on the fitness of the individual and the kind of physical activity being performed. The modification or increase of energy stores through training, significantly improves physical performance (Fox and Bowers, 1993). Other methods of altering energy stores via ergogenic substances mainly target one or more of the body's energy systems to aid the natural production and release of energy for enhanced performance.

In the body nutrients, as an indirect energy source, go through a profound series of chemical reactions or metabolic pathways leading to the formation of adenosine triphosphate (ATP), the body's direct source of energy for all biological work. Studying these pathways allows one to make valid and safe applications to physical activity programs concerning nutrition and performance, the onset and delay of muscular fatigue, body weight control, specificity of training programs and heat balance (Fox and Bowers, 1993).

Unlike the physical properties of matter, it is difficult to define energy in concrete terms of size, shape or mass. Rather, the term energy suggests a dynamic state related to a condition of change, because the presence of energy is revealed only when change has taken place. Within this context, energy relates to the ability to perform work. As work increases, the transfer of energy also increases so that change occurs (McArdle et al.,1991). Any physical or chemical process that results in the release of energy to its surroundings is termed exergonic. Exergonic reactions can be viewed as "downhill" processes and result in a release of free energy. This energy is

useful for work and is typically utilized to fuel or drive "uphill" endergonic reactions which require and absorb energy.

The above is exemplified in the energy liberated during the breakdown of food being employed to manufacture ATP, which is stored in all muscle cells. In turn, the energy released by the breakdown of this compound is used by the cell to perform its specialized work. The structure of ATP consists of one complex component, adenosine and three less complex but "energetic" phosphate groups. For the purpose of exercise physiology, ATP's chemical value lies in these phosphate groups. The bonds between the two terminal phosphate groups represent so-called high-energy bonds. When 1 mole of these phosphate bonds is broken down, 7 to 12 kilocalories of energy are liberated, with adenosine diphosphate (ADP) and inorganic phosphate (Pi) being formed as byproducts.

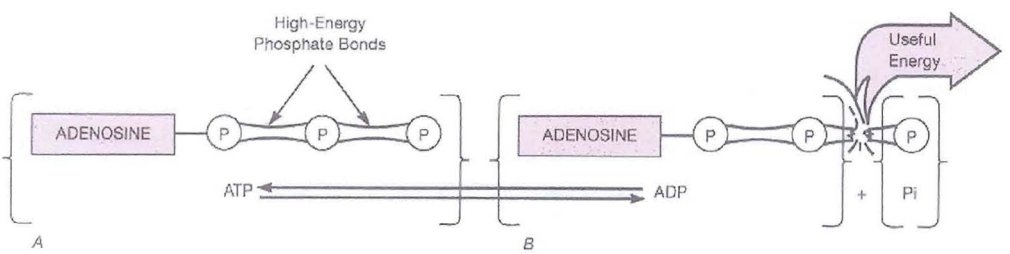


**Figure 2.1: A. simplified structure of ATP, showing high-energy phosphate bonds. B. Breakdown of 1 mole of ATP to ADP and inorganic phosphate (Pi), with the release of useful energy. (Fox and Bowers, 1993).**

## 2.2 ENERGY FOR METABOLIC WORK

Contraction of skeletal muscle, like all biological work, is powered by the energy released through hydrolysis of the high-energy ATP. This reaction is catalyzed by the enzyme myosin ATPase. One must keep in mind that at any given time there are limited amounts of ATP in the muscle cell and that ATP is constantly being used and regenerated. The regeneration of ATP is endergonic and requires energy. There are three common exergonic processes

for the production of ATP. Muscle fibres contain the metabolic machinery to produce ATP by these common energy-yielding pathways, viz.:

1. creatine phosphate (CP) system;
2. glycolysis; and
3. aerobic oxidation of nutrients.

The CP or phosphagen system involves the immediate transfer of high-energy phosphate from CP to rephosphorylate ADP to ATP. This reaction is rapid because it involves only one enzymatic step. Although this reaction is not dependent on oxygen in the cell, CP exists in finite quantities and thus the total amount of ATP that can be produced through this mechanism is limited.

The second metabolic pathway capable of producing ATP without the involvement of oxygen exists in the cytoplasm of the muscle cell and is termed glycolysis or the lactate system. Glycolysis entails the the partial degradation of carbohydrate to pyruvate or lactate and involves a series of enzymatically catalyzed steps to provide energy for the rapid, short-term resynthesis of ATP.

The final aerobic metabolic pathway active in cells for the long-term production of ATP is a combination of two complex metabolic processes and functions within the mitochondria. The process involves the initial breakdown of carbohydrate (glycolysis), fat (lypolysis) and protein (proteolysis) followed by further decarboxylation and dehydrogenation of these precursors in the Krebs cycle. Subsequently, during the electron transport mechanism the oxygen acts as the final hydrogen acceptor to form water and large amounts of ATP via oxidative phosphorylation (Durstine et al., 1993; McArdle et al., 1991; Fox and Bowers, 1993; Meyer and Meij, 1996; Martini, 1995).

## 2.3 FACTORS RELATED TO PERFORMANCE

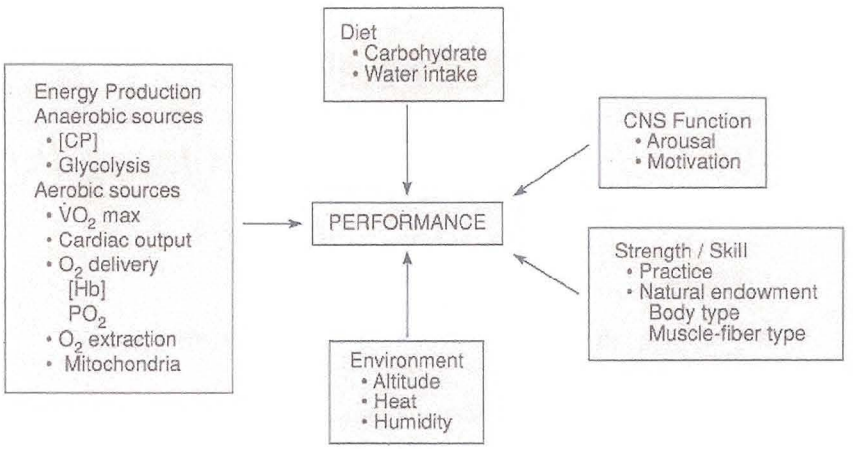


**Figure 2.2 Factors affecting performance (Powers and Howley, 1994)**

As indicated in Figure 2.2, various variables exists that influence the performance of an athlete. Training techniques as well as physiological, dietary and environmental factors contribute to the level of success or failure that an athlete experiences. Some of these variables could be considered to be controllable factors, i.e. diet and training, while others like physiological and environmental factors cannot be altered by the individual. Studying these variables and their influence on performance is important in understanding the human body and its capabilities and limitations.

### 2.3.1 Maximal Oxygen Uptake ($V0_2max$)

$V0_2max$ functionally represents the maximal amount of oxygen that can be removed from circulating blood and used by the working tissues during a specified period. Whether the relationship between increasing oxygen consumption and running speed is linear or curvilinear has been a subject of great interest and varying opinion ever since the early experiments of Hill and Lupton in 1923 (Martin and Coe, 1997). Maximal oxygen consumption can be defined as the maximal rate at which oxygen can be consumed per minute during large-muscle-group activity of continuously progressively increasing intensity until exhaustion. The region where oxygen uptake plateaus and shows no further increase, or increases only slightly with an additional

workload, is called maximal oxygen uptake, maximal oxygen consumption, maximal aerobic power or simply $V0_2max$ (McArdle et al., 1996).

The above concept has been the topic of heavy debate during the past few years. Recent literature has questioned the very existence of $V0_2max$. It is necessary to clarify the physiological basis of maximal oxygen utilization. Noakes recently considered $V0_2max$, defined as reaching a plateau of $V0_2$ at high power outputs, a myth (Noakes, 1998). Further questions arose regarding the traditional view that maximal muscle effort is constrained by cardiopulmonary system limitation. Lets assume that the phenomenon of a $V0_2$ plateau does exist, since it can be seen in well conditioned athletes who are accustomed to high intensity exercise. Attainment of a plateau is also typical of many animal species. It is true that the phenomenon is not seen universally, but that is not a valid argument against its existence (Wagner, 2000).

What happens when the metabolic processes in the body reach maximum ATP generation and a $V0_2$ plateau is reached? What could be described as the mechanistic basis of $V0_2max$? The basic equation describing ATP generation by this process is useful to consider:

$$\mathbf{3\ ADP + 3\ P_i + \tfrac{1}{2}\ 0_2 + NADH + H^+ \rightarrow 3\ ATP + NAD^+ + H_20}$$

What determines the maximal velocity of this reaction? Although a simplified equation of the more complex pathways, it is still useful because it can be reduced to the issue of whether or not $0_2$, as one of the reactants in the equation, reaches concentrations low enough to be the rate-limiting component during exercise. If not, one would conclude that basic metabolic capacity, and not $0_2$ availability is, at some important pathway step rate-limiting (Wagner, 2000). The following points need to be considered here:

1. Depending on conditions, maximal velocity of oxidative phosphorylation may be limited by oxygen availability, or by oxygen-independant metabolic capacity.

2. Manipulations that alter either the supply of oxygen or the concentrations of any of the non-oxygen related biochemical species independently have the capacity to alter the maximal rate of oxidative phosphorylation and thus $V0_2max$. Thus, $V0_2max$ is not an absolute concept it is acutely changeable by altering parts of the metabolic pathway.
3. The stated equation also indicates that the term "anaerobic" is a total misnomer in the context of oxidative phosphorylation. The term means absence of oxygen, and if mitochondrial partial oxygen pressure ($P0_2$) were indeed zero, both the velocity of this reaction and $V0_2$ itself would have to fall to zero and exercise would stop, according to the law of mass action. A more appropriate use of the term "anaerobic" would be to describe processes that do not depend on $0_2$ irrespective of its availability (Wagner, 2000).

When considering conditions were oxygen supply limits $V0_2max$, there is clearly no single factor limiting oxygen transport. Research individually altering the fraction of inspired oxygen ($F_{I02}$), hemoglobin (Hb), cardiac output or muscle blood flow, or Hb-$0_2$ affinity have all indicated $V0_2max$ can be increased by any one of these tactics (Jones and Lindstedt, 1993; Wagner, 1996). The possible contributing factors to oxygen supply limitation to $V0_2max$ include the following: 1) arterial $0_2$ saturation; 2) arterial $0_2$ concentration ($0_2$ saturation and [Hb]); 3) muscle blood flow; and 4) muscle $0_2$ extraction. The first three factors govern convective flow of $0_2$ to the muscle microcirculation; the fourth reflects those factors that act together to determine $0_2$ extraction. The factors that govern extraction are: a) the diffusive conductance for $0_2$ between microcirculatory red cells and mitochondria; b) the perfusive conductance of the muscle microcirculation, in essence the product of [Hb] and blood flow; and c) any flow/ metabolism heterogeneity that exists in the muscle (Wagner, 2000).

Overall conclusions include the following:

- The absence of a plateau in $V0_2$ at peak exercise in some people is expected and is not evidence that $V0_2max$ is a myth;
- The ongoing debates concerning its $0_2$ dependence or metabolic dependence must be viewed in the context of the experimental conditions;
- If $V0_2max$ is oxygen-dependent, one should ask which components of oxygen transport are most important in this rate-limitation;
- If $V0_2max$ is metabolically limited, one should ask, which steps of the glycolytic/ Krebs cycle/ cytochrome/ shuttle pathways are primarily responsible?; and
- Interventions manipulating either oxygen supply or metabolic components may change the basic nature of how $V0_2max$ is set from oxygen-dependent to metabolically dependent and vice versa. There is, therefore, no single universal answer to the question of what limits $V0_2max$.

Running economy and fractional utilization of $V0_2$ max also affect endurance performance. The speed at lactate threshold (LT) integrates all three of these variables and is the best physiological predictor of distance running performance (Basset and Howley, 2000).

At rest your heart rate is regulated by signals from the brain that travel to your heart via the parasympathetic nervous system. Cardiovascular training increases the sensitivity of the heart to these nerves, which lowers the heart's resting rate. Although resting heart rate is generally lower in endurance athletes, it is not always a reliable indicator of aerobic fitness. For example, resting heart rate decreases with age and with some medications (beta-blockers) and tends to increase with such factors as emotion, anticipation before exercise or a race, and chemical stimulants like caffeine and nicotine. However, monitored on a regular basis, a slower resting heart rate (early morning heart rate) indicates increasing fitness. Conversely, a consistent

increase in resting heart rate reflects over-training or possible dehydration, emotional stress, poor sleeping habits, illness, poor nutritional status, or a combination of two or more of these. Heart rate comprises one of the two important factors influencing cardiac output, the other being stroke volume.

**Q (Cardiac Output, litres per minute) = SV (Stroke Volume, litres per beat) x HR (beats per minute)**

Cardiac output (Q) is defined as the amount of blood ejected per minute by the heart, specifically the left ventricle. At rest there is little difference in cardiac output between trained and untrained subjects, with average values ranging between 5 and 6 litre per minute. Maximal cardiac output in trained male subjects can reach values in excess of 30 litres per minute, twice as high as in untrained individuals. This variable is the one that differs the most when elite athletes are compared with untrained individuals (Wagner, 2000). This has led many to proclaim that cardiac output is the key factor limiting $V0_2max$. Cardiac output is undeniably important, but without parallel upward adjustment in both pulmonary and muscle $0_2$ diffusive transport conductance, a very high cardiac output would cause substantial arterial desaturation and also impair muscle $0_2$ extraction. Both conditions are caused by shortened transit times (Dempsey and Fregosi, 1985). Cardiac function has been postulated to play another, more critical role than described in limiting maximal oxygen consumption. It is suggested that maximal exercise may be regulated primarily to prevent hypoxic cardiac damage. Thus, it may have nothing to do with $0_2$ supply limitation to exercising skeletal muscle. This theory has some teleological appeal but lacks experimental support. Most healthy exercising subjects do not experience myocardial ischemia by any criteria at maximal exercise; it is possible to exercise at extreme altitude yet still have no objective evidence of ischemia or myocardial dysfunction (Wagner, 2000).

Women tend to have a slightly higher cardiac output when performing at the same level of oxygen consumption. This difference amounts to between 1.5 and 1.75 litre per minute. This means that, the cardiac output will be 1.5 to

1.75 litres per minute higher on the average in woman than in men for a given oxygen consumption. The reason for this is probably compensatory due to the woman's lower oxygen-carrying capacity of blood, resulting from lower levels of haemoglobin. Also, the maximal cardiac output of both trained and untrained woman is generally lower than that of their male counterparts (Fox and Bowers, 1993). The increase in cardiac output and redistribution of blood flow that occur during exercise can best be summarized by developing the concept of the oxygen transport system. The components of the system and their interrelationship are as follows:

**$V0_2$ (oxygen transported) = SV x HR x a-$v0_2$ diff (arteriovenous oxygen difference)**

From this equation we can derive that to maintain a certain $V0_2$ during exercise with lower comparative heart rates, the subjects must either experience an increase in stroke volume or a increase in arteriovenous oxygen difference. Athletes who excel in endurance sports generally have a large capacity for aerobic energy transfer. The maximal oxygen consumption recorded for competitors in distance running are at most double those of sedentary men and woman. This is not to say that the $VO_2$ max is the only determinant of endurance performance. Other factors, principally those at local tissue level such as capillary density, enzymes, mitochondrial size and number, and muscle fibre type, exert a strong influence on a muscle's capacity to sustain a high level of aerobic exercise (McArdle et al., 1996). The $VO_2$ max does, however, provide important information on the capacity of the long term energy system. In addition, this measure has significant physiological meaning in that attaining a high $VO_2$ max requires the integration of a high level of ventilatory, cardiovascular and neuromuscular functions (McArdle et al., 1996). Martin and Coe (1997) find a high statistical correlation between aerobic power and competitive performance.

### 2.3.2 Blood Lactate Accumulation

Lactate is one of the products of glycolysis. It is both produced and used by the muscles. It's rate of production increases as the exercise rate increases and as more carbohydrate is used to fuel exercise (Noakes, 1992). Glycolysis refers to the process where carbohydrates are broken down to pyruvic acid or lactic acid (Meyer and Meij, 1996). Lactic acid does not necessarily accumulate at all levels of exercise. During light and moderate exercise the energy demands are adequately met by reactions that use oxygen. In biochemical terms, the ATP for muscular contraction is made available predominantly through energy generated by the oxidation of hydrogen. Any lactic acid formed during light exercise is rapidly oxidized. As such, the blood lactic acid levels remains fairly stable even though oxygen consumption increases. Lactic acid begins to accumulate and rise in an exponential fashion at about 55% of the healthy, untrained subject's maximal capacity for aerobic metabolism. The usual explanation for the increase in lactic acid is based on the assumption of a relative tissue hypoxia in heavy exercise (McArdle et al.,1991). For this reason it would be beneficial to the athlete if either ergogenic aid could help the oxygen supply to the muscle and surrounding tissue, preventing or delaying the onset of hypoxia due to increased exercise intensity. Although the energy released during glycolysis is rapid and does not require oxygen, relatively little ATP is resynthezised in this manner. Consequently, aerobic (absence of hypoxia) reactions provide the important final stage for energy transfer, especially if vigorous exercise proceeds beyond several minutes. An untrained individual who fasted overnight and who has a sample of blood collected in the morning from an arm vein before any exercise, has a lactate level ranging from 0.44 to 1.7 mmol/L. Martin and Coe (1997) also found the equivalent of 0.3 to 0.6 mmol/L to be true for trained individuals, providing that they are not over-trained. Within an hour after an intensive training session during which blood lactate levels reach the highest achievable values (15mmol/L), muscle lactate levels will return to normal (Noakes, 1992). Most of the lactic acid produced during vigorous exercise is removed by direct oxidation (55-70%) while the balance amount is converted to glycogen (<20%), protein constituents (5-10%) and other compounds

(<10%) (Gupta et al., 1996). Lactic acid produced in working muscles is almost completely dissociated into $H^+$ and lactate within the range of physiological pH, which contributes to the metabolic acidosis (Hirokoba et al., 1992).

### 2.3.3 The Aerobic and Anaerobic Systems during Rest and Exercise

There are at least three important features of the aerobic and anaerobic systems under conditions of rest and exercise that need some consideration:

- The types of foodstuffs being metabolised,
- The relative roles played by each system, and
- The presence and accumulation of lactic acid in the blood

**Rest**

During rest, two thirds of the food fuel is contributed by fats and the other third by carbohydrates (glycogen and glucose). The aerobic system is the principle system in operation. The oxygen transport system (heart and lungs) is capable of supplying each cell with sufficient oxygen, therefore there is adequate ATP to satisfy all the energy requirements of the resting state. Protein is not mentioned due to the fact (as mentioned earlier) that the contribution of proteins as food fuel is negligible (Fox and Bowers, 1993).

The molecules of ATP shown coming from the anaerobic system are considered as part of the aerobic yield, because, as indicated they are likewise formed in the presence of oxygen. Although the aerobic system is the primary one in operation, one can note that there is a small but constant amount of lactic acid present in the blood (about 10mg for every 100ml of blood). The reason for this relates to the abundance and effectiveness of LDH (lactic dehydrogenase), the enzyme that catalyses the reaction of pyruvic acid to lactic acid. LDH is always converting some pyruvate to lactate. The fact that the lactic acid level remains constant and does not accumulate tells us that anaerobic glycolysis is not operating at any significant level. One can

summarize that during rest, the foodstuffs utilized are fats and carbohydrates, and the necessary ATP is produced primarily by the aerobic system (Fox and Bowers, 1993).

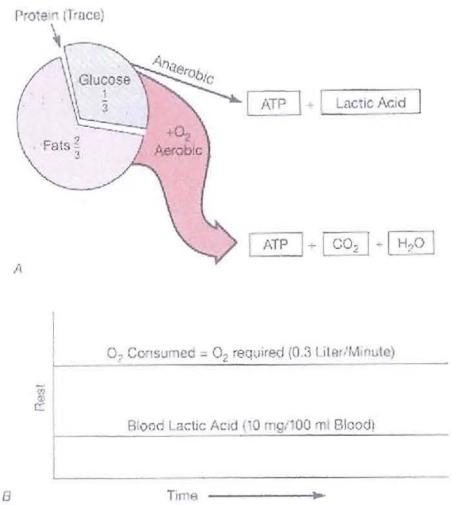


**Figure 2.3: The aerobic system supplies all the ATP required in the resting state (Fox and Bowers, 1993).**

**Rest to Exercise Transition**

During the transition from rest to light or moderate exercise, oxygen consumption increases rapidly and reaches a steady state within one to four minutes (balance between the energy required by the working muscles and ATP production via aerobic metabolism). The fact that $V0_2$ does not increase instantaneously to a steady state value suggests that anaerobic energy sources contribute to the overall production of ATP at the beginning of exercise. There is much evidence to suggest that at the onset of exercise, the ATP-PC system is the first active bioenergetic pathway, followed by glycolysis and finally aerobic energy production. Theoretically once steady state has been attained, exercise could continue indefinitely. However, other limiting factors such as the following do play a role:

- Fluid loss;
- Electrolyte depletion; and
- Maintenance of adequate fuel reserves (Fox and Bowers, 1993).

Of considerable importance during prolonged exercise is maintaining adequate fuel reserves, particularly liver and blood glucose for the functioning of the central nervous system, and muscle glycogen to power exercise. Work capacity dramatically decreases when muscle glycogen stores are depleted. It must however, be kept in mind that the maximal level at which steady state can be maintained, differs for each individual. For some the steady state level may be running a marathon at 4 minutes per km while for others it may be during walking. Steady state levels are dependant on how well circulation can deliver oxygen to working muscles and how well active tissues can utilize this oxygen. Once steady state oxygen consumption has been reached, lactate production equals removal and small amounts of lactate accumulated prior to this time, remain relatively constant until the end of exercise (McArdle et al., 1991).

The difference between the total oxygen actually consumed during exercise and the total that would have been consumed had a steady rate of aerobic metabolism been reached at the start of exercise, is referred to as one's oxygen deficit. This transitional phase represents the anaerobic energy being used. Trained athletes reach this steady state more rapidly and therefore have a smaller oxygen deficit. This is due to factors such as cardiovascular or muscular adaptations, resulting in the total aerobic energy provision being greater for a trained person and therefore the anaerobic energy transfer smaller (Fox and Bowers, 1993).

The readjustment of oxidative phosporylation to meet the new ATP demand after a step increase in work rate is delayed and follows an approximately exponential time course. Investigations into muscle $0_2$ uptake ($Q0_2$) kinetics have sought to confirm one of two hypotheses, namely, whether the rate of increase in oxidative phosphorylation is limited by the adaptation of oxygen utilization or oxygen transport mechanisms. An oxygen utilization limitation reflects a metabolic inertia. This means that the rate of oxidative phosphorylation at any point during the adaptation to steady state is determined solely by levels of cellular metabolic controllers (Barstow et al., 1994) and/or mitochondrial enzyme activation (Hochacka and Matheson,

1992; Timmons et al., 1996). It implies that mitochondrial $P0_2$ ($P_{mito}\ 0_2$) in all active muscle fibres at all time points during the adaptation, is adequate to support the highest rate of oxidative phosphorylation possible for the current level of metabolic potential.

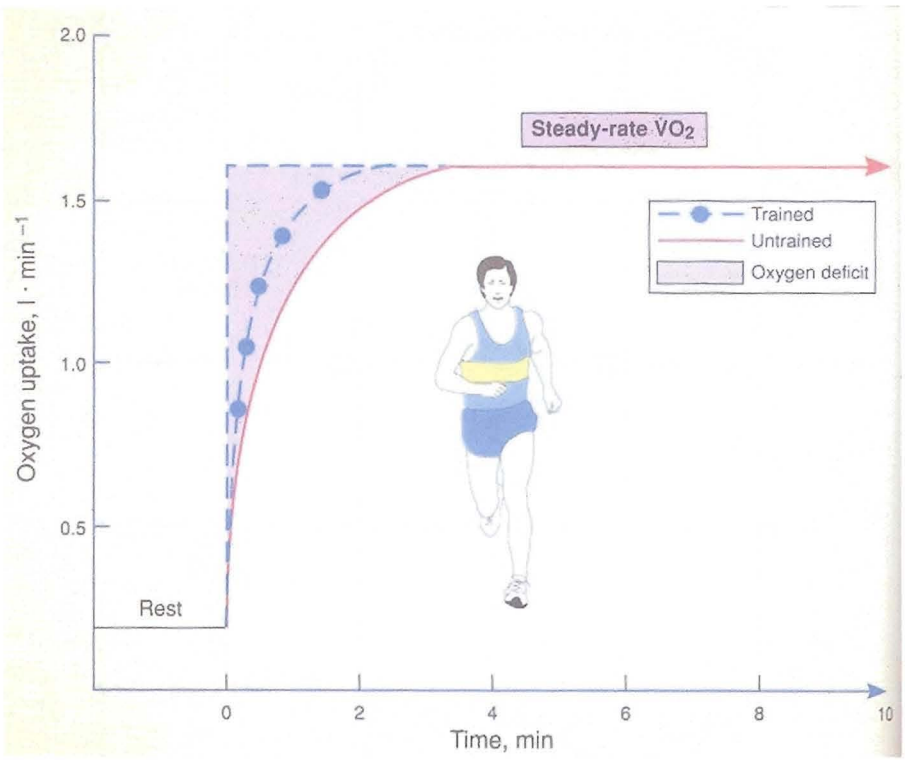


**Figure 2.4: Time course of oxygen uptake during a continuous jog at a relatively slow pace for 10 minutes. The shaded area indicates the oxygen deficit or the extra quantity of oxygen that would have been consumed had the oxygen uptake reached a steady rate immediately (McArdle et al., 1991)**

An oxygen transport limitation reflects the inertia of oxygen delivery to the mitochondria. In this case, at least some of the oxidative metabolic machinery is capable of increasing its utilization of oxygen more rapidly if more oxygen is made available (Hughson, 1990). This infers that mitochondrial $P0_2$ is not saturating in all active muscle fibres at all time points during the adaptation to a steady state (Tschakovsky and Hughson, 1999).

**Evidence for utilization and transport limitations to $Q0_2$ kinetics**

Early measurements of oxygen uptake indicated an initial rapid adaptation, followed by a continued increase over the next 2-3 min. Among the first to provide quantitative descriptions of the response (Berg, 1947; Henry, 1951; Henry and De Moor, 1956), observed that the time course of change was generally similar between the adaptation to and the recovery from exercise. Cerretelli (1966) and colleagues introduced the term "early blood lactate" to denote the obligatory lactate production associated with a slow $V0_2$ response. This concept supports the notion that there is a primary inadequacy of aerobic metabolism to meet the ATP demand at the onset of exercise. Either an oxygen transport inertia or a metabolic inertia could account for these findings.

**Altered $0_2$ transport**

In humans, alterations in the content and $P0_2$ of the arterial blood or the blood flow adaptations have been used to test the hypothesis of an oxygen transport limitation to $Q0_2$ kinetics. Obviously, to support an oxygen transport limitation it would be necessary to show that increased oxygen delivery accelerated $Q0_2$ kinetics, compared with the "normal" condition. However, it must be recognised that what constitutes the control or normal condition is open to debate. Whether $Q0_2$ kinetics is accelerated with increases in oxygen transport depends on the exercise condition chosen as the control condition. When sea level (~ 21% inspired $0_2$), upright cycling exercise is defined as the normal exercising condition, then hypoxia (10-14% inspired oxygen is commonly used) slows the $V0_2$ kinetic response (an estimate of $Q0_2$) during cycling exercise (Linnarsson et al., 1974), whereas hyperoxia (> 60% inspired $0_2$) accelerates the $V0_2$ kinetic response during cycling exercises only at work rates above the ventilatory threshold but not below (MacDonald et al., 1997). Similarly, impairment of cardiac output adaptation via β-blockade and light-to-moderate exercise transition vs. rest-to-light or rest-to-moderate exercise transition, or reduction of the local arterial perfusion pressure via supine exercise have all resulted in slower $V0_2$ kinetics. In contrast, attempted impairment of muscle blood flow with lower body positive pressure during

semi-upright cycling failed to slow $V0_2$ kinetics, whereas slightly faster cardiac output kinetics in heart-transplant patients obtained by a preceding exercise bout did not speed up $V0_2$ kinetics (Grassi et al., 1996).

Although this evidence suggests that the adjustment of $Q0_2$ can often be impaired with reductions in oxygen transport, there is little evidence to suggest that $Q0_2$ kinetics can be accelerated, except perhaps at work rates above the ventilatory threshold. This evidence might lead to the conclusion that $0_2$ transport is not limiting under normal exercise conditions. However, this does not preclude a role for an $0_2$ transport limitation under a number of common exercise conditions such as exercise at altitude, athletic activities in which the exercising muscles are not well-below heart level, and activities in which the duration of contractions significantly reduced the time allowed for the muscle perfusion to occur (e.g. rowing, downhill skiing). If a different exercise mode is used as the control condition, then acceleration of $Q0_2$ kinetics relative to the normal condition can be achieved by improving $0_2$ delivery (Tschakovsky and Hughson, 1999).

Most studies have inherent limitations in their measurement of actual $Q0_2$ uptake kinetics. Typically, cycling exercise $Q0_2$ kinetics is estimated from $V0_2$ (i.e. alveolar oxygen uptake). The $V0_2$ response is biphasic, with early increase influenced predominantly by increased pulmonary blood flow and second phase to steady-state levels additionally influenced by $0_2$-depleted venous blood from the exercising muscle. Modelling of $V0_2$ and $Q0_2$ kinetics during exercise transients and observations of equivalence between phosphocreatine (PCr) kinetics and the time-constant of the phase-two $V0_2$ response, suggests that this second phase closely represents the dynamics of $Q0_2$ across a variety of exercise intensities (Barstow and Mole, 1991). Because the second phase is thought to represent the arrival of the oxygen-depleted blood from the exercising muscle (Whipp and Ward, 1990), these lines of evidence support the use of the phase-two time-constant when evaluating effects on $Q0_2$ kinetics under different oxygen delivery conditions via measurements of $V0_2$. However, Essfeld et al. (1991) have shown that the relationship between $V0_2$ and $Q0_2$ kinetics is sensitive to differences between

muscle blood flow and $Q0_2$ kinetics. Their modelling suggests that $V0_2$ and $Q0_2$ kinetics are similar when there is a small difference between the time constants of muscle perfusion and $Q0_2$ kinetics, but $V0_2$ estimates of $Q0_2$ should be viewed with caution when the adaptation of muscle perfusion differs from $Q0_2$.

When $Q0_2$ is estimated by using the Fick principle across the vascular bed of a muscle during voluntary exercise, certain limitations must also be recognized. The Fick principle refers to the basis of some direct methods of measuring the output of the rate and of blood flow to some of the organs, e.g., the kidneys. It can be used when arterial and venous concentrations of a substance can be measured and the amount of uptake or removal of the substance can be determined. Oxygen consumption is equal to the product of the pulmonary blood flow and the increase in oxygen content of the blood passing through the lungs, usually rearranged so that flow equals oxygen consumption divided by the arteriovenous difference in blood oxygen concentration (Stedman, 1982). With in-situ animal preparations it is possible to isolate the vascular supply and return of the exercising muscle and to ensure activation of all muscle fibres by electrical stimulation. In contrast, for studies of voluntary sub-maximal exercise in humans, the venous effluent at in-vivo venous sampling sites will invariably be a mixture of blood from both exercising and nonexercising tissues because of the heterogeneous nature of motor unit recruitment and vascular supply (Berg, 1947). Therefore, any differences in the relative contribution of nonworking and working muscle venous effluent during different phases of the dynamic adaptation to exercise, could introduce error in the estimate of exercising muscle fibre arteriovenous $0_2$ difference.

In their study of blood flow and leg oxygen uptake kinetics with upright cycling exercises, Grassi et al. (1996) interpreted the transient increase in venous $0_2$ content in the first 0-15 seconds and the subsequent minimal change in calculated leg $V0_2$, to indicate that $0_2$ delivery was in excess of $0_2$ demand in the initial 15 seconds of exercise. However, they also acknowledged the potential effect of blood flow heterogeneity in determining the mixed venous $0_2$ content. One contributor to such an effect might be the potentially

disproportionate effect of the muscle pump on initial blood flow distribution vs. later in exercise, which may have been a factor in their results. Activation of the muscle pump at exercise onset would serve to increase flow through capillaries adjacent to both active and inactive fibres. Depending on the amount of active muscle mass and the effect on intramuscular pressure of the contractions, early venous effluent may, to a large degree, come from elevated flow past nonactive fibres and, therefore, result in the observation of a transient reduction or lack of increase in (a-v) $D0_2$ measured at a site draining the exercising limb. As exercise progresses, an increase in metabolic vasodilatation occurs, effectively "stealing" flow from adjacent capillary modules that are not dilated as part of a feedback regulation (Berg, 1947). The contribution of venous effluent from venules draining active fibres would be expected to predominate as exercise continues and the measured components of the Fick principle (total limb blood flow and venous effluent $0_2$ content) would be more accurately related to muscle $0_2$ consumption. Transit delay should therefore only account for a minor portion of the observed delay in $0_2$ consumption (Tschakovsky and Hughson, 1999).

**Cardiac Output Kinetics and Muscle Blood Flow Kinetics vs. Estimates of $Q0_2$ Kinetics**

The first combined measurements of cardiac output and $V0_2$ kinetics indicated that cardiac output adapted more rapidly to exercise (Chance and Williams, 1956). Subsequent estimates of cardiac output kinetics in similar exercise conditions confirmed this. The kinetics of bulk blood flow is often faster (MacDonald et al., 1998). However, it has been observed by some that blood flow during the second phase of adjustment closely matches the metabolic adaptation (Grassi et al., 1996). These results have been interpreted to indicate that bulk $0_2$ delivery to the exercising muscle is adequate at the onset of exercise to meet the $0_2$ demands of the muscle, since $0_2$ transport appears to reach steady state before $0_2$ consumption.

**Phosphocreatine and $V0_2$ Kinetics**

Since the initial experiments of Mahler (1985) in frog sartorius muscle, similarities between PCr kinetics and $V0_2$ or $Q0_2$ kinetics have been

demonstrated in both animal and human models across a range of work rates. This reflects what is believed to be the first-order nature of respiratory control. These data have been interpreted as evidence that metabolic controllers determine the rate of adaptation of $0_2$ consumption. In addition $Q0_2$ during the transition from rest to exercise in electrically stimulated dog muscle can be adequately described as the result of changes in phosphorylation potential and redox potential (Connett et al., 1990). Interpreting these observations to mean that the kinetic responses of these metabolites control the increase in oxidative phosphorylation may be valid under conditions where $0_2$ is present in saturating amounts, but they do not confirm that oxygen supply is adequate.

Analysis has shown that, at moderate exercise levels where little glycolytic contribution to ATP production occurs during the exercise onset, the kinetics of PCr will mirror those of $Q0_2$. This is because the net ATP demand is met by aerobic and PCr sources, and as aerobic supply of ATP increases exponentially the net breakdown of PCr decreases proportionally. It can be shown mathematically that, under conditions of no glycolytic contribution to ATP production, the time constant of PCr breakdown will always be equivalent to that of aerobic metabolism, regardless of whether PCr is acting as a primary controller of mitochondrial respiration or a buffer of ATP levels. This means that if the adaptation of aerobic metabolism was being limited by inadequate oxygen availability, the similarity in PCr and $Q0_2$ kinetics could simply be caused by the need for PCr depletion to compensate for the greater $0_2$ deficit in the face of minimal contribution by anaerobic glycolysis (Binzoni et al., 1990).

Since the first relationship between PCr depletion and steady-state levels of $Q0_2$ in normoxia was first observed, subsequent studies have confirmed this relationship (Meyer and Foley, 1994). It implicates phosphorylation potential in the determination of cellular respiration rate. However, observation of different levels of PCr for the same $Q0_2$ or $V0_2$ under different arterial oxygenation conditions, indicates that $0_2$ can exert a modulatory effect on the level of metabolic controllers required to achieve, or be associated with, a given rate of mitochondrial respiration. If this is the case for steady-state

exercise, then it is likely to also apply during the non-steady state, since the cytochrome-c oxidase reaction is a function of the combined drive of the phosphorylation potential, the redox potential, $H^+$ concentration, and the $P0_2$. An important implication of this is that the level of proposed metabolic controllers does not have to change as much to achieve the same rate of ATP production by oxidative phosphorylation when more oxygen is made available (Tschakovsky and Hughson, 1999).

**Determinants of $Q0_2$ Kinetics: Cellular Metabolic State, Enzyme Activation, and $P_{mito}0_2$**

Limitations of experimental and theoretical approaches have contributed to the scope of conflicting evidence in this field. If $Q0_2$ kinetics truly were limited only by intrinsic metabolic inertia or extrinsic oxygen transport inertia in a mutually exclusive manner, it is unlikely that such a degree of conflict would exist. Therefore one must try to understand how metabolic controllers and mitochondrial $0_2$ supply interact, to determine mitochondrial respiration at any given instant during exercise.

The overall reaction of oxidative phosphorylation is:

$$\mathbf{NADH + ½\ 0_2 + H^+ + 3ADP + 3P_i \Rightarrow 3ATP + NAD^+ + H_20}$$

Oxidation of fuels in the Krebs cycle provides reducing equivalents (NADH, FADH: electron donors) for the electron transport chain (ETC). The ETC is composed of four coenzyme complexes, with the terminal one being cytochrome-c. Oxygen acts as the terminal electron receptor from cytochrome-c, in an irreversible reaction catalyzed by cytochrome-c oxidase, resulting in formation of $H_20$ and allowing for continued ETC flux. ATP synthesis from ADP and Pi is not directly involved in the terminal reaction of the ETC but coupled to it, such that changes in concentrations of ATP to ADP and Pi can considerably alter the rate of electron transfer. The release of free energy in the transfer of electrons down the ETC is used to "pump" $H^+$ from the matrix side to the outside of the inner mitochondrial membrane, creating an

electrochemical gradient. The $H^+$ ions then flow back along this gradient into the mitochondrial matrix through protein channels with associated ATP synthase complexes. The energy from the flow of H+ is used to rephosphorylate ADP, forming ATP (Wilson and Rumsey, 1988).

For sustained ATP turnover to occur during skeletal muscle contractions, ATP demand needs to be matched by aerobic ATP supply. For this to occur, regulation of mitochondrial oxygen consumption must be achieved by a precise communication of ATP demand to the mitochondrial ATP-producing machinery. Some mechanisms have been proposed as regulators of mitochondrial respiration, the following are likely the most important in determining its rate of adaptation:

- Cellular metabolic state
- Latent mitochondrial enzyme activation
- $P_{mito}0_2$
- Factors determining $P_{mito}0_2$
- Interaction of cellular metabolic state, enzyme activation, and $P0_2$

Whether the evidence from a given experiment supported an intrinsic metabolic inertia or an extrinsic oxygen transport inertia depended on the nature of the experimental control condition. This is likely because different exercise conditions can impact $0_2$-delivery kinetics in dramatically different ways, whereas the mechanisms determining metabolic adjustments are likely more uniform across a wide variety of exercise conditions (e.g. supine vs. upright leg exercise). An exception to this may be prior exercise, which might alter the rate of adjustment of metabolic controllers (Timmons et al., 1996). Tschakovsky and Hughson (1999) propose that metabolic inertia and $0_2$-transport inertia likely interact to determine the adaptation of muscle aerobic metabolism at exercise onset, under a number of common exercise conditions.

### 2.3.4 Prolonged Exercise

The energy to perform long-term exercise comes primarily from aerobic metabolism. A steady state oxygen uptake can generally be maintained during sub-maximal exercise of moderate duration (McArdle et al., 1991).

Major foodstuffs for prolonged exercise include carbohydrates and fats. For activities lasting up to 20 minutes, carbohydrates are the dominant fuel. As time proceeds beyond an hour, glycogen stores decrease and fats become more important as an energy source. The mix of glycogen and fat utilization will vary with different athletes for a variety of reasons:

- Initial glycogen stores;
- Proportions of fast and slow twitch muscle fibres; and
- State of training.

In prolonged (>20minutes) exercise the major energy pathway for ATP is supplied by the aerobic system. The lactic acid and ATP-PC system also contribute, but only at the beginning of the exercise, before oxygen consumption reaches a new steady-state level. Once oxygen consumption reaches a new steady state level the aerobic system is sufficient to supply all of the ATP energy required for exercise. For this reason lactic acid does not accumulate to very high levels during exercise lasting for more than an hour. Understandably the anaerobic systems might be re-engaged during "kick" efforts to win a long distance race, thereby raising blood lactate levels at the end. In other runners an event might be ended with an aerobic steady-state effort. An example of this would be marathon running. Some athletes run 42.2km in about 2.5 hours, but at the end of the race their blood lactic acid levels are only about two to three times that found at rest. The fatigue experienced by these runners at the end of a race, is therefore due to factors other than high blood lactic acid levels. Some of the more important factors leading to this type of fatigue are:

- Low blood glucose levels due to depletion of liver glycogen stores;
- Local muscular fatigue due to depletion of muscular glycogen stores;

- Loss of water (dehydration) and electrolytes, which leads to high body temperature; and
- Boredom and the physical stress in general that the body has sustained.

## 2.4 FACTORS LIMITING PERFORMANCE

There is no single cause of fatigue. Fatigue is task-specific, its causes are multifocal and may vary from occasion to occasion. Fatigue is often due to impairment within the active muscles themselves, in which case the fatigue is peripheral to the central nervous system (CNS) and is due to muscle fatigue. Muscle fatigue can also be due to more diffuse, or more central factors (Brooks et al., 1996).

Fatigue can be defined as the inability to maintain a power output or force during repeated muscle contractions. Causes for fatigue vary and are usually related to the type of activity performed (Powers and Howley, 1994).

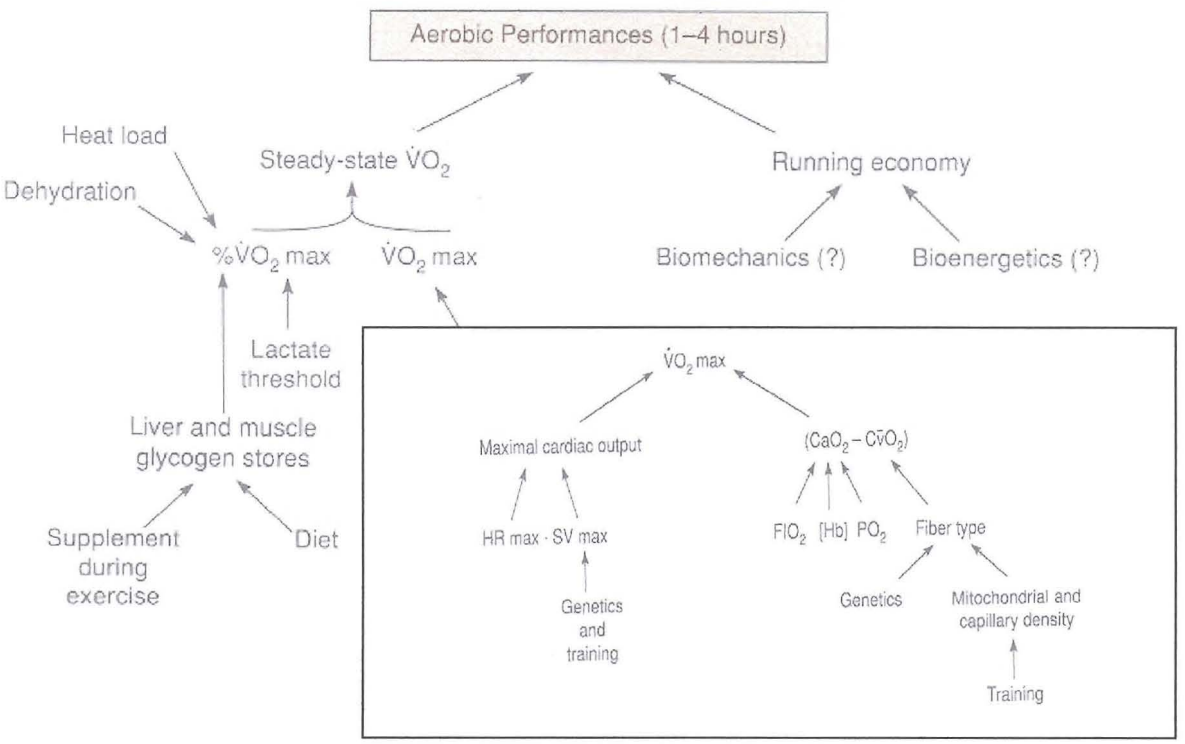


**Figure 2.5: Factors affecting fatigue in aerobic performance lasting one to four hours, adapted from Powers and Howley, 1996.**

### 2.4.1 Metabolite Depletion

**The Phosphagens (ATP and CP)**

Fatigue can be viewed as the result of a simple imbalance between the ATP requirements of a muscle, and it's ATP-generating capacity. When exercise begins and the need for ATP accelerates, a series of ATP-generating reactions occur to replenish the ATP. As the cross-bridges use the ATP and generate the ADP, creatine phosphate provides for the immediate resynthesis of the ATP (CP+ADP→ATP+Cr). As the creatine phosphate becomes depleted, ADP begins to accumulate and the myokinase reaction occurs to generate ATP (ADP+ADP→ATP+AMP). The accumulation of all these products stimulates glycolysis to generate additional ATP, which may result in $H^+$ accumulation. However, as ATP demand continues to exceed supply, a variety of reactions occur in the cell that limit work and may protect the cell from damage. ATP is needed to pump ions and maintain cell structure, so in this sense fatigue serves as a protective function. When the ATP generating mechanisms can't keep up, AMP begins to accumulate and may be metabolized to inosine monophosphate and ammonia ($AMP+H_20 \rightarrow IMP+NH_3$). IMP and $NH_3$ increase with exercise intensity, and the depletion of muscle glycogen. Further, if $NH_3$ accumulates in plasma, central nervous system function may also be affected (Powers and Howley, 1994).

The different ways of ATP production can be linked to the different muscle fibre types that are recruited during various types of activities. Up to an exercise intensity of about 40% of $V0_2$ max, the Type I slow-twitch oxidative muscle fibre is recruited to provide tension development. This fibre type is dependent on a continuous supply of blood to provide the oxygen needed for the generation of ATP from carbohydrates and fats. Any factor that may limit the amount of oxygen that is delivered to this muscle fibre type would cause a reduction in tension development in these fibres and necessitate the recruitment of Type IIa fibres to generate the needed tension. Various factors, including altitude, dehydration, blood loss or anemia could influence the oxygen supply to these fibres. Type IIa fast-twitch, fatigue-resistant muscle

fibres are recruited at an intensity of between 40%-75% of $V0_2$ max. These fibres are rich in mitochondria making them dependant on oxygen delivery for tension development. They also have a great capacity to produce ATP via anaerobic glycolysis. The mitochondrial content of Type IIa fibres is sensitive to endurance training, so that with detraining more of the ATP supply would be provided by glycolysis, leading to lactate production. If oxygen delivery to this fibre type is decreased, tension development will fall, requiring Type IIb fibres to come into play to maintain tension (Powers and Howley, 1994). Type IIb fibres are fast-twitch muscle fibres with a low mitochondrial content. This fibre can generate great tension via anaerobic sources of energy, but fatigues quickly. It comes into play at an intensity of about 75% of maximal oxygen consumption (Powers and Howley, 1994).

**Muscle Glycogen**

Glycogen depletion in skeletal muscle is associated with fatigue during prolonged submaximal exercise to exhaustion. It is possible for an athlete to exercise to exhaustion and fatigue because of glycogen depletion from specific muscle fibres, while glycogen remains in adjacent fibres within the tissue. These glycogen reserves can be mobilized if epinephrine levels rise, stimulating glycogenolysis, glycolysis, lactate production and release, and energy (lactate) exchange via the lactate shuttle (Brooks et al., 1996).

**Blood Glucose**

During prolonged exercise, glucose production may be reliant on gluconeogenesis because of hepatic glycogen depletion. This may cause the fall of glucose production below that required by the working muscle and other essential tissue such as the brain. Also, in prolonged exercise leading to dehydration and hyperthermia, shunting of blood flow away from the liver and kidneys occurs. Thus, levels of gluconeogenic precursors (lactate, pyruvate, alanine) rise, and hepatic glucose production decreases. In this case of falling blood glucose, exercise becomes subjectively more difficult because of CNS starvation and difficulty in oxidizing fats in muscle due to the absence of anaplerotic substrates (Brooks et al., 1996).

### 2.4.2 Metabolite Accumulation

**Lactic Acid Accumulation (Lactic Acidosis)**

Lactate accumulates due to production being greater than its removal. At a physiological pH, lactic acid, a strong organic acid, dissociates a proton ($H^+$). It is the $H^+$ rather than the lactate that causes pH to decrease. Although the lactate accumulation in blood is directly related to $H^+$ accumulation in blood, because the muscle cell membrane exports both the lactate anions and protons into the blood, in muscle the cause of acidosis is different. All the glycolytic intermediates of glycolysis are weak organic acids and dissociate protons, while the degradation of ATP also results in $H^+$ formation. This means that lactate accumulation is associated with acidosis for more than one reason, but it is important to recognize that it is unbuffered protons (i.e., $H^+$) and not lactate anions that pose difficulties for the performer. The actions mentioned above can have several negative effects. Within the muscle, the lower pH may inhibit phosphofructokinase (PFK) and ATPase and slow glycolysis. $H^+$ may also act to displace $Ca^{2+}$ from troponin, thereby interfering with muscle contraction. A low pH may also trigger pain receptors (Brooks et al., 1996).

**Phosphate and Diprotenated Phosphates**

Phosphagen depletion during exercises results in phosphate (Pi, or $HPO_4^{2-}$) accumulation. Studies on isolated muscle and enzyme systems indicate that phosphate behaves much like hydrogen ion in interfering with glycolysis (PFK) and excitation-contraction coupling ($Ca^{++}$ binding to troponin) (Brooks et al., 1996).

**Calcium Ions**

The accumulation of $Ca^{2+}$ within muscle mitochondria during prolonged exercise may be more debilitating than the decrease in cytoplasmic pH from lactic acid formation. Some of the $Ca^{2+}$ liberated in muscle from the sarcoplasmic reticulum during excitation-contraction coupling may be sequestered by mitochondria. Some increase in mitochondrial $Ca^{2+}$ is probably beneficial, as it stimulates the dehydrogenases of the tricarboxylic acid or Krebs (TCA) cycle. However, $Ca^{2+}$ excretion from mitochondria is energy

linked, and so, too much $Ca^{2+}$ sequestration results in oxygen consumption and saps the mitochondrial energy potential for phosphorylating ADP to ATP (Brooks et al., 1996).

### 2.4.3 $O_2$ Depletion

The inadequacy of circulatory oxygen delivery to muscle can result in fatigue. Athletes with impaired circulatory or ventilatory function, those engaged in exercise at high altitudes, or those engaged in strenuous exercise at sea level can fall short in the balance between muscle respiratory requirement and the actual oxygen supply.

The effects of inadequate oxygen supply or utilization can be represented by increased lactate production or decreased CP levels, or both. This indicates that inadequate oxygenation of contracting muscle can result in at least two fatigue-causing effects.

The utilization of oxygen in the mitochondria is associated with the liberation of free radicals, which present a real threat to the mitochondria. Research has supplied evidence of mitochondrial damage due to free radical accumulation at the point of fatigue (Brooks et al., 1996).

### 2.4.4 Central and Neuromuscular Fatigue

Central Fatigue:

The CNS (central nervous system) would be indicated in fatigue if there were a reduction in the number of functioning motor units involved in the activity; or a reduction in motor unit firing frequency. There is evidence both for and against, the concept of central fatigue.

Peripheral Fatigue:

The vast majority of evidence points to the periphery as the most likely site of fatigue. Here neural, mechanical or energetic events could hamper tension

development. Fatigue due to neural factors could be associated with failure at the neuromuscular junction, the sarcolemma, or the transverse tubules.

1. Neuromuscular Junction

   The action potential appears to reach the neuromuscular junction even when fatigue occurs, suggesting that the potential "weak link" is a depletion of acetylcholine or a reduced excitability of the motor end plate. Evidence suggests that the neuromuscular junction is not the site of fatigue (Powers and Howley, 1994).

2. Sarcolemma and Transverse Tubules

   Evidence shows that stimulating the muscle at a high rate can lead to a slowing of the action potential waveform along the sarcolemma and the transverse tubules. This might be related to an accumulation of $K^+$, which would increase the excitation threshold of the membranes (Powers and Howley, 1994).

The primary mechanical factor that may be related to fatigue is the cross-bridge. The action of the cross-bridge depends on:

- the functional arrangement of actin and myosin
- Ca++ being available to bind with the troponin to allow the cross-bridge to bind with the active site on actin, and
- ATP, which is needed for both contraction and relaxation (Powers and Howley, 1994).

**2.4.5 Psychological Fatigue**

At present one can only begin to address the question of how afferent input during competition (pain, breathlessness, nausea, audience response) can influence the physiology of the CNS. A behaviorial (psychological) approach to understanding these questions may be beneficial. Through training some athletes learn to minimize the influences of distressing afferent input and therefore approach performance limits set in musculature. In order to perform optimally in an activity, the experiences of prior training and competition are

often necessary for an athlete to evaluate afferent inputs properly and to utilize them in determining the maximal rate at which physiological power can be meted out during competition (Brooks et al., 1996).

### 2.4.6 The Heart as Site of Fatigue

In healthy individuals there is no direct evidence that exercise, even prolonged endurance exercise, is limited by fatigue of the heart muscle. Since arterial $P0_2$ is well maintained during exercise, and the heart in effect gets the first choice at cardiac output, the heart is well oxygenated and nourished, even at maximal heart rate. Because the heart is "omnivorous" in its choice for fuels, it can be sustained by either lactic acid (which rises in short-term work) or fatty acids (which rises in long-term work). During prolonged work which leads to severe dehydration and major fluid and electrolyte shifts, changes in plasma $Na^+$, $K^+$, or $Ca^{2+}$ can effect excitation-contraction coupling of the heart. In these cases, cardiac arrhythmias are possible, and exercise is not advised (Brooks et al., 1996).

## 2.5 ERGOGENIC AIDS

The premise and promise of ergogenic aid use is rooted in antiquity and is based upon superstition and ritualistic behaviour of athletes who perceive that past performances were predicted upon unique dietary constituents or dietary manipulation (Applegate and Grivetti, 1997). Coaches and athletes are continually searching for ways to gain the competitive edge and improve athletic performance. It is therefore not surprising that a variety of ergogenic substances and procedures are used routinely at almost all levels of competition. Williams (1998), estimated that approximately 89 brands of supplements exist which offer more than 300 products. Of these, 235 claim to contain unique ingredients that purportedly enhance growth and/or performance. Unfortunately, the marketing of such products depends on emotional appeal and is often loosely based on scientific evidence. Sadly, the climate generated from such tactics is one of dashed hopes and seldom-realized dreams. Overall, these disappointments only lead to a continued feeling of distrust toward the sports nutrition supplement industry as it seeks

the next blockbuster product (Earnest, 2001). Pharmacological agents are most often used by University and professional athletes, whereas nutrition supplementation and warm-up procedures are common to individuals who train for fitness and sport activities.

The term "ergogenic" relates to the application of a nutritional, physical, mechanical, psychological, or pharmacological procedure or aid to improve physical work capacity or athletic performance (McArdle et al., 1991). An ergogogenic aid, simply defined, is any substance, process, or procedure that may, or is perceived to, enhance performance through improved strength, speed, response time, or the endurance of the athlete. Another area of interest in ergogenic aids is to hasten recovery. The nature of the action of any supposed ergogenic aid may be elicited through the following:

- Direct action on muscle fibre;
- Counteraction of fatigue products;
- Fuel supply needed for muscular contraction;
- Affecting the heart and circulatory system;
- Affecting the respiratory system; and
- Counteraction of the inhibitory affects of the central nervous system on muscular contraction and other functions (Fox and Bowers, 1993).

Frequently ergogenic aids are thought of only as pharmacological agents that may be consumed to give the athlete an advantage. Pharmacological agents constitute only one of several classes of ergogenic aids. Others include nutritional (carbohydrates, proteins, vitamins, minerals, water, and electrolytes), physiological (oxygen, blood boosting, conditioning, and recovery procedures), psychological (hypnosis, suggestion, and rehearsal), and mechanical (improved body mechanics, clothing, equipment, and skill training) components.

In its broadest sense, one could call anything that can be related to an improvement in work or performance, or a delay in the onset of fatigue an

ergogenic aid. Ergogenic aids affect different people differently, as might be expected. For some, studies show a positive influence on work performance and for others, no affect whatsoever. What might prove effective with the athlete may prove inconsequential to the non-athlete and vice versa. Certain ergogenic aids may influence a person's endurance performance but may have little or no effect on activities requiring short bursts of strength and power (Fox and Bowers, 1993; Williams, 1983).

For the purpose of this review three main categories of ergogenic aids are distinguished namely: pharmacological and physiological aids and nutritional aids.

### 2.5.1 Pharmacological and Physiological Agents

Pharmacology can be described as the study of the distribution, actions, and fate of drugs in the body. A drug is any absorbed substance that changes or enhances any physical or psychological function in the body (Liska, 1990). If our body responds in some way to a substance, either physically, biochemically or mentally, that substance can be said to have a drug effect (Mottram, 1988)

The term "doping" is often used when describing the use of a substance to enhance performance and can be defined as follows: Doping is the administration of, or the use by a competing athlete, of any substance foreign to the body or of any physiological substance taken in abnormal quantity or taken by any abnormal route or entry into the body, with the sole intention of increasing in an unfair manner his/ her performance in competition. When necessity demands medical treatment with any substance, which because of its nature, dosage, or application is able to boost the athlete's performance in competition in an artificial and unfair manner, this is to be regarded as doping (Fox and Bowers, 1993). The clinical manipulation of natural substances in the body for the same purpose is also regarded as doping. The use of so-called masking agents and methods or agents to adulterate urine in order to prevent

the detection of prohibited substances is also regarded as a doping offence (MIMS, 1996).

The International Olympic Committee (IOC) Medical Commission and the International Amateur Athletics Federation (IAAF) rules state that a doping offence is committed when:

- A prohibited substance is found to be present within an athlete's body tissue or fluids;
- An athlete uses or takes advantage of a prohibited technique, or
- An athlete admits having used or taken advantage of a prohibited substance or prohibited technique.

The practice of using various pharmacological agents and drugs has raised much controversy and presents numerous ethical, legal and clinical questions. The indiscriminate use of pharmacological agents also poses the greatest threat to the health and welfare of the athlete. Most of the contemporary controversy centres on the use of anabolic/ androgenic steroids, human growth hormone, and blood boosting abuses. Other substances of concern include amphetamines and, to a lesser degree, bicarbonates, caffeine, analgesics, stimulants like decongestants and appetite suppressants, diuretics, beta-blockers, corticosteroids, and vitamins and minerals (Fox and Bowers, 1993; MIMS, 1996).

**Blood Doping/ Blood Boosting**

This is one of the techniques particularly used by endurance athletes to enhance their performance. The South African Institute for Drug Free Sport regard blood doping as a prohibited method and describe the method as follows: "Blood doping : means the administration of blood, red blood cells and/or related blood products to an athlete, which may be preceded by withdrawal of blood from the athlete, who continues to train in such a blood-depleted state" (South African Institute for Drug-Free Sport, 2002).

Further the American College of Sports Medicine position stand concerning blood doping clearly condemns the practice for sport while recognizing the scientific and medical value of infusion of autologous RBC (red blood cells). As with other banned practices, blood doping is considered to be unethical and, consequently, unjustifiable in sport (Fox and Bowers, 1993).

The medical risks include the development of allergic reactions, acute haemolytic reaction with kidney damage if incorrectly typed blood is used, as well as delayed transfusion reaction resulting in fever and jaundice, transmission of infectious disease, overload of the circulation, shock, septicemia, air embolism, and thrombosis (MIMS, 1996; Fox and Bowers, 1993).

With the procedure, usually between 1 to 4 units of a person's own blood (autologos) are withdrawn, the plasma is removed and immediately reinfused, and the packed red cells are placed in frozen storage. To prevent a dramatic reduction in blood cell concentration, each unit of blood is withdrawn over a 3 to 8 week period because it generally takes this long for the person to re-establish normal red cell levels. The stored cells are re reinfused 1 to 7 days before an endurance event. As a result, the red cell count and haemoglobin level of the blood is often elevated some 8 to 20%. This hemoconcentration relates to an average increase in haemoglobin for men from a normal 15g per 100ml of blood to 19g per 100ml (or from hematocrit of 40% to 60%). These hematologic characteristics remain elevated for at least 14 days. It is theorized that the added blood volume contributes to a larger cardiac output and that the red blood cell packing increases the blood's oxygen carrying capacity and thus the quantity of oxygen available to the working muscles. This would be beneficial to the endurance athlete, especially the marathoner, for whom oxygen transport is often a limiting factor in exercise (McArdle et al., 1991).

Scientific studies of blood doping and endurance performance have produced conflicting results. Several studies have shown that blood doping increases endurance performance between 13% and 39% (measured by a treadmill run to exhaustion) and maximal oxygen consumption between 5% and 31% in

both non-athletic and highly trained endurance athletes (Belko, 1987; Ekblom et al., 1973; Ekblom et al., 1976). An equal number of studies (mostly from earlier literature), however, have found no effects of blood doping on endurance performance, maximal oxygen consumption, heart rate responses during exercise, or perceived exertion (Cunningham, 1978; Pate et al., 1979; Videman and Rytomaa, 1977). An examination of research design differences clarifies much of the conflicting evidence. Two critical factors became apparent: (1) when between 800 and 1200ml of blood, or its equivalent, is reinfused (as opposed to 450 to 500ml), aerobic capacity and endurance increases and (2) when 5 to 6 weeks elapse before reinfusion, "positive" results also are seen (Fox and Bowers, 1993). It is now clear that blood doping reduces blood lactate levels during exercise and alters the lactate turn point to higher running speeds. These effects are likely to be the more important explanations for the increased running performance after blood doping. Blood doping may also enhance heat tolerance during exercise (Noakes, 1992).

The possibility that blood doping can be detected is raised by the work of Berglund and colleagues (Berglund, 1988; Berglund and Hemmingson, 1987). They showed that the measurement of serum levels of erythropoietin, iron and bilirubin can identify 50% of boosted athletes within seven days of blood doping. An alternative technique may be to measure the distribution of red blood cell sizes, as the reinfused cells are likely to be larger than the athlete's remaining red blood cells. Thus the size distribution of the athlete's red cells will probably show an abnormal distribution of large cells. However even this technique will be unable to detect what is likely to become the new form of blood doping in the 1990's – the use of erythropoietin to naturally stimulate the overproduction of the athlete's own red blood cells (Noakes, 1992).

**Erythropoietin**

Endurance athletes, e.g. cyclists and marathon runners have long known that they can improve their athletic performance by increasing the flow of oxygen to their working muscles. Another technique for boosting red blood cells became apparent in the late 1980's. Erythropoietin (EPO), a hormone produced by the kidneys, stimulates the production of RBC's under conditions

of hypoxia (chronic low oxygen tension in the blood) and anemia. It travels via the circulation to the bone marrow, where it stimulates the production of red cells. The rate of formation of new red cells, is, in part determined by EPO. Whenever the kidneys senses a decrease in the circulating red cells (oxygen tension), it releases EPO into the circulation, which then stimulates the bone marrow to produce more red cells (Hopkins, 2000). Injections of EPO are very effective, athletes can expect enhancements in endurance performance of 5% or more (Sawka et al., 1996; Birkeland et al., 2000).

The benefits of this technique is similar to those achieved by blood doping. The non-therapeutic uses of EPO poses a significant health risk. The inappropriate use of EPO increases the thickness or viscosity of the blood so that the blood has difficulty passing through small blood vessels, in essence simulating the disease of erythrocythemia and polycythemia. When this increased viscosity effect is combined with the dehydration that is encountered in competitive athletics, the viscosity of the blood increases further, producing sludging of the blood in the vessels. At hematocrit above 55%, the blood viscosity increases exponentially, thereby substantially increasing the risk of a coronary artery occlusion or a cerebral artery occlusion. Similarly, occlusions can occur in other blood vessels producing other complications. With this in mind, it has been speculated that EPO may have contributed to the unusually high number of deaths that have occurred in competitive cyclists from the Netherlands and Belgium (MIMS, 1996; Fox and Bowers, 1993; McArdle et al., 1991; Noakes, 1992).

Unfortunately there has been no dependable and fair test for EPO abuse. The International Cycling Union (UCI) now tests for the thicker blood by measuring the proportion of the red cells (the hematocrit or packed cell volume) in a blood sample. By itself, this test is not a good indicator of EPO abuse, because a few athletes have a naturally high hematocrit, while others can get a high proportion from altitude training. A cyclist exceeding the upper limit is therefore not banned for EPO abuse, but is simply not permitted to compete because of the health risk. In any case, cyclists can cheat the test. When told they are to be tested, apparently they have 10 minutes to report to

the medical team. A cynical informant claims that is long enough for an athlete to run 500ml of saline into a vein. By diluting the blood, the saline immediately brings the hematocrit down by a few percent. The normal hematocrit for "clean" elite cyclists is around 44% (Schumacher et al., 2000).

**Oxygen**

How important is oxygen to the healthy body? Many experts conclude that the lack of oxygen in human cells and tissue is linked to a vast variety of health problems and disease, and that supplemental oxygen therapies have remarkable physiological benefits. A diversity of beneficial oxygen therapies is being utilized today. What is oxygen therapy? Oxygen therapy is any supplemental process that safely increases the available dissolved oxygen content in the body. Therapies may also include the processes that enhance the body's ability use or promote oxygen absorption. Most treatments are generally expensive and should be administered or supervised by a licensed medical professional. Here are brief descriptions of some accepted oxygen therapies (Nu Science Corporation, 2001d):

- Bottled Oxygen: is often prescribed as inhalation therapy for serious bronchial and other respiratory problems.
- Hydrogen Peroxide Therapy ($H_20_2$): hydrogen peroxide is manufactured in the bloodstream to help fight bacteria, viruses, yeast, fungi and other invading pathogens. The ingestion of $H_20_2$ is extremely controversial because it can cause an adverse reaction in the digestive tract: excess hydrogen causes an unbalanced pH, as well as possibly produce dangerous free radicals. $H_20_2$ therapy should only be utilized under the direct supervision of a licensed health care professional

Studies have been conducted regarding the ergogenic effects of breathing oxygen (1) prior to exercise, (2) during exercise, and (3) during recovery from exercise (Fox and Bowers, 1993). It is common to observe athletes breathing oxygen-enriched or hyperoxic gas mixtures during times out, at half time, or following strenuous exercise. The belief is that this procedure significantly enhances the blood's oxygen carrying capacity and thus facilitates oxygen

transport to the exercising muscles. The fact is however, that when healthy people breathe ambient air at sea level, the haemoglobin in arterial blood leaving the lungs is about 95 to 98% saturated with oxygen. Thus, breathing high concentrations of oxygen could increase oxygen transport by haemoglobin to only a small extent, i.e., about 1 ml of extra oxygen for every 100ml of whole blood. The oxygen dissolved in plasma when breathing a hyperoxic mixture would also increase slightly from its normal quantity of 0.3ml to about 0.7ml per 100ml of blood. Thus, the blood's oxygen-carrying capacity under hyperoxic conditions would be increased potentially by about 1.4ml of oxygen for every 100ml of blood, with 1.0ml extra attached to hemoglobin and 0.4ml extra dissolved in plasma (McArdle et al., 1996). There is some evidence that breathing oxygen immediately prior to exercise has some beneficial effects on performance, provided that the exercise is performed while holding the breath. Studies in which oxygen was breathed prior to a non-breath-holding type of exercise show very little if any effect on performance (Fox and Bowers, 1993).

There is a rather large body of information indicating that breathing oxygen-enriched air (33 to 100% oxygen) has a beneficial effect on exercise performance (Allen and Pandolf, 1977; Hughes et al., 1968; Miller, 1952). Oxygen breathing during both light and heavy exercise has resulted in reduced blood lactic acid levels, heart rates, ventilation volumes, and a significant increase in maximal oxygen consumption. Since available evidence does not indicate that hyperoxic gas mixtures increase cardiac output, the increase in maximal oxygen consumption must be due to an expanded a-$v0_2$ difference. This may be partially explained by the fact that even a small increase in haemoglobin saturation during hyperoxia, as well as additional oxygen dissolved in the plasma, increases total oxygen availability during strenuous exercise where the total blood volume is circulated 4 to 7 times each minute. The increase in partial pressure of oxygen in solution breathing hyperoxic gas also facilitates its diffusion across the tissue-capillary membrane to the mitochondria. This may account for its more rapid rate of utilization in the beginning phase of exercise. When considering the increase in arterial oxygen content when breathing hyperoxic gas that is reported in the literature,

however, it appears that the maximum increase does not exceed 10% (Eiken and Tesch, 1984). In terms of exercise performance, the reduction in pulmonary ventilation commonly observed breathing hyperoxic gas would reduce the oxygen cost of breathing and theoretically liberate significant oxygen for the use by the working muscles. Evidence also suggests that hyperoxia increases local muscular performance in static and dynamic movements in which the central circulation does not appear to be a limiting factor. The proposed mechanism for this ergogenic benefit is that the local high oxygen pressure enhances the rate of energy release in the active muscle. Although the breathing of hyperoxic mixtures appears to offer positive ergogenic benefits during endurance performance, its practical application in sports seems limited. Even if an appropriate breathing system could be devised, its legality during actual competition is unlikely (Fox and Bowers, 1993; McArdle et al., 1991).

Although there is not a great deal of research on the practice of administering oxygen during recovery, any beneficial effects, either on the recovery process itself or on performance of a subsequent work-bout, are inconsequential. Research indicated that oxygen inhalation did not preferentially alter lactate removal. Although there may be a psychological effect, there is no physiological basis for use of oxygen during recovery (Fox and Bowers, 1993; McArdle et al., 1996).

**$HB0_2$**

In recent years, professional and university teams have started using hyperbaric oxygen therapy to treat sports injuries. From muscle contusions and ankle sprains to delayed-onset muscle soreness (Borromeo et al., 1997). Because of the importance of oxygen in the aerobic energy system, many athletes and researchers have also investigated the possible ergogenic effects of hyperbaric oxygen (Delaney and Montgomery, 2001).

Normally, 97% of the oxygen delivered to the body tissues is bound to hemoglobin, while only 3% is dissolved in the plasma. At sea level, barometric pressure is 1 ATA, or 760 mmHg, and the partial pressure of

oxygen in arterial blood ($Pa0_2$) is approximately 100 mmHg. At rest, the tissues of the body consume about 5ml of oxygen per 100 ml of blood. During hyperbaric oxygen treatments, barometric pressure is usually limited to 3 ATA or lower. The oxygen content of inspired air in the chamber is typically 95% to 100%. The combination of increased pressure (3 ATA) and increased oxygen concentration (100%) dissolves enough oxygen in the plasma alone to sustain life in a resting state. Under hyperbaric conditions, oxygen content in the plasma is increased from 0.3 to 6.6 ml per 100 ml of blood with no change in oxygen transport via hemoglobin. $HB0_2$ at 3.0 ATA increases oxygen delivery to the tissues from 20.0 to 26.7 ml of $0_2$ per 100 ml of blood (Delaney and Montgomery, 2001).

Professional athletes have reportedly received hyperbaric oxygen before sports participation, believing that performance would improve. Contradictory findings have been reported regarding the effect of a single hyperbaric oxygen treatment on aerobic performance. A Yugoslavian study (Staples and Clement, 1996), demonstrated that hyperbaric oxygen prior to treadmill running to volitional exhaustion increased peak running velocity and maximal oxygen consumption when measured 30 minutes and 3 hours post treatment. $HB0_2$ was administered for 60 minutes at 2.8 ATA. Enhanced performance and $V0_2$ max were attributed to additional oxygen storage in skeletal muscle. However to their knowledge, this link has yet to be definitely established (Delaney and Montgomery, 2001). In contrast, two recent studies (James et al., 1993; Potera, 1995), reported no change in submaximal and maximal exercise performance following hyperbaric oxygen therapy. It is difficult to rationalize how prior hyperbaric oxygen could enhance performance. Tissue retention of oxygen following treatment is unlikely since tissue autoregulation reduces oxygen levels upon return to a normobaric, normoxic environment (Delaney and Montgomery, 2001). Only two human studies (Staples et al., 1999; Potera, 1995) have examined hyperbaric oxygen to alleviate exercise-induced fatigue. These research studies indicated that recovery from exercise-induced fatigue was not enhanced following a single hyperbaric oxygen treatment (Delaney and Montgomery, 2001). Hyperbaric oxygen treatments are not without risks.

Its side effects can be divided into two categories: pressure effects and oxygen toxicity

### 2.5.2 Nutritional Aids

There are three basic rules regarding nutrition. Firstly, the body requires essential nutrients: carbohydrates, proteins and fats (energy supplying nutrients) and the vitamins, minerals, trace elements and water that are necessary for the utilization of that energy. Second, these nutrients are contained in four basic food groups: (i) the meat, fish and meat substitute group; (ii) the fruit and vegetable group; (iii) the milk and diary produce group; and (iv) the bread and cereal group. Third, these four basic food groups should be eaten in specific portions each day (Noakes, 1992). The manipulation of the following is the most common usage of nutritional substances as ergogenic aids: carbohydrates, water and electrolytes and vitamin and mineral supplements.

**Carbohydrates**

Carbohydrates serve the primary function of supplying energy for cellular work. They are the only stored nutrient that can generate ATP anaerobically and aerobically depending on the availability of oxygen. Carbohydrates supply approximately half of the body's energy requirements during light and moderate exercise. Another important fact concerning carbohydrates is that they must continually be degraded via the "carbohydrate flame" so that lipid nutrient can be processed during activities such as marathon running which is prolonged and of high intensity (Meyer en Meij, 1996)

The breakdown of glucose is complex and involves three pathways:

1. glycolysis/ Embden- Meyerhoff pathway (within the cytoplasm of cell)
2. the Krebs cycle (occurs in the mitochondria of the cell)
3. electron transport chain (occurs within the mitochondria of the cell) (McArdle et al., 1991)

A simplified equation to represent the complete breakdown of glucose:

**$C_6H_{12}O_6 \rightarrow 6\ H_2O + 6\ CO_2 + 38\ ATP + Heat$**

**The Krebs Cycle (Citric acid/ tricarboxylic cycle)**

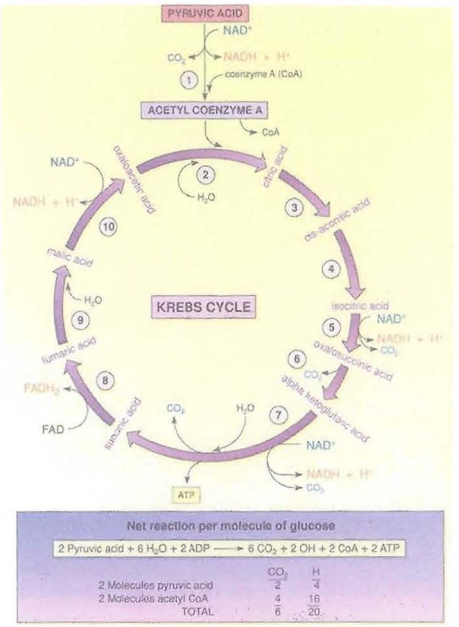


**Figure 2.6: A flow sheet for release of hydrogen and carbon dioxide during the degradation of one molecule of pyruvic acid in the mitochondrion (McArdle et al., 1991).**

Although the glycolytic pathway is exclusive to carbohydrate oxidation, breakdown products of carbohydrates, fats and proteins can be oxidized in the Krebs cycle reactions. Fatty acids destined to be oxidized for energy metabolism can be freed directly into the cycle as Acetyl-CoA. In the same way Acytel-CoA can be used to synthesize fatty acids. For this reason fat and glucose metabolism is closely interwoven. Amino acids to be used for ATP synthesis are deaminated and converted to keto acids, which enter the citric acid cycle. In reverse, keto acids can be converted to non- essential amino acids as needed. Therefore in addition to serving as the final common metabolic pathway for the oxidation of food fuels, it is also a source of building materials for anabolic reactions (De Vries, 1986).

Pyruvic acid is converted to Acetyl-CoA, before it enters the Krebs cycle. Three important events play a role to enable this to take place:

1. Decarboxylation

2. Oxidation
3. Acetic acids combine with co-enzyme A to form Acetyl- CoA

Pyruvic acid + $NAD^+$ + CoA → acetyl – CoA + NADH + $H^+$ (Seeley et al., 1992).

The citric acid cycle begins with the production of citric acid (6- carbon molecule) from the combination of acetyl–CoA (2 carbon molecules) and a four-carbon molecule called oxaloacetic acid. A series of reactions occur, resulting in the formation of another oxaloacetic acid, which can start the cycle again by combining with another acetyl-CoA. During the reactions of the citric acid cycle three important events occur (Marieb, 1995; Fox and Bowers, 1993):

1. ATP production: For each molecule of citric acid, one molecule of ATP is offered.
2. NAD + FADH: For each citric acid molecule, three NAD+ molecules are converted to NADH+$H^+$ molecules, and one FAD molecule is converted to $FADH_2$. The NADH +$H^+$ and $FADH_2$ molecules act as electron carriers that enter the electron transport chain to produce more ATP.
3. Carbon dioxide production: Each of the 6-carbon citric acid molecules that are found at the start of the cycle is changed to a 4-carbon oxaloactic acid molecule at the end of the cycle. Two of the carbon atoms found from the citric acid molecule are used to form two carbon dioxide molecules. For each glucose molecule that starts aerobic respiration, two pyruvic acid molecules are produced in the process of glycolysis. Each of these pyruvic acid molecules is converted into Acetyl-CoA molecules that enter the citric acid cycle. This means to be able to determine the number of molecules produced from glucose by the citric acid cycle, “two turnovers” of the cycle must be counted. The result from this would be 2 ATP, 6 NADH + $H^+$, 2$FADH_2$ and 4 carbon dioxide molecules (Marieb, 1995).

**The Electron Transport Chain and Oxidative Phosphorylation**

Similar to the glycolysis, none of the reactions in during the Krebs cycle makes direct use of oxygen. This is the exclusive function of the electron transport chain. However because the reduced coenzymes produced during the Krebs cycle are the substrates of the electron transport chain "mill", these pathways are coupled and both phases are considered to be aerobic (Martini, 1995). The hydrogen removed during the oxidation of food fuels are finally combined with molecular oxygen in the electron transport chain and the energy released during those reactions is harnessed to attach inorganic phosphate groups to ADP. This type of phosphoralytion is known as oxidative phosphoralytion (Marieb, 1995).

Most components of the electron transport chain are proteins bound to metal atoms (cofactors). Most of these proteins are a brightly coloured iron containing pigments called cytochromes. Neighbouring carriers are clustered together to form three major respiratory enzyme complexes that are alternatively reduced and oxidized by picking up electrons and then passing them on to the next complex in the sequence. The first of these complexes accepts hydrogen atoms from NADH+ $H^+$ oxidizing it to $NAD^+$. $FADH_2$ transfers its hydrogen baggage slightly further along the chain. The hydrogen delivered to the electron transport chain by reduced coenzymes is quickly split into protons and electrons.

The protons escape into the watery matrix and the electrons are shuttled along the membrane from one receptor to the next. Ultimately hydrogen is delivered to molecular oxygen to form water. The transfer from NADH+ $H^+$ to oxygen, release large amounts of energy. If hydrogen combined directly with molecular oxygen the energy would be released in one big burst and most of it would be lost to the environment as heat. Instead energy is released in many small steps as the electrons move from one electron receptor to the next. Each successive carrier has greater affinity for electrons than those preceding it. Thus the electrons cascades "downhill" from NADH + $H^+$ to lower energy levels until they are finally delivered to oxygen, which has the greatest affinity of all for the electrons. The electron transport chain uses the stepwise release

of electronic energy to pump protons from the fluid matrix into the inter-membrane space. Since the membrane is nearly impermeable to $H^+$, this chemiosmotic process creates an electro-chemical proton gradient across the inner membrane that temporarily stores the potential energy that will be utilized in the synthesis of ATP (Seeley et al., 1992).

This proton gradient has two important functions:

1. It creates a pH gradient, with the hydrogen concentration in the matrix much lower than that in the inter-membrane space.
2. It generates a voltage across the membrane that is negative on the matrix side and positive in the mitochondrial membranes. This results in the strong attraction of the protons back into the matrix. The only areas of the membranes that are freely permeable to $H^+$ are large enzyme protein complexes called ATP synthase. As the protons take this route they create an electrical current, and ATP synthase harnesses this electrical energy to catalyse the attachment of a phosphate group to ADP to form ATP, thereby ensuring the completion of oxidative phosphoralytion (Marieb, 1995).

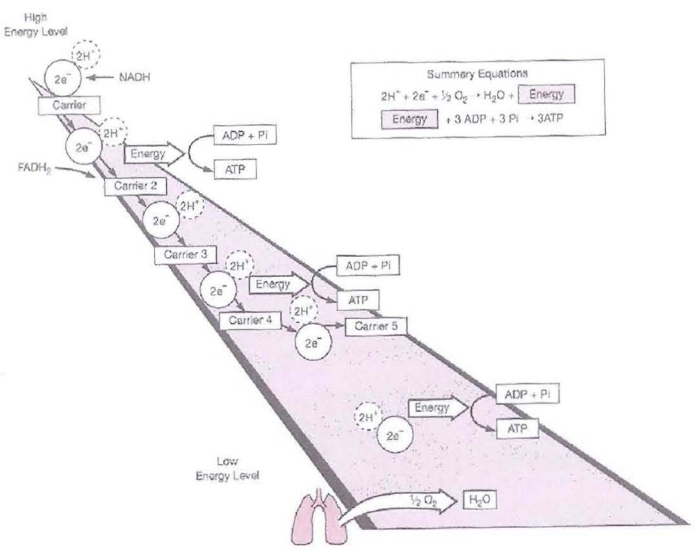


**Figure 2.7: The electron transport system (Fox and Bowers, 1993).**

**Total energy transfer from Glucose metabolism**

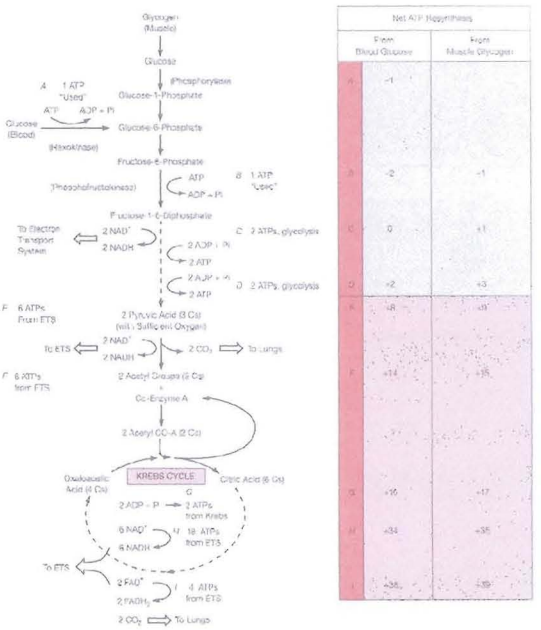


**Figure 2.8: Sources of ATP resynthesis from the complete oxidation of carbohydrate in the form of either blood glucose or muscle glycogen (Fox and Bowers, 1993).**

Carbohydrate as an ergogenic aid has its beginnings strongly rooted in science. Early in the 20th century it was apparent that during very heavy, intense exercise, the primary fuel source was carbohydrate (Horstman, 1972). Carbohydrate (CHO) loading is one of the more popular methods of nutritional modification used by endurance athletes to improve performance. It is also one of the most studied ergogenic aids for athletic performance (Walberg-Rankin, 1995). Although the judicious adherence to this dietary technique can significantly improve specific performances, there are also some negative aspects that could prove detrimental (McArdle et al., 1993). Reduction of body stores of carbohydrate and blood glucose is related to the perception of fatigue and the inability to maintain high-quality performance. This has been clearly shown with aerobic, endurance events of moderate intensity of over 90 minutes duration. Carbohydrate intake may also have relevance for athletes involved in short, high-intensity events, especially if body weight control is an issue (Walberg-Rankin, 1995). The process of glycogen loading (carbohydrate loading) may be incorporated to elevate muscle glycogen stores above their normal resting levels prior to endurance

competition (Fox and Bowers, 1993). Generally glycogen super-compensation is applicable where the athlete is continuously in motion for more than an hour at a time. Super-compensation may have value for events with an anaerobic component to the extent that lowered levels of glycogen can have adverse effects on lactate production (anaerobic power) (Fox and Bowers, 1993). Some recent studies further confirm that consumption of a high-carbohydrate diet for 2 or more days prior to an endurance event enhances performance relative to a low carbohydrate diet. For example, O'Keefe et al. (1989) found that 1 week on a 72% carbohydrate diet allowed cyclists to exercise at 80% of $V0_2$ max for 113 minutes, whereas they could only cycle 60 minutes when they consumed a 13% carbohydrate diet for the same period (Walberg-Rankin, 1995). Under circumstances where an athlete must perform multiple events in one day, super-compensation is appropriate. For these purposes one can simply increase the dietary intake of carbohydrates for 48 to 72 hours prior to competition. The practice of ingesting glucose 30 to 45 minutes before competition is not recommended. It can lead to a rapid fall in blood glucose levels with the onset of exercise and increase the rate of glycogen utilization. One other point of consideration is that with the storage of one gram of glucose about 2.7 grams of water will be taken into storage. Thus, with a storage of 700 gm of glucose an additional storage of about 1.9 kg of water will occur. So the athlete should not be surprised to have a precompetition weight gain. This can be an advantage or disadvantage depending on the event.

One aspect that has not received a lot of thought until now is that there are differences between the genders in the metabolic response to exercise. Recently research has demonstrated that females oxidize proportionally more lipid and less carbohydrate during endurance exercise as compared to males (Horton et al., 1998; Friedlander et al., 1998). These gender differences are partially mediated by higher estrogen concentrations in females. Specific areas where there are gender differences in nutritional/ supplement recommendations include carbohydrate nutrition, protein requirements and creatine supplementation. The research indicate that females do not carbohydrate load in response to an increase in dietary carbohydrate when

expressed as a percentage of total energy intake (i.e., 55-75%), however if they consume >8g CHO/ $kg^{-1}$/ $d^{-1}$ they show similar increases compared to males (Tarnopolsky, 2000). In a study using treadmill running, Tarnopolsky et al., (1991), found that females have significantly less glycogen depletion in the vastus lateralis following 15.5 km of treadmill running, as compared to males. The hypothesis explaining this phenomenon is that the glycogen sparing was due to an enhanced oxidation of lipid by the muscles. The mechanism behind the potential glycogen sparing effect is likely the female sex hormone, 17-β-estradiol. Two studies have demonstrated that the administration of 17-β-estradiol to male (Rooney et al., 1993) and female oophorectomized (Kendrick et al., 1987) rats resulted in significant muscle glycogen sparing during exercise.

**Water and Electrolytes**

Competing in ultra-endurance events lasting longer than 2-3 hours probably puts more demand on the fluid and energy balance of the body than any other from of exercise (Brendon and Hopkins, 2000). Of all the physiological perturbations that can cause early fatigue during exercise, dehydration is arguably the most important, if only because the consequences of dehydration are potentially life threatening. The rise in body temperature that normally accompanies exercise stimulates an increase in blood flow to the skin and the onset of sweating (Murray, 1995). Water loss in amounts as low as 2 to 3 % of body weight can impair performance through the disruption of circulatory and thermoregulatory functions (Fox and Bowers, 1993). Normal hydration is protective of these thermoregulatory responses, whereas even a slight amount of dehydration results in measurable declines in cardiovascular and thermoregulatory function. Mild to severe dehydration commonly occurs among athletes, even when fluid is readily available. This voluntary dehydration compromises physiological function, impairs exercise performance, and increases the risk of heat illness. Recent research illustrates that maintaining normal hydration (or close to it) during exercise maintains cardiovascular and thermoregulatory responses and improves exercise performance. Consequently, it is in the athlete's best interest to adopt fluid-

replacement practises that promote fluid intake in proportion to sweat loss (Murray, 1995). For an acclimatized person, water loss by sweating may reach a peak of about 3 litres per hour during severe work and average nearly 12 litres on a daily basis. Furthermore, several hours of intense sweating can cause sweat-gland fatigue that ultimately leads to the inability to regulate core temperature. Elite marathon runners frequently experience fluid losses in excess of 5 litres during competition (McArdle et al., 1991). The daily intake of fluid is usually closely balanced with the volume of fluid that is lost in urine, faeces, sweat and respiration and via insensible water loss through the skin so that, at rest in thermo neutral conditions, body fluid balance is maintained at more or less 0.2% of total body weight. This balance requires the constant integration of input from hypothalamic osmoreceptors and vascular baroreceptors so that drinking behaviour closely approximates fluid loss, a minimum of about 2 l/day (Murray, 1995). Noakes (1992), feels that the rates of fluid ingestion are probably acceptable in most runners, with the increasing probability that the fluid intakes of runners competing in very long races will be greater than required. It would seem that the only runners whose fluid intakes may be inadequate, are those who run the fastest in races of between 10 to 42km. At these high exercise intensities, rates of gastric emptying and possibly intestinal absorption are likely to be impaired. In addition, their high rates of ventilation make the actual process of drinking both difficult and uncomfortable. Of course the fast running speeds of these elite athletes ensure high metabolic rates and therefore also high sweat rates. Thus it is precisely these runners, who also have the greatest difficulty in replacing their fluid loss during exercise.

Slower runners, especially during ultra marathon races, have less difficulty in drinking adequately and some may even have too much of a good thing. By drinking (for example) 1000ml instead of 500ml each hour during an ultra marathon, some runners have developed potentially fatal water intoxication or hyponatraemia (low blood sodium concentrations). Typically runners who are affected are not elite, competitive runners but those who are completing these ultra marathons in between 9 and 11 hours. Their slow running speeds allow them ample time to drink fluid from the vast number of feeding stations

available during these races. But, more importantly, their slow running speeds and resultant slow metabolic rates cause them to sweat at much slower rates than those calculated by previous workers, who studied only elite marathoners. It is clear that sweat rate calculations based on elite runners are erroneous if applied to the average runner of the same body mass, who runs much more slowly. For example, researchers originally believed that if a 50kg runner loses 5,5 l of sweat during a 05:30:00 ultra marathon, then that runner should obviously drink a litre of fluid every hour to maintain a water balance. This calculation ignores the water lost from glycogen, which may not have to be replaced. Thus the general (but incorrect) rule was devised that a 50kg person should drink a litre of fluid for every hour of running, and that those who are heavier should drink a little more. But now it is known that this advice is safe only if the runner is able to finish the race in 05:30:00. A less competitive 50kg runner who religiously followed that advice but took 10:00:00 to complete the race would finish the race with a fluid credit of 4l , enough to cause water intoxication if the runner is predisposed to the condition.

The finding that the incidence of hyponaetremia is on the increase among slower ultra marathon runners suggests that this is happening more frequently. The question would be why this extra fluid causes the runner to develop this condition. One possibility is that it is not so much the absorbed fluid that is the problem, but rather the unabsorbed fluid in the intestine. Thus one theory is that most of the fluid ingested by these athletes is not absorbed, but remains in the intestine. This causes sodium in particular to move from the body into that undigested fluid. Whenever fluid that does not contain sodium is ingested, sodium moves into the fluid before it is absorbed. In other words, sodium is needed for water to be absorbed into the intestine. Sodium moves out of the cells lining the gut into the digested water. The loss of this sodium then causes all the bodily changes that produce this disturbing condition. But whatever the mechanism, this condition does show that drinking too much during exercise can be detrimental to the health of some predisposed individuals (Noakes, 1992)

The content of fluid replacement drinks is very important. The diet normally contains sufficient electrolytes to compensate for any acute losses experienced through activity. Exception is noted where very high sweat rates over a period of days may occur. A concerted effort will be needed to insure added electrolyte intake, especially as it relates to potassium (Fox and Bowers, 1993). Obviously one possible aim of fluid ingestion would be to match the the electrolyte losses in sweat (Noakes, 1992). The minerals sodium, potassium, and chlorine are collectively termed electrolytes because they are dissolved in the body as electrically charged particles called ions. Sodium and chlorine are the chief minerals in blood plasma and extracellular fluid. A major function of these electrolytes is to modulate fluid exchange within the body's various fluid compartments. This allows for a constant, well regulated exchange of nutrients and waste-products between the cell and its external fluid environment. Potassium is the chief intracellular mineral. Perhaps the most important function of the mineral electrolytes sodium and potassium is their role in establishing the proper electrical gradients across cell membranes. This electrical difference between the interior and exterior of the cell is required for the transmission of nerve impulses, for the stimulation and contraction of muscle, and for the proper functioning of glands. The electrolytes are also important in maintaining the permeability of the cell membranes and controlling the balance between the acid and base qualities of the body fluids, especially the blood (McArdle et al., 1991).

**Vitamins and Minerals**

In addition to protein and carbohydrate, athletes have been interested in vitamin supplementation since the 1930's after the discovery and isolation of these compounds. By 1939, leading Tour de France cyclists reportedly performed better after taking vitamin supplements (Applegate and Grivetti, 1997). In spite of widespread usage, there appears to be little compelling evidence for supplemental intake of various vitamins with the exception of iron and vitamin C. Most vitamins, when taken in excess, are merely excreted in urine. There is no justification for the consumption of megadoses of vitamins. None of the known vitamins, when taken in excess of their recommended daily allowance, produces an ergogenic effect. One

consideration for recommending vitamin supplementation to athletes relates to those who restrict caloric intake to "make weight" (wrestlers, boxers or jockeys, among others) or to keep body weight to a minimum for cosmetic and other reasons (gymnasts, dancers, and figure skaters, among others). Because vitamin intake is closely related to caloric intake it would not be inappropriate to take a multivitamin/ mineral pill on a regular basis for those who restrict caloric intake (Fox and Bowers, 1993).

Recent studies have provided the scientific basis for the use by athletes of some micronutrients, such as antioxidants (Barrarre et al., 1993, Clarkson, 1995, Nieman et al., 1989). This has led to the development of commercial products to enhance antioxidant intake and to prevent antioxidant damage due to endurance and high intensity exercise.

**Caffeine**

Caffeine is one of the best researched substances in food supply. The overwhelming scientific evidence suggests that, in moderation, it has no adverse health effects. According to the International Food Information Council, moderation refers to 1 to 2 mugs of brewed coffee per day (Clark, 1997). Caffeine is the most widely ingested psychoactive drug in the world. Because caffeine enhances performance in many individuals, it has been banned by the International Olympic Committee. But ironically, the level at which caffeine is banned far exceeds the amount needed to enhance performance. Higher, illegal levels are generally attained with caffeine supplements, since a 68kg-athlete would need to drink 3 to 4 large cups of coffee within an hour before activity to reach the upper acceptable limit. Just 1.5 to 3 milligrams of caffeine per 0.454 kg of body weight (225 to 450 milligrams for a 68kg man) is enough for an energy-enhancing effect. That's as little as one 283.5 gram cup of coffee. Habitual caffeine consumers experience less ergogenic effect than people who consume it rarely. Caffeine affects each person's performance differently (Clark, 1997).

As many know, chronic use of caffeine leads to dependence, tolerance, drug craving, and upon abrupt cessation unpleasant withdrawal symptoms. Thus,

caffeine fulfils pharmacological criteria by which agents are classified as drugs of abuse. Nevertheless, its use is legal and only at high, but readily attainable, levels is it banned from sport. Its use is widespread by athletes as young as 11 years of age who are seeking athletic advantage over fellow competitors. It is likely that its use will not decline soon because it is inexpensive, readily available, medically quite safe, socially acceptable, and by most measures legal. However, at levels allowed in sport, caffeine through its wide-ranging physiological and psychological effects increases endurance in well-trained athletes (Sinclair and Geiger, 2000). The IOC has set a standard of greater than 12mcg/ml in the urine as doping. This is the equivalent of six to eight cups of coffee consumed in one sitting and then being tested within 2 to 3 hours following consumption (Fox and Bowers, 1993).

Results of studies reported over the last five years strongly indicate that caffeine effectively increases athletic performances in endurance events; less clear however is whether caffeine affords benefit in short burst-type events (Graham et.al., 1994; Doherty, 1998). In reviewing the primary literature on effects of caffeine on performance in endurance events, one is struck by the variability of results reported. Two principal reasons help explain the variable results. First, care was not taken to use only well-trained athletes. Second, test subjects were included in whom prior use of caffeine was not carefully controlled. These variables, likely prevented researchers from finding statistically significant differences between control and test subjects (Sinclair and Geiger, 2000).

If a metabolic ergogenic effect of caffeine does exist, it is probably related to its role in aiding the mobilization of free fatty acids (FFA). Fats are the bodies most concentrated source of energy. The energy yield from the breakdown of fats is approximately twice that gained from either proteins or glucose. Most products of fat digestion are transported in lymph in the form of fatty protein droplets called chylomicrons. Eventually, the lipid in the chylomicrons are hydrolysed by plasma enzymes, and the resulting fatty acids and glycerol

(three fatty acids and one glycerol = triglycerol), are taken up by the body cells where they are processed in various ways (lipolysis) (Marieb, 1995).

**Oxidation of Glycerol and Fatty Acids**

The only fats that are routinely oxidized for energy are neutral fats. Catabolism of these fats involves the breakdown of their two building blocks namely glycerol and fatty acids (Marieb, 1995). Glycerol is accepted into the anaerobic reactions of glycolysis as 3- phosphoglyceraldehyde, a glycolysis intermediate which then flows into the Krebs cycle. ATP energy harvest from the complete oxidation of this compound is approximately half of that of glucose (18 – 19 ATP/ glycerol). The gluconeogenic role of glycerol is important when carbohydrates are restricted in diet or during long duration activities. The process of fatty acid catabolism takes place within the mitochondria of the cell. This process is known as beta-oxidation. Each fatty acid molecule is split/ cleaved into two carbon acetyl fragments. ATP is used to phosphorylate the reactions, water is added, hydrogen is passed to $NAD^+$ and FAD, and the acetyl fragments joins with the coenzyme A to form an acetyl-CoA. This enters the Krebs cycle. The process of beta-oxidation cannot take place unless oxygen is able to accept hydrogen. The term beta-oxidation reflects the fact that the carbon in beta ($3^{rd}$) position is oxidized during the process. The splitting step occurs between the second (alpha) and third (beta) carbon atoms in each case (Marieb, 1995).

**Total Energy Transfer from Lipid Catabolism**

For each 18-carbon fatty acid molecule, 147 molecules of ADP are phosphorylated to ATP during beta-oxidation and the Krebs cycle metabolism. Since there are three fatty acid molecules in each triglyceride molecule, 441 ATP molecules are formed from the fatty acid component. The fact that 19 molecules of ATP are formed during glycerol metabolism, a total of 460 molecules of ATP is generated for each neutral fat catabolized. The efficiency of energy conservation is about 40% (Fox and Bowers, 1993).

The caffeine may have a glycogen-sparing effect in that it enables more fat to be used as fuel, with less usage of glycogen. Glycogen-sparing is known to

reduce muscular fatigue (Fox and Bowers, 1993). Caffeine also appears to cross the membranes of all tissues in the body, making pure investigations of mechanism in the exercising human impossible. For example, because caffeine enters both the nervous system and skeletal muscle, it is not possible to separate central and peripheral effects. It also seems likely that different mechanisms could be responsible for performance enhancement in different types of exercise. There are three major theories for the ergogenic effect during exercise. The first theory involves a direct effect on some portion of the central nervous system that affects the perception of the effort and/ or affects the propagation of neural signals somewhere between the brain and the neuromuscular junction. The second theory proposes a direct effect of caffeine or one of its by-products on skeletal muscle. Possibilities include handling of irons, inhibition of phosphodiesterase (PDE) leading to an elevation in adenosine 3', 5'- cyclic monophosphate (cyclic AMP), and direct effects on key regulatory enzymes such as phosphorylase (PHOS). The third theory involves an increase in fat oxidation and decrease in carbohydrate oxidation. Caffeine or a caffeine metabolite may mobilize free fatty acids (FFA) from adipose and/ or intramuscular stores indirectly by increasing circulating epinephrine (EPI) or directly by antagonizing adenosine receptors that normally inhibit FFA mobilization. The greater FFA availability increases muscle fat oxidation and decreases CHO oxidation, presumably improving performance in exercise situations where CHO availability limits performance (Spriet, 1995).

Many of the potential side effects of caffeine ingestion are well known: anxiety, jitters, inability to focus, gastrointestinal discomfort, insomnia, irritability and, with higher doses, heart arrhythmias and hallucinations. While the side effects associated with doses below 9ml/kg body weight do not appear to be dangerous, they can be disconcerting if present prior to a competition. It appears that complaints about side effects are reduced when 6 vs. 9ml/kg doses are administered. There is a great variability in almost all performance and metabolic responses to caffeine. This appears to be true for all groups studied, including mild and heavy caffeine users, users who abstained from caffeine for varying lengths of time, and non-users. The variability of muscle

glycogen sparing following caffeine ingestion is greater in samples of untrained males than in trained males (Chesley et al., 1994).

Caffeine also has a diuretic effect, that is, it enhances urine formation, often causing a need to urinate within an hour after consumption. Yet two studies with subjects who took caffeine before they exercised showed no detrimental effects on hydration during exercise (Falk et al., 1990; Gordon et al., 1982). Thus it appears that caffeine does not increase urine production during exercise. The extra adrenaline the body secretes during exercise may block caffeine's effect on the kidneys. After exercise, caffeine is a poor choice for fluid replacement. The best approach is to use non-caffeineated beverages just after activity (Clark, 1997).

**Cellfood®**

Cellfood® is a proprietary super energized complex concentrate held in colloidal suspension. It is ingested orally in the form of fluid droplets added to water. It contains 78 trace elements and minerals, combined with 34 enzymes, 17 amino acids, dissolved and nascent oxygen, suspended in a solution of deteurium sulphate ($D_2SO_4$ ). Cellfood® is unique due to its ability to create nascent oxygen or "newly born" oxygen (Latin- Nascere). In biochemical terms nascent oxygen refers to this newly born single oxygen (elemental oxygen) that has not yet entered into biochemical reaction. Nascent oxygen is negatively charged ($O^-$). Free radicals on the other hand are positively charged ions of single oxygen ($O^+$). The opposite charge of these ions cause them to attract each other, forming a single pure oxygen molecule ($O_2$). Nascent oxygen "seeks out" and neutralizes dangerous free radicals, combining to form pure oxygen in the process.

{$O^-$ [ nascent oxygen] and $O^+$ [free radical ions] = $O_2$ [stable oxygen]}

According to the manufacturer the main conceivable benefits of Cellfood® with regards to aerobic metabolism include the following (Storey, 1982):

- Increase in cellular respiration: When Cellfood® is mixed into water, an exothermic reaction takes place providing oxygen and hydrogen to the individual cells of the body. The steady flow of oxygen and hydrogen to all parts of the body allow for simultaneous oxygenation and reduction within the cells.
- Metabolic efficiency catalyst: Cellfood® enhances nutrient absorption and increases metabolism. It promotes greater availability of vitamins, minerals, herbs, and other nutrients.
- Energy boosting properties: Cellfood® allows the body to function cleanly and efficiently, resulting in an increased energy level over time.
- Colloidal minerals: The minerals contained in Cellfood® are in a special colloidal suspension for easier absorption and utilization by the body.

The development background to Cellfood® is thus, according to the product literature (Oxygen for Life, 1999), the genius and inventor behind Cellfood® is Everet Storey, twice Nobel Laureate, who worked on the American "Manhattan Project". This project was top-secret, and to this day, not much has been revealed about it. Albert Einstein credited Storey with the "water splitting technology" that he patented; and from his research, the hydrogen bomb was developed. Because of exposure to extreme radiation, the people on the project began to die. Everett Storey himself was affected and, by the early 1950's he had lost 30kg in weight.

So, Storey worked on saving his own life and giving mankind something useful. In 1956 he invented a deuterium-based product, which he called "Cell Food" or "Liquid Life". In the development of "Cell Food", Storey used work of Dr. Harold Urey, who in 1932 had discovered deuterium (the only non-radioactive isotope of hydrogen), which had subsequently been kept secret because of its role in the hydrogen bomb and as the principal fuel for space exploration. Storey spent most of his life researching deuterium's incredible

health benefits, which kept him alive until his death at the age of 74 in 1984 (Oxygen for Life, 2000).

In January 1978, Everett Storey applied for Food and Drug Administration (FDA) registration of "Cell Food" (also known as Deutrosulfazyme). On the Pharmaceutical Composite Form he described it as: "Champagne colour to amber colour with passage of time, but instead of a loss in potency, there is actually a small increase each year."

Under the section "Therapeutic effects: he stated:

- Aids materially in the digestive process;
- Assists in the cleansing of upper intestine and lower intestine, and restores normal bowel function;
- Enables the blood stream to deliver directly to each body cell a minimum of 78 assimilable elements for complete, direct and quick nutrition; and
- Provides a steady flow of both oxygen and hydrogen to all parts of the body, thus effecting the hitherto "impossible" achievement of simultaneous oxidation and reduction within a given cell".

In 1985 the American Government passed the "Deuterium freedom act of 1985" in which recognition was given to the work of Everett Storey and his product. The ACT, section 2(b) line 15 states: " Deuterium can and does form all other elements, and stands at the very core of the Universe. The ashes of hydrogen constitute water. Heavy hydrogen combined with water becomes 'heavy water' (deteurium oxide). Line 25 states: Because of deteurium's facility to speed up the digestive process, it will aid in patients getting more mileage out of the food they consume; and, at the same time, reduce the toxicity in the blood stream. Deutrosulfazyme is a systemic normalizer. In 1995, with the change in American legislation, Cellfood® was classified as a nutritional supplement and not as a drug or patented medicine. Until then, over $2 million had been spent on clinical tests, and Cellfood® had only been available for experimental purposes. After 1995, it was made available to the public.

In 1997, Cellfood® was unanimously voted by the Inventors Clubs of America for the 1997 Advanced Technology Award which was presented by the International Hall of Fame in Atlanta, U.S.A. Cellfood® received this award because of: 1) it's unique ability to produce both nascent oxygen and hydrogen inside the body, resulting in the simultaneous cleansing and building of body cells and tissues; and 2) it's unique ability to hold 78 elements, trace minerals and minerals in liquid colloidal suspension.

All the substances in Cellfood® are natural substances. Cellfood® has no alcohol, no glucose, and no substances that are on the banned list of substances regarding international, professional and amateur athletic associations. Cellfood® is made from the finest natural substances which are cryogenically, not chemically, extracted and are totally non-toxic. The nutrients in Cellfood® are in colloidal form. Colloidal particles are minute (4-7 nanometres in diameter), and because of the Brownian Movement Phenomenon, they take on a negative charge, and remain suspended in liquid. Because most bodily fluids (like blood and lymph) are colloidal and negatively charged, the body perceives Cellfood® as a normal healthy body fluid, and allows the nutrients in Cellfood® to pass immediately through the sensitive membranes of the mouth, throat and oesophagus, directly into the blood stream.

The vast majority of living organisms rely on oxygen to generate oxidative power. The actual mechanism is not a direct chemical reaction, rather a series of electron transfers through a number of intermediate compounds that readily accept and release electrons alternating between an oxidized and reduced form. This route is called the electron transport chain and is similar in all organisms. As the strongest oxidizing agent of the chain, oxygen is the final electron accepter. Oxygen's vital role in living organisms is essentially as a substance on which to "dump" electrons. Many micro organisms are anaerobic and do not require oxygen for survival. These organisms are able to utilize sulphur and other compounds as oxidizing agents. All organisms generate reducing power through the reversible biochemical reactions of nicotinamide-

adenine dinucleotide (NAD), flavins, cytochromes, and other substances while existing in an oxidized or reduced form. By participating in the electron transport chain, the reduced form is continually regenerating from the oxidized form (Nu Science Corporation, 2001b). The Krebs cycle can be compared to machine designed to remove hydrogens from food; the hydrogens are sent to the Electron Transport System (ETS). Each molecule of the hydrogen carrier in the NAD delivers two electrons and one proton of a hydrogen molecule to the ETS. The energy produced by the ETS is used to form the chemical bond between Adenosine Diphosphate (ADP) and inorganic phosphate to form ATP. This highly effective delivery system enables over 95% of the nutrients in Cellfood® to be absorbed and utilized at cellular level. This percentage is high compared to the low absorption rates of tablets (15%) and gel caps (25%). Furthermore, because Cellfood® is colloidal, the similarity between it and other bodily fluids increases the bioavailability of nutrients (Nu Science Corporation, 2001a).

Many oxygen products tend to flood the body with oxygen, often creating harmful oxygen free radicals. The release of these reactive oxygen species results in oxidative injury to biologic systems such as lipids found in cell membranes, and proteins found in blood vessels and myocardial tissues. Cellfood® is different in the sense that it scavenges and bonds with dangerous oxygen free radicals, supplying the body with usable oxygen in a controlled and time-released manner, at cellular level, only where it is needed. Cellfood® therefore, in no way creates free radicals. It causes free radical singlet atoms of oxygen to be neutralised. Another defence mechanism against free radicals is the enzyme catalase. Catalase breaks down hydrogen peroxide, a metabolic waste product in the body, and liberates oxygen for the body to use. Cellfood® contains the enzyme catalase. If people use other products, such as ozone and stabilised oxygenated water, they should use antioxidants to minimise the free radical effect that can be caused by the flooding effect of too much oxygen too quickly in the body (Oxygen for Life, 1999).

Hydrogen is mainly used for reduction purposes. Hydrogenation (also called reduction) is the addition of hydrogen to a molecule. Most body processes

require hydrogen while playing a vital role in the electron transport chain. Fed by fusion and fission, hydrogen is the most common element in the universe (Nu Science Corporation, 2001c). The nascent hydrogen atoms that are produced by Cellfood® are used by the body for many functions, such as irrigating, building and strengthening cells and organs; preventing inflammation, promoting osmosis; moistening lung surfaces for gas diffusion; and regulating body temperature. Hydrogen is essential for the processes of digestion, assimilation and elimination; and for transporting nutrients through the arteries to the brain and all body tissues. A person who weighs 80kg has about 7kg of hydrogen in his body. The body normally obtains hydrogen from water, other liquids, fruits and vegetables. Lack of hydrogen leads to dehydration from inside and outside the cells; and extreme dryness and abnormal nerve heat are generated in the body.

Cellfood® is a liquid concentrate, taken by mixing a number of drops in a quarter of a glass of distilled or filtered water. How much Cellfood® one takes depends upon the individuals needs. Each person has unique needs, and because Cellfood® is a nutritional supplement, everyone responds in a unique manner. Most people take about 12 drops first thing in the morning. One cannot overdose on Cellfood®. Because it is a nutritional supplement made from natural substances, the body only uses what it needs, and eliminates the rest through the normal channels of elimination. Cellfood® can be taken at any time. Most people take it first thing in the morning before brushing their teeth or eating.

**Switch™**

Switch™ contains all of the above mentioned ingredients of Cellfood® with two added substances. The first substance being Citrin K and the second being L-Carnitine. Citrin-K contributes 25% to the total Switch™ make up. L-Carnitine contributes 20% to the total Switch™ make up. A 100ml bottle of Switch™ contains about two months supply at 20 drops per serving. Each of these servings contains: 250mg Cellfood® proprietary blend; 110mg Citrin K; and 90mg L- Carnitine.

**Citrin K**

Hydroxy Citric Acid (HCA) is a natural compound extracted from the rind of the fruit Garcinia cambogia. HCA supplementation acts as an appetite suppressant, and it has shown the ability to inhibit the actions of ATP-citrate lyase in the liver. This enzyme is partially responsible for the conversion of dietary carbohydrates to fat. This may make it extremely effective for low fat diets. HCA has also been shown to increase glycogen storage, which may actually act to curb hunger and increase athletic performance (Phillips, 1997).

**L- Carnitine**

Carnitine is a quaternary amine whose physiologically active form is beta-hydroxy-gamma-trimethylammonium butyrate. This is found in meats and diary products and is synthesized in the human liver and kidneys from two essential amino acids, lysine and methionine (Armsey and Green, 1997). Carnitine plays a number of important roles in exercise metabolism (Hawley and Burke, 1998).

Firstly, this nonessential amino acid is a very popular "fat-burning" supplement in the sport nutrition market (Philips, 1997). It is well-known as a transport molecule for taking fatty acids inside the mitochondria of muscle cells where they are oxidised. It also plays a role in regulating the balance between key chemicals in other metabolic processes and is known to act as a buffer for pyruvate, thus reducing muscle lactate accumulation associated with fatigue (Armsey and Green, 1997).

It has been reported that after a period of carnitine supplementation, well-trained subjects increased their maximal oxygen consumption. The key claim of this supplement is that it can enhance fat metabolism by increasing the transport of fat to its site of oxidation. Long-chain fatty acid oxidation in all tissues is carnitine dependent; therefore, hereditary and acquired carnitine deficiencies cause triglyceride to accumulate in the skeletal muscles, impair fatty acid utilization, and reduce exercise capacity. Carnitine supplementation can usually reverse these changes (Hawley, 1998). Thus it is often an

ingredient in fat loss supplements, as well as making claim to increase exercise capacity (Hawley and Burke, 1998).

The possible mechanisms by which carnitine could have a positive effect include enhancing oxidation of fatty acids, a critical energy compound during exercise; preserving muscle glycogen during exercise, a factor potentially related to fatigue resistance; shifting fuel use towards glucose, thereby decreasing the oxygen requirement of exercise; improving resistance to muscle fatigue; and increasing the oxidative capacity of skeletal muscle (Philips, 1997)

More recent studies have found flaws in some of these claims, and have failed to replicate the findings of improved performance in athletes. Muscle biopsy studies have failed to find evidence that heavy training reduces muscle carnitine levels, or that these levels are increased by carnitine supplementation of up to one month. A change in muscle content after supplementation is a prerequisite if any benefits are to take place. Clinical studies investigating carnitine and its effects on exercise performance or metabolism during exercise have usually involved a small number of test subjects, but this background has provided sufficient foundation to encourage further studies (Hawley and Burke, 1998).

# CHAPTER 3

# METHODS AND PROCEDURES

## 3.1 SUBJECTS

Thirty marathon runners (19 males and 11 females) between the ages of 20-51 years (mean age = 38.4 ± 8.2 years) volunteered to take part in the study. The subjects had a mean body mass of 73 ± 9.5 kg and a stature of 175 ± 7.2 cm. The mean body mass for the males and females were 75.6 ± 8.0 kg and 61.3 ± 8.0 kg, respectively. The mean stature for the males and females were 177.1 ± 5.5 cm and 167.1 ± 7.6 cm, respectively. All of the participants were members of marathon clubs in and around Pretoria. The subjects were all briefed on the nature of the research project and the possible risks and benefits prior to providing their written informed consent (Appendix A) to participate in the study.

The following specific exclusion criteria were applied:

a) haematology results not within the normal physiological limits;
b) not being able to maintain a minimum running speed of 8 km/h on the treadmill;
c) use of any other ergogenic supplement or aid; and
d) prescription medication usage.

## 3.2 STUDY DESIGN

The primary aim of the study was to determine the efficacy of both Cellfood® and Switch™ as an ergogenic aid for endurance athletes. In order to reach this goal a pre-test – post-test, double-blind cross-over, placebo controlled experimental design, with two levels of the independent variable, was adopted for the study. Accordingly subjects were randomly assigned to either a placebo, Cellfood® or Switch™ group.

Each of the groups underwent a supplementation period comprising three four-week cycles of varying dosages, as recommended by the manufacturer. After each cycle the subjects stopped supplementation during a two-week washout period, prior to crossing-over to an alternative supplementation and dosage cycle.

Accordingly the groups were arranged as follows over the duration of the study:

| | Cycle 1 | | Cycle 2 | | Cycle 3 | |
|---|---|---|---|---|---|---|
| **Group** | **Product** | **Dosage** | **Product** | **Dosage** | **Product** | **Dosage** |
| **A** | Placebo | 28ml | Cellfood® | 39.2ml | Switch™ | 91.7ml |
| **B** | Cellfood® | 28ml | Switch™ | 78.4ml | Placebo | 44.8ml |
| **C** | Switch™ | 53.2ml | Placebo | 39.2ml | Cellfood® | 44.8ml |

No statistically significant differences ($p>0.05$) were found between any of the groups regarding the variables measured during the baseline tests at the onset of the study, thus reflecting the effectiveness of the pre-study random assignment process. At the end of every cycle each group was subjected to the same testing protocol as during the pre-test.

In order to enhance compliance an individualized dosage schedule was given to each subject. The schedule required ingesting one daily dose upon waking first thing in the morning. This schedule indicated the dates when the subject was required to start and stop using each of the products as well as the relevant dosage of the product for the specific cycle. On recommendation of the manufacturer, the Switch™ dosage was roughly double that of both the Cellfood® and the placebo due to a difference in the relative concentrations of the products (Appendix B).

## 3.3 INDEPENDENT VARIABLES

### 3.3.1 Cellfood®

**Product content and characteristics as described by the manufacturer:**

Cellfood® is a proprietary super energized complex concentrate held in colloidal suspension. It is ingested orally in the form of fluid droplets added to water. It contains 78 trace elements and minerals, combined with 34 enzymes, 17 amino acids, dissolved and nascent oxygen, suspended in a solution of deteurium sulphate ($D_2SO_4$ ). Cellfood® is unique due to its ability to create nascent oxygen or "newly born" oxygen (*Latin- Nascere*). In biochemical terms nascent oxygen refers to a newly born single oxygen (elemental oxygen) that has not yet entered into biochemical reaction. Nascent oxygen is negatively charged ($O^-$) while free radicals, on the other hand, are positively charged ions of single oxygen ($O^+$). The opposite charge of these ions cause them to attract each other, forming a single pure oxygen molecule ($O_2$). Nascent oxygen "seeks out" and neutralizes dangerous free radicals, combining to form pure oxygen in the process.

{$O^-$ [nascent oxygen] and $O^+$ [free radical ions] = $O_2$ [stable oxygen]}

**Elements, minerals and trace minerals found in Cellfood®**

| | | | | |
|---|---|---|---|---|
| Actinium | Cobalt | Indium | Niobium | Tin |
| Antinomy | Copper | Iodine | Nitrogen | Titanium |
| Argon | Dysprosium | Iridium | Osium | Tungsten |
| Astatine | Erbium | Iron | Oxygen | Vanadium |
| Barium | Europium | Krypton | Palladium | Xenon |
| Beryllium | Fluorine | Lanthanum | Phosphorus | Ytterbium |
| Bismuth | Gadolinium | Lithium | Platinum | Zinc |
| Boron | Gallium | Lutetium | Polonium | Zirconium |
| Bromine | Germanium | Magnesium | Potassium | |
| Calcium | Gold | Manganese | Praseodymium | |
| Carbon | Hafnium | Molybdenum | Promethium | |
| Cerium | Helium | Neodymium | Rhenium | |
| Cesium | Holmium | Neon | Rhodium | |
| Chromium | Hydrogen | Nickel | Rubidium | |

**Digestive and Metabolic Enzymes**

- Hydrolases and Carbohydrases: Maltase, Sucrase and Emulsin
- Nucleases: Polynucleotidase and Nucleotidase
- Amidase: Urease
- Peptidase: Aminopolypeptidase, Dipeptidase and Prolinase
- Esterase: Lipase, Phophotase and Sulfatase
- Iron Enzymes: Catalase, Cytochrome oxidase and Peroxidase
- Enzyme containing Coenzymes 1 and / or 2: Lactic Dehydrogenase, Robison Ester and Dehydrogenase
- Copper Enzymes: Tyrosinase and Ascorbic acid oxidase
- Enzymes which reduce Cytochrome: Succinic Dehydrogenase
- Hydrases: Fumarase and Enolase
- Yellow Enzymes: Warburg's Old Yellow Enzymes, Diaphorase, Haas Enzyme and Cytochrome C reductase
- Mutases: Aldehyde mutase and Glyoxalase
- Other Enzymes: Phosphorylase, Phosphohexisomerase, Hexokinase and Phosphoglucomutase

**Amino Acids**

- Alanine
- Aginine
- Asphartic Acid
- Cystine
- Glutamic Acid
- Glycine
- Histidine
- Isoleucine
- Lysine
- Methionine
- Phenylalanine
- Proline
- Serine
- Threonine
- Tryptophan

- Tyrosine
- Valine


**Figure 3.1: Cellfood®**

### 3.3.2 Switch™

**Product content and characteristics as described by manufacturer:**

Switch™ contains all of the afore-mentioned ingredients of Cellfood® with two added substances. The first substance being Citrin K and the second being L-Carnitine. Citrin-K is a herbal extract from the Garcinia Cambogia fruit plant and contributes 25% to the total Switch™ make-up. L-Carnitine is a nutrient produced naturally in the liver and contributes 20% to the total Switch™ make-up.

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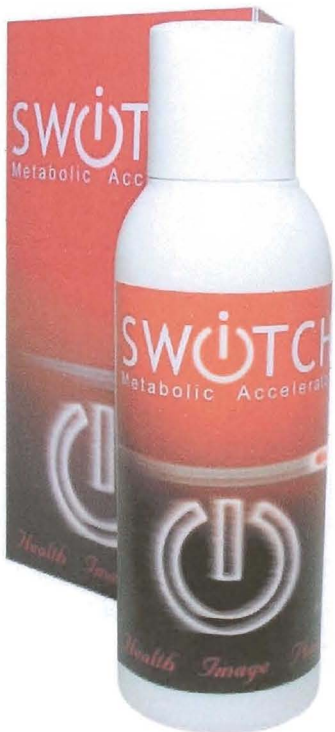



**Figure 3.2: Switch™**

### 3.3.3 Placebo

The placebo comprised a solution with a similar appearance, smell and lemon-flavouring corresponding to the organoleptic (taste) characteristics of both Cellfood® and Switch™.

## 3.4 DEPENDENT VARIABLES

The following dependent variables were measured. The subjects were not permitted strenuous training the day before each test.

1. Anthropometry
    - Stature
    - Body mass
2. Haematology
    - Ferretin values
    - Haemoglobin
    - Red blood cell count

- Hematocrit
- Fasting glucose

3. Pulse oximetry
4. Rate of perceived exertion
5. Heart rate
6. Capillary blood lactate concentrations
7. Oxygen utilization and related spirometry

### 3.4.1 Anthropometric Measurements

**Stature**

The stature was measured with a calibrated stadiometer. The subject stood barefoot, feet together with the heels, buttocks and upper part of the back touching the gauge, with the head in the Frankfort plane, not necessarily touching the gauge. The Frankfort plane was considered as the orbital (lower edge of the eye socket) being in the same horizontal plane as the tragion (notch superior to the tragus of the ear). When so aligned the vertex was the highest point on the skull. The measurement was taken to the nearest 0.1 cm at the end of a deep inhalation (Lohman et al., 1988).

**Body Mass**

Body mass was measured using a Detecto beam balance scale. The measurement was taken to the nearest 0.1 kg, with the subject barefoot, clothed only in appropriate running clothes, and taking care that the:

- Scale was reading zero;
- Subject stood on the centre of the scale without support;
- Subject's weight distribution was even on both feet; and
- Subject's head was held up and the eyes looked directly ahead (Lohman et al., 1988).

**Figure 3.3: Detecto scale**

### 3.4.2 Haematology

The blood analyses were performed by a professional pathology laboratory, namely AMPATH (a division of Du Buisson and Partners pathologists).

The following reference ranges were utilized:

| | |
|---|---|
| Ferretin | 22 - 322 ng/mL |
| Haemoglobin | 14.0 – 18.0 g/dL |
| Red blood cell count | 4.60 – 6.00 10^12/L |
| Hematocrit | 42 – 52% |
| Fasting glucose | 3.5 – 6.0 mmol/L |

### 3.4.3 Oxygen Utilization

The maximum oxygen uptake ($V0_2$ max) was determined through direct (open) circuit spirometry, using a Schiller CS-100 gas analyser and a Quinton motorized treadmill (model 24-72). The gas analyser was calibrated before each test with the appropriate gas mixtures supplied by Air Products. The tests were conducted within an air-conditioned laboratory at a temperature of 20°C and barometric pressure of approximately 655 mmHg. The treadmill protocol started at a running speed of 8 km/h and the elevation remained constant at 2% throughout the test. The speed was increased every two minutes (with 2km/h)

until a running speed of 16 km/h was reached. After this point, the treadmill speed was increased by 1 km/h every two minutes, until exhaustion. The athletes were verbally encouraged and the tests were terminated when the athletes could not maintain the running speed. The following criteria were utilized to determine whether a subject had reached their $V0_2$ max:

- respiratory exchange ratio of at least 1.1;
- plateau or decrease in maximal oxygen uptake;
- severe exhaustion; and
- not being able to maintain the running speed despite verbal encouragement (MacDougal et al., 1991).

Gas values were sampled every ten seconds. The following gas analysis values were recorded during the $V0_2$ max test, presented in their abbreviated and defined format as defined by the Schiller CS 200 User Manual (CS-200 User guide, 2000):

- METS: Metabolic Equivalents. Oxygen uptake required for a given task expressed as multiples of resting oxygen uptake.
- RR: Respiration rate. Number of breaths per minute
- VT: Tidal volume. The volume of air actually breathed per breath in ml.
- VE: Minute ventilation. The volume of air taken into or exhaled from the body in one minute. This is conventionally expressed at body temperature, saturated with water at atmospheric pressure (BTPS).
- $V0_2$: Oxygen consumption. The amount of oxygen extracted from the inspired gas in a given period of time, expressed in millilitres or litres per minute, standard pressure and temperature, dry (STPD). This can differ from oxygen consumption under conditions in which oxygen is flowing into or being utilized from the body's stores. In the steady-state, oxygen uptake equals oxygen consumption.
- $V0_2$ relative: $V0_2$ expressed in ml/kg/min.
- $VC0_2$: The amount of carbon dioxide ($C0_2$) exhaled from the body into the atmosphere per unit time, expressed in millilitres or litres per minute, STPD. This differs from $C0_2$ production rate under conditions in which

additional $C0_2$ may be evolved from the body stores or $C0_2$ is added to the body stores. In steady state, $C0_2$ output equals $C0_2$ production rate. In rare circumstances, appreciable quantities of $C0_2$ can be eliminated from the body as bicarbonate via the gastro-intestinal tract or by haemodialysis.

- Respiratory Exchange Ratio (RER): The ratio of carbon dioxide production to oxygen consumption. This ratio reflects the metabolic exchange of gasses in the bodies' tissue and is dictated by substrate utilization.
- $VE/V0_2$: Respiration equivalent for oxygen. This is the actual ventilation against absolute oxygen uptake. This parameter indicates how much air (l) must be inhaled to obtain a litre of oxygen.
- $VE/VC0_2$: Respiration equivalent for carbon dioxide. This is the actual ventilation against absolute carbon dioxide exhaled. This parameter indicates how much air (l) must be exhaled for one litre of carbon dioxide to be expelled. The smaller this parameter the better the carbon dioxide exchange efficiency.
- $et0_2$: End tidal expired oxygen partial pressure (mmHg). This is the partial oxygen pressure ($P0_2$) determined in the respired gas at the end of an exhalation. This is typically the lowest $P0_2$ determined during the alveolar portion of the exhalation.
- $etC0_2$: End tidal expired carbon dioxide partial pressure (mmHg). This is the partial carbon dioxide pressure ($PC0_2$) of the respired gas determined at the end of an exhalation. This is commonly the highest $PC0_2$ measured during the alveolar phase of exhalation.

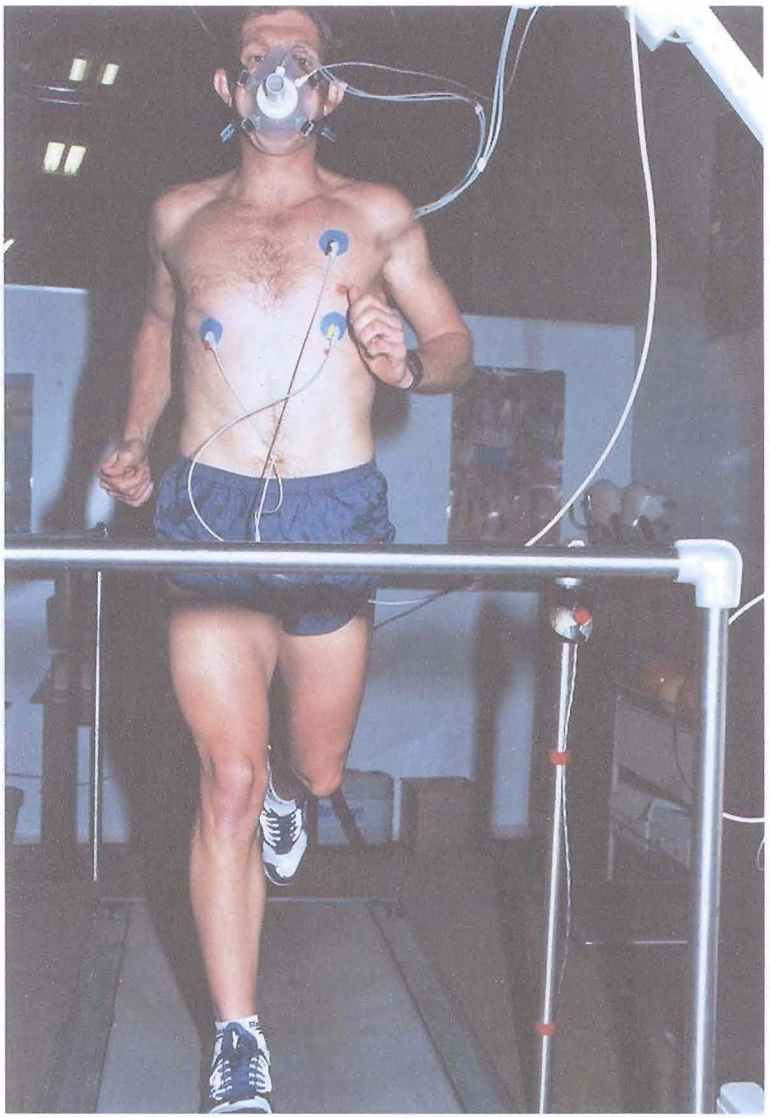


**Figure 3.4: Athlete connected to gas analyser and performing a test.**

### 3.4.4 Pulse Oximetry

Incremental haemoglobin oxygen saturation levels were measured using a Datex- Ohmeda TuffSat hand-held pulse oximeter. The measurements were taken using a finger probe (ClipTip -sensor). These measurements were taken at the end of each two-minute stage directly after the blood samples were taken, expressed as a percentage.


**Figure 3.5: Datex-Ohmeda Tuffsatt Hand-Held Pulse Oximeter**

### 3.4.5 Capillary Blood Lactate Concentration

Incremental capillary blood lactate measurements were taken during the treadmill test by using an Accurex BM lactate meter (Roche diagnostics). This required a puncture of the fingertip to obtain a peripheral blood sample. These samples were taken at the end of each two-minute stage during the treadmill test. The values were reported in mmol/l.

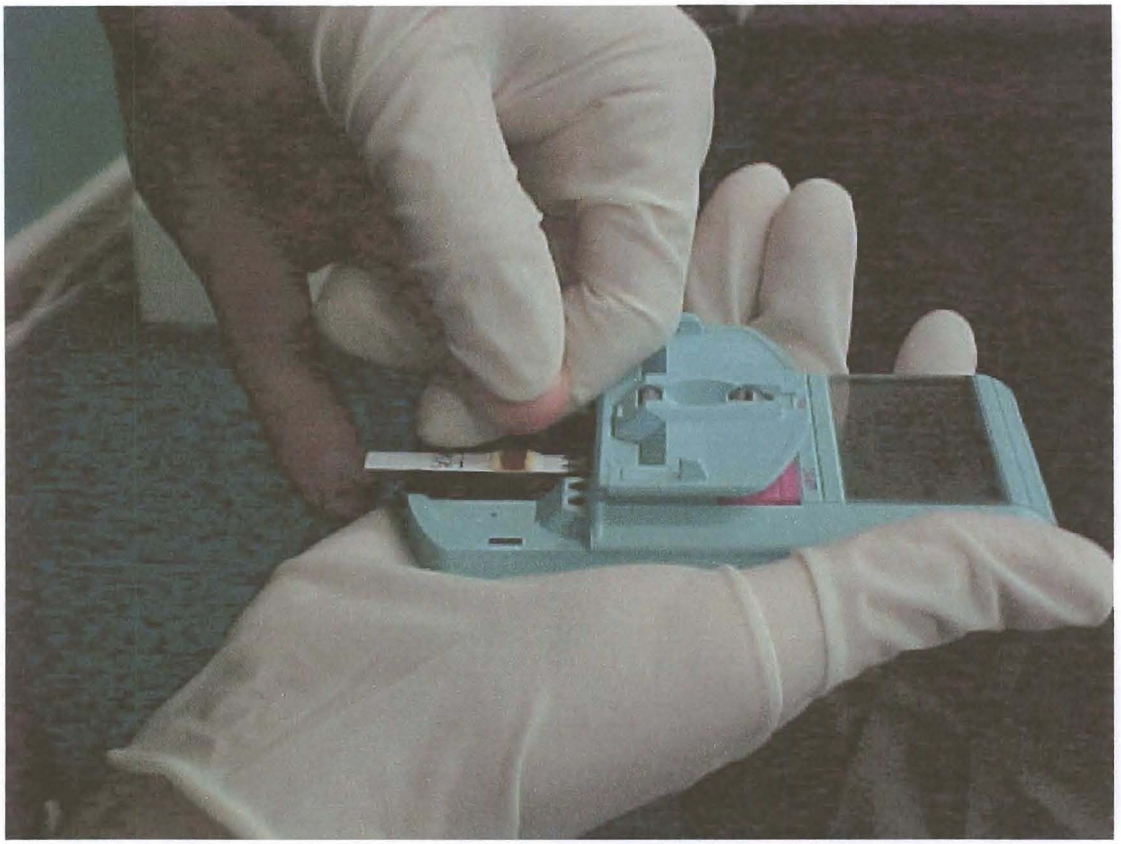


**Figure 3.6: Accurex BM Lactate Meter**

### 3.4.6 Rate of Perceived Exertion

The original Borg scale (6-20) was used to determine the rate of perceived exertion (RPE) for each subject (Borg, 1973). Subjects were asked to indicate their perceived level of exertion on the scale at the end of each two-minute stage during the treadmill run.

### 3.4.7 Heart Rate

Heart rates were recorded using a Polar Accurex Plus heart rate monitor. Heart rates were recorded continuously during the entire test.


**Figure 3.7: Polar Accurex Plus Heart Rate Monitor**

## 3.5 STATISTICAL ANALYSIS

An independent statistician was consulted to perform all the statistical analyses. Alpha was set at a minimum of $p<0.05$ to indicate significant differences between sets of data. The Kruskall-Wallis method of statistical analyses was used for the analysis of the data. This method is the non-parametric equivalent of a one-way analysis of variance (ANOVA) (Howel, 1992).

Computations to determine standard descriptive statistics (mean and standard deviation) and the non-parametric analysis (Kruskall - Wallis test) were performed using the Statistical Package for Social Science (SPSS), Microsoft Windows release 9.0 (1999).

# CHAPTER 4

## RESULTS AND DISCUSSION

The primary aim of the study was to determine the efficacy of both Switch™ and Cellfood® as ergogenic aids for endurance athletes. The term "ergogenic" relates to the application of a nutritional, physical, mechanical, psychological, or pharmacological procedure or aid to improve physical work capacity or athletic performance (McArdle et al., 1991). An ergogogenic aid, simply defined, is any substance, process, or procedure that may, or is perceived to, enhance performance through improved strength, speed, response time or the endurance of the athlete. Another area of interest in ergogenic aids is to hasten recovery. The nature of the action of any supposed ergogenic aid may be elicited through the following:

- Direct action on muscle fibre;
- Counteracting fatigue producing by-products;
- Providing fuel needed for muscular contraction;
- Affecting the heart and circulatory system;
- Affecting the respiratory system; and
- Counteracting the inhibitory affects of the central nervous system on muscular contraction and other functions (Fox and Bowers, 1993).

The primary aim of the study was to determine the efficacy of both Cellfood® and Switch™ as ergogenic aids for endurance athletes. In order to reach this goal a pre-test – post-test, double-blind cross-over, placebo controlled experimental design, with two levels of the independent variable, was adopted for the study. Accordingly subjects were randomly assigned to either a placebo, Cellfood® or Switch™ group. Each of the groups underwent a supplementation period comprising three four-week cycles of varying dosages, as recommended by the manufacturer. After each cycle the subjects stopped supplementation during a two-week washout period, prior to crossing-over to an alternative supplementation and dosage cycle.

Accordingly the groups were arranged as follows over the duration of the study:

| Group | Cycle 1 | | Cycle 2 | | Cycle 3 | |
|---|---|---|---|---|---|---|
| | **Product** | **Dosage** | **Product** | **Dosage** | **Product** | **Dosage** |
| **A** | Placebo | 28ml | Cellfood® | 39.2ml | Switch™ | 91.7ml |
| **B** | Cellfood® | 28ml | Switch™ | 78.4ml | Placebo | 44.8ml |
| **C** | Switch™ | 53.2ml | Placebo | 39.2ml | Cellfood® | 44.8ml |

The results of the study are displayed in tabular and graphic form and are reported in the following categories of dependant variables:

1. Haematology
   - Ferretin values
   - Haemoglobin
   - Red blood cell count
   - Hematocrit
   - Fasting glucose
2. Pulse oximetry
3. Rate of perceived exertion
4. Heart rate
5. Capillary blood lactate concentrations
6. Oxygen utilization and related spirometry

**Haematology**

**4.1 Ferretin**

Absolute pre- and post-test values can be observed in Table I and the relative changes are presented graphically in Figure 4.1.

Cycle 1 (Low Dosage)

An increase in ferretin levels were observed in two of the groups while the remaining group showed a decrease from the pre-test. Switch™ showed an increase of 44.8%

while the placebo showed an increase of 58.8%. Cellfood® showed a decrease of 24.2%. There were, however, no statistically significant differences ($p>0.05$) in the changes between groups.

Cycle 2 (Intermediate Dosage)

Both Cellfood® and placebo showed increases in ferretin values of 72.9% and 4.7% respectively, while Switch™ showed a decrease of 14.1%. There were, however, no statistically significant differences ($p>0.05$) in the changes between groups.

Cycle 3 (High Dosage)

Both Switch™ and Cellfood® showed increases of 18.3% and 37.4%, respectively. The placebo showed a decrease of 6.6%. There were, however, no statistically significant differences ($p>0.05$) in the changes between groups.

**Discussion**

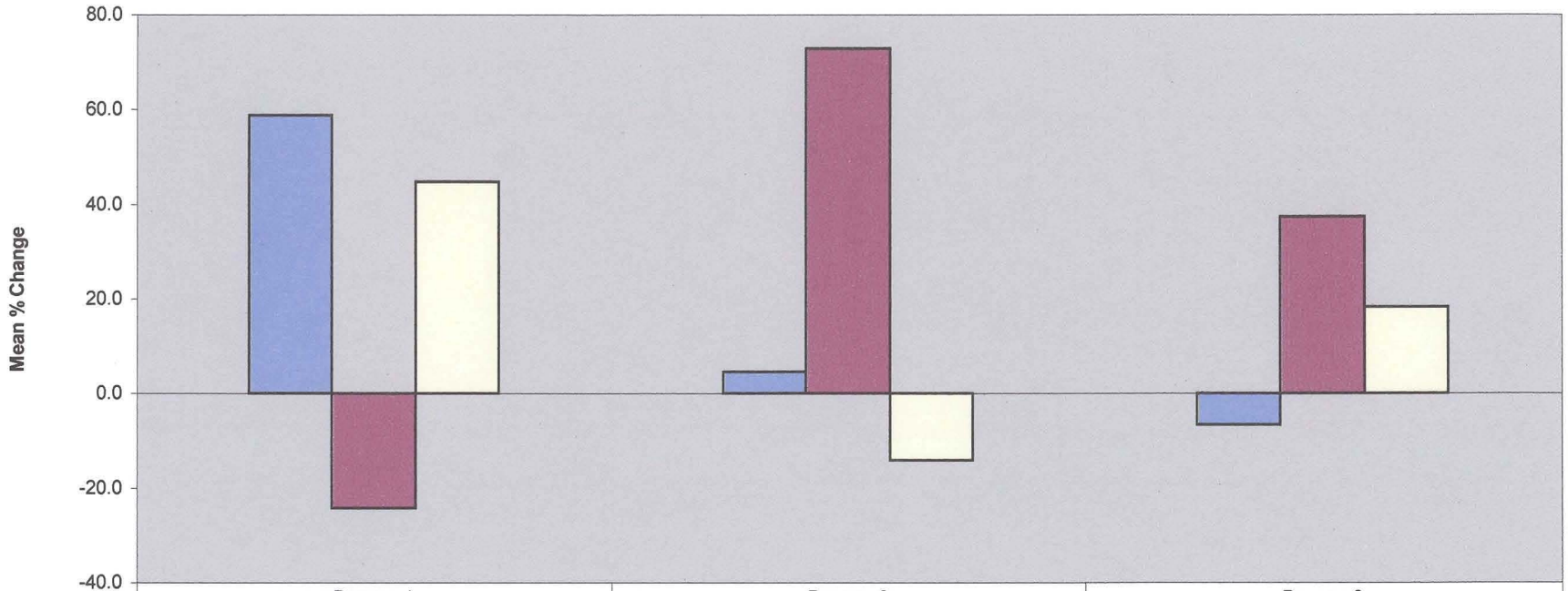
Iron has two very important exercise-related functions. Firstly, about 80% of the iron in the body is found in functionally active compounds combined with haemoglobin in red blood cells. This iron-protein compound increases the oxygen carrying capacity of the blood about 65 times. Secondly, iron (about 5%) is a structural component of myoglobin, which aids in the transport and storage of oxygen within muscle cells (McArdle et al., 1991). About 20% of the iron in the body is found in the liver, spleen and bone marrow in the forms of hemosiderin and ferretin. Since ferretin is present in the plasma it is an excellent indicator of the iron stores of the body (Meyer and Meij, 1996). Normal iron levels are crucial in preventing conditions such as iron deficiency anaemia (McArdle et al., 1991). Iron deficiency anaemia is characterized by sluggishness, loss of appetite and a reduced capacity for sustaining even mild exercise (McArdle et al., 1991). Keeping the above mentioned in mind one can see why it would be beneficial if either one of the products would be effective in increasing the iron stores in the body.

## TABLE I: HAEMATOLOGICAL ANALYSIS

* = p< 0.05; % Δ = Relative Change; NS = Not Significant (p> 0.05)

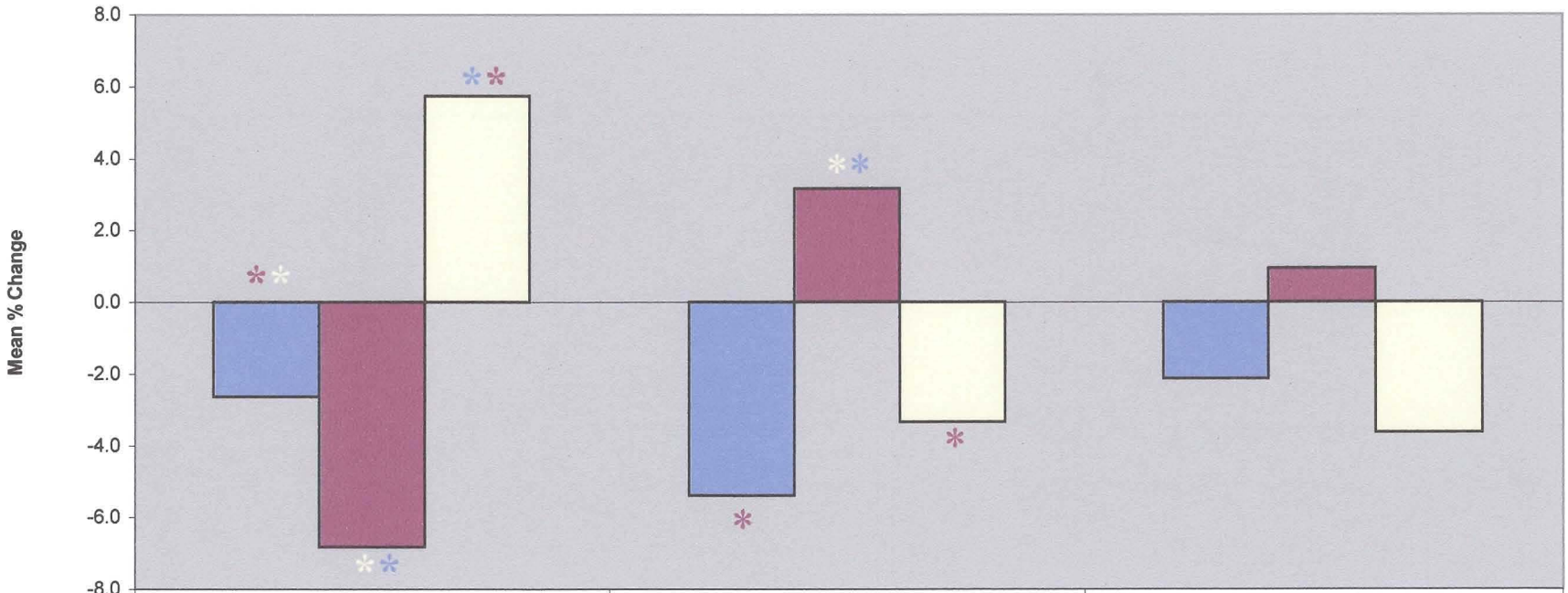
| VARIABLES | | | PL: PLACEBO (N=10) | | | | | CF: CELLFOOD (N=10) | | | | | SW: SWITCH (N=10) | | | | | SIGNIFICANCE | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BLOOD VALUES | Cycle | UNITS | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PL vs CF | PL vs SW | CF vs SW |
| **Ferretin** | 1 | ng/mL | 67.5 | 54.5 | 107.2 | 127.8 | **58.8** | 123.7 | 152.1 | 93.7 | 72.7 | **-24.2** | 97.2 | 65.9 | 140.6 | 113.3 | **44.8** | | | |
| **Ferretin** | 2 | ng/mL | 97.2 | 65.9 | 101.7 | 122.3 | **4.7** | 67.5 | 54.5 | 116.7 | 81.6 | **72.9** | 123.7 | 152.1 | 106.2 | 113.8 | **-14.1** | | **NS** | |
| **Ferretin** | 3 | ng/mL | 123.7 | 152.1 | 115.6 | 120.4 | **-6.6** | 97.2 | 65.9 | 133.5 | 131.3 | **37.4** | 67.5 | 54.5 | 79.9 | 59.9 | **18.3** | | | |
| **Haemoglobin** | 1 | g/dL | 15.2 | 1.6 | 14.8 | 1.5 | **-2.6** | 15.0 | 1.4 | 13.9 | 1.2 | **-6.8** | 14.8 | 1.3 | 15.7 | 1.0 | **5.7** | * | * | * |
| **Haemoglobin** | 2 | g/dL | 14.8 | 1.3 | 14.0 | 1.2 | **-5.4** | 15.2 | 1.6 | 15.7 | 1.6 | **3.2** | 15.0 | 1.4 | 14.5 | 1.5 | **-3.3** | * | **NS** | * |
| **Haemoglobin** | 3 | g/dL | 15.0 | 1.4 | 14.6 | 1.2 | **-2.1** | 14.8 | 1.3 | 15.0 | 1.6 | **0.9** | 15.2 | 1.6 | 14.6 | 1.8 | **-3.6** | | **NS** | |
| **Red Blood Cell** | 1 | 10^12/L | 4.9 | 0.6 | 4.7 | 0.5 | **-4.8** | 4.6 | 1.1 | 4.6 | 0.5 | **-1.2** | 4.7 | 0.4 | 5.1 | 0.3 | **7.8 *** | **NS** | * | * |
| **Red Blood Cell** | 2 | 10^12/L | 4.7 | 0.4 | 4.6 | 0.4 | **-3.7 *** | 4.9 | 0.6 | 5.0 | 0.6 | **2.4** | 4.6 | 1.1 | 4.8 | 0.5 | **2.8** | | | |
| **Red Blood Cell** | 3 | 10^12/L | 4.6 | 1.1 | 4.8 | 0.5 | **3.4** | 4.7 | 0.4 | 4.8 | 0.5 | **1.1** | 4.9 | 0.6 | 4.7 | 0.5 | **-4.3** | | **NS** | |
| **Hematocrit** | 1 | % | 45.0 | 4.3 | 43.1 | 4.3 | **-4.3** | 46.9 | 10.6 | 41.4 | 3.7 | **-11.8** | 44.0 | 4.1 | 46.7 | 3.1 | **6.2 *** | * | * | * |
| **Hematocrit** | 2 | % | 44.0 | 4.1 | 41.4 | 3.8 | **-6.0 *** | 45.0 | 4.3 | 46.4 | 4.5 | **3.0** | 46.9 | 10.6 | 43.3 | 3.8 | **-7.7** | * | **NS** | * |
| **Hematocrit** | 3 | % | 46.9 | 10.6 | 43.0 | 3.7 | **-8.3** | 44.0 | 4.1 | 44.1 | 4.8 | **0.1** | 45.0 | 4.3 | 43.1 | 5.4 | **-4.4** | | **NS** | |
| **Glucose** | 1 | mmol/L | 4.7 | 0.6 | 4.6 | 0.4 | **-1.1** | 4.6 | 0.6 | 4.6 | 0.5 | **2.0** | 4.5 | 0.5 | 4.8 | 0.5 | **6.0** | | | |
| **Glucose** | 2 | mmol/L | 4.5 | 0.5 | 4.7 | 0.4 | **5.3** | 4.7 | 0.6 | 4.7 | 0.5 | **0.4** | 4.6 | 0.6 | 4.4 | 0.5 | **-2.4** | | **NS** | |
| **Glucose** | 3 | mmol/L | 4.6 | 0.6 | 4.5 | 0.5 | **-0.7** | 4.5 | 0.5 | 4.7 | 0.6 | **3.3** | 4.7 | 0.6 | 4.8 | 0.6 | **1.9** | | | |

## FIGURE 4.1: FERRETIN CONCENTRATION




| | Dosage 1 | Dosage 2 | Dosage 3 |
|---|---|---|---|
| Placebo | 58.8 | 4.7 | -6.6 |
| Cellfood | -24.2 | 72.9 | 37.4 |
| Switch | 44.8 | -14.1 | 18.3 |

## FIGURE 4.2: HEAMOGLOBIN CONCENTRATION (* = p< 0.05)




| | Dosage 1 | Dosage 2 | Dosage 3 |
|---|---|---|---|
| Placebo | -2.6 | -5.4 | -2.1 |
| Cellfood | -6.8 | 3.2 | 0.9 |
| Switch | 5.7 | -3.3 | -3.6 |

When evaluating the ferretin levels, it seems that Cellfood® was not effective at all during cycle 1, when Cellfood® was administered at the lowest dosage. Cellfood® was the most effective during cycle three when it was administered at the highest dosage. The inverse seems to be true for the Switch™ product. The most effective dosage was during the first cycle when the dosage was the lowest. It seems that the efficacy of the Switch™ product declined at the higher dosages during cycle 3. This pattern seems to repeat itself throughout all of the haematology results. Both Cellfood® and Switch™ had beneficial effects on the ferretin levels of the subjects. Although the products differed regarding their optimal dosage it seems that Cellfood® was the superior product regarding the increase of iron stores in the body.

**4.2 Haemoglobin**

Absolute pre- and post-test values can be observed in Table I and the relative changes are presented graphically in Figure 4.2.

Cycle 1 (Low Dosage)

Switch™ was the only group to show an increase (5.7%) in haemoglobin (Hb) concentration after the first cycle. Both placebo and Cellfood® showed a decrease of 2.6% and 6.8%, respectively. The improvement in Switch™ was significantly greater ($p<0.05$) than the decreases in both the placebo and Cellfood®. The decrease in placebo was significantly less ($p<0.05$) than in Cellfood®.

Cycle 2 (Intermediate Dosage)

Cellfood® showed an increase of 3.2%, while both Switch™ and placebo showed decreases in haemoglobin values of 3.3% and 5.4%, respectively.. The improvement in Cellfood® was significantly greater ($p<0.05$) than the decreases in both Switch™ and the placebo. The decreases in Switch™ and placebo did not differ significantly ($p>0.05$).

Cycle 3 (High Dosage)

Cellfood® showed an increase of 0.9 % in haemoglobin concentration. Both Switch™ with 3.6% and placebo with 2.1% showed decreases. There were, however, no statistically significant differences ($p>0.05$) in these changes between groups.

**Discussion**

Haemoglobin is essential for the transport of both oxygen and carbon dioxide. Haemoglobin also serves the important function of acting as an acid base balance buffer (Meyer and Meij, 1996). Oxygen is not very soluble in fluid substances, only about 0.3ml gaseous oxygen dissolves in each 100ml of plasma. Although this is a very small amount it serves an important physiological purpose in establishing the $P0_2$ of the blood and the tissues. This pressure plays a role in the regulation of breathing and also determines the loading and release of oxygen from haemoglobin in the lungs and tissues respectively (McArdle et al., 1991). This means that the majority of oxygen is carried through the body in chemical combinations. This takes place with the help of haemoglobin. Haemoglobin contributes to about 34% of the volume of a red blood cell. Haemoglobin increases the blood's oxygen carrying capacity with about 65 to 70 times compared to that of the dissolved oxygen in the plasma. Thus for each litre of blood about 197ml of oxygen are carried through the body in chemical combination with haemoglobin (McArdle et al., 1991) Men have approximately 15-16 g of haemoglobin in each 100ml of blood. The blood's oxygen carrying capacity changes only slightly with normal variations in haemoglobin values, while a significant decrease in iron content of the red blood cells will lead to a decrease in the blood's oxygen carrying capacity and corresponding reduced capacity for sustaining even mild aerobic exercise (McArdle et al., 1991). Both Cellfood® and Switch™ had beneficial effects on the haemoglobin content of the subjects. Again the Cellfood® was more effective at the intermediate and higher dosages while Switch™ showed the best results when administered at the lowest dosage.

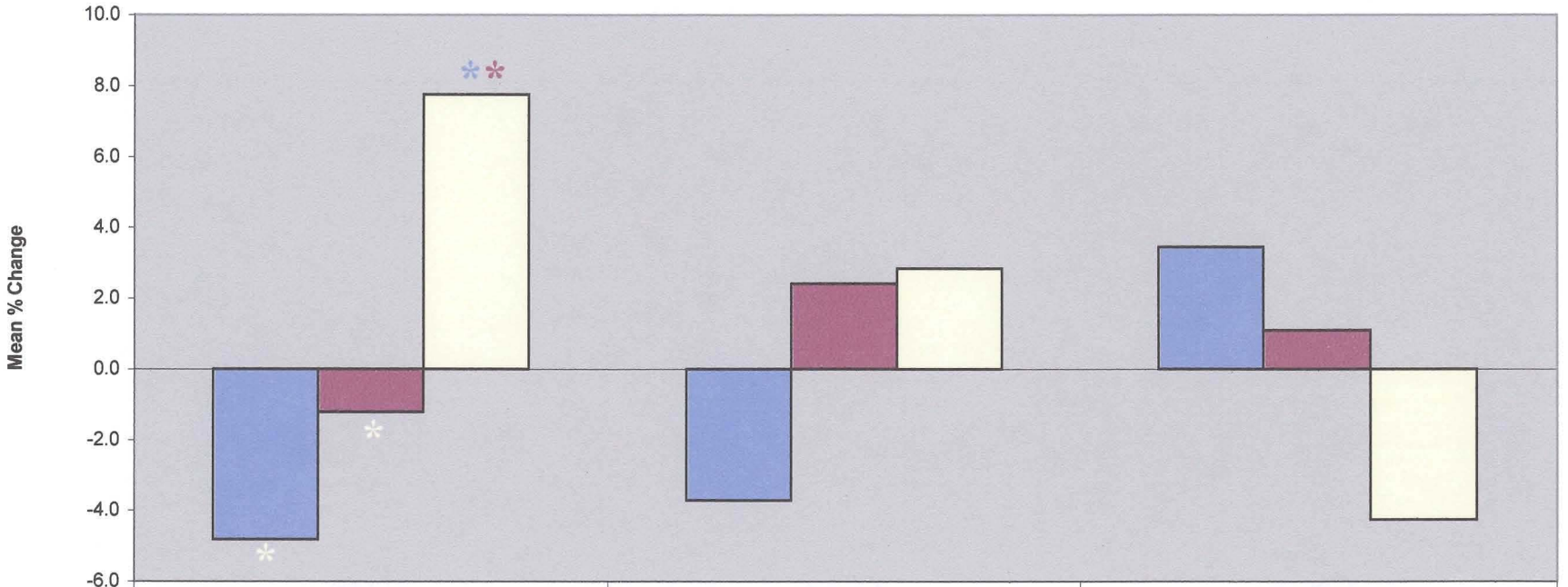
**4.3 Red Blood Cell Count**

Absolute pre- and post-test values can be observed in Table I and the relative changes are presented graphically in Figure 4.3.

Cycle 1 (Low Dosage)

Switch™ showed an increase in red blood cell count of 7.8%, while both placebo and Cellfood® showed decreases of 4.8% and 1.2%, respectively after the first cycle. The improvement in Switch™ was significantly greater ($p<0.05$) than the decreases in

## FIGURE 4.3: RED BLOOD CELL COUNT (* = p< 0.05)




| | Dosage 1 | Dosage 2 | Dosage 3 |
|---|---|---|---|
| Placebo | -4.8 | -3.7 | 3.4 |
| Cellfood | -1.2 | 2.4 | 1.1 |
| Switch | 7.8 | 2.8 | -4.3 |

both Cellfood® and the placebo. The decrease in Cellfood® was, however, not significantly less ($p>0.05$) than in the placebo. The within-group ergogenic improvement from base-line values of 7.8% in red blood cell count observed in Switch™ was statistically significant ($p<0.05$).

Cycle 2 (Intermediate Dosage)

Both Switch™ and Cellfood® showed increases in red cell count of 2.8% and 2.4%, respectively. The placebo showed a decrease of 3.7%. The improvement in Switch™ did not differ significantly ($p>0.05$) from either the decreases in the placebo or the incease in Cellfood® ($p>0.05$).

Cycle 3 (High Dosage)

Cellfood® and placebo showed an increase of 1.1% and 3.4%, respectively. Switch™ showed a decrease of 4.3%. There were, however, no statistically significant differences ($p>0.05$) in these changes between groups.

**Discussion**

It is possible to determine the amount of red blood cells per volume unit of blood. The average count for adult males vary from 4.6 to 6.2 x $10^{12}$ /l blood and adult woman from 4.2 to 5.4 x $10^{12}$ /l. The red cell count is higher in newborn babies as well as people who live at high elevations above sea level. The values could also be higher or lower during certain illnesses (Meyer and Meij, 1996). Three of the main functions of red blood cells include the following: firstly they are responsible for the transport of oxygen from the lungs to the tissue and transport of carbon dioxide from the tissue to the lungs. Secondly, red blood cells help to maintain pH homeostasis within the body. Thirdly, red blood cells contribute just as much to the viscosity of the blood as plasma proteins.

Both Cellfood® and Switch™ were effective in increasing the red blood cell counts of the subjects. Cellfood® was the most effective at the intermediate and high dosage while Switch™ showed the best results at the lowest dosage tested. Switch™ was the superior product for increasing the red blood cell counts.

**4.4 Hematocrit**

Absolute pre- and post-test values can be observed in Table I and the relative changes are presented graphically in Figure 4.4.

Cycle 1 (Low Dosage)

The only increase in hematocrit was found in Switch™ with 6.2%. Both Cellfood® and placebo showed lower hematocrit values with decreases of 11.8% and 4.3%, respectively. The improvement in Switch™ was significantly greater ($p<0.05$) than the decreases in both Cellfood® and the placebo. The decrease in placebo was significantly less ($p<0.05$) than in Cellfood®. The within-group ergogenic improvement from base-line values of 6.2% in hematocrit observed in Switch™ was statistically significant ($p<0.05$).

Cycle 2 (Intermediate Dosage)

Only Cellfood® showed an increase of 3.1%. Both Switch™ and placebo showed decreases in hematocrit values of 7.7% and 6.0%, respectively. The improvement in Cellfood® was significantly greater ($p<0.05$) than the decreases in both Switch™ and placebo. The decreases in Switch™ and placebo did not differ significantly ($p>0.05$).

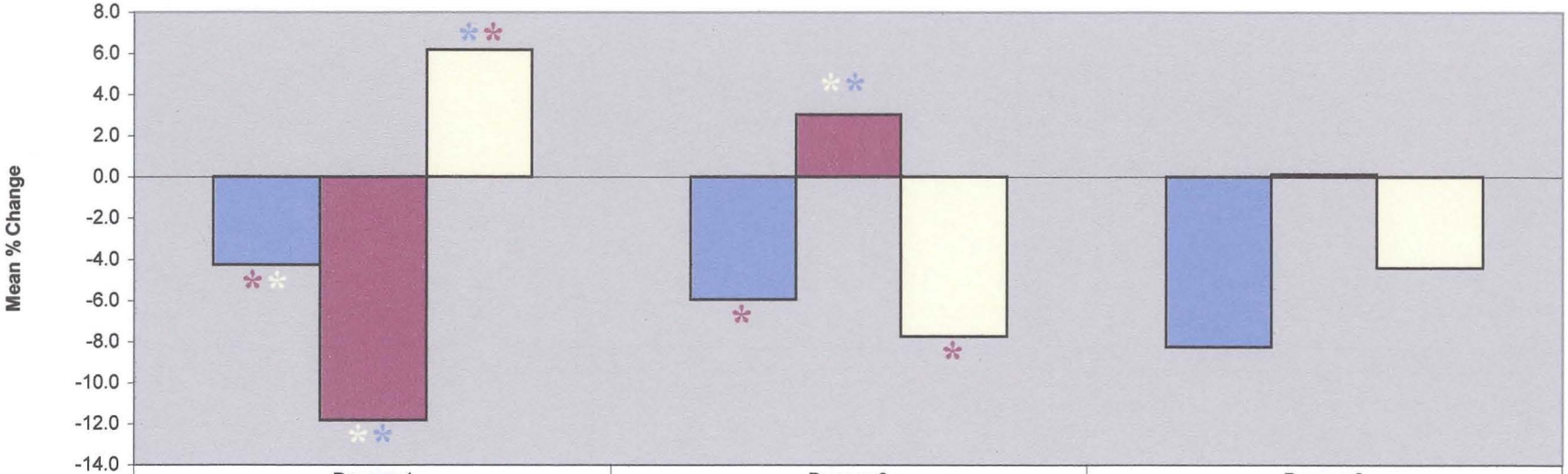
Cycle 3 (High Dosage)

Although a very slight increase of 0.1%, Cellfood® was the only group that showed an increase in hematocrit. Both Switch™ and placebo showed lower and reduced hematocrit values 4.4 % and 8.3%, respectively. There were no statistically significant differences ($p>0.05$) in these changes between groups.

**Discussion**

Hematocrit refers to the contribution of cells to a certain volume of blood. White blood cells contribute less than 0.08% to the hematocrit. The contribution of cells is higher in newly born infants and people who live at high elevations above sea level as well as people who are dehydrated and people with naturally high red cell counts. The values are lower in people who suffer from anaemia (Meyer and Meij, 1996). The haemoglobin, red blood cell count and hematocrit values showed significant results during the first two cycles.

**FIGURE 4.4: HAEMATOCRIT VALUES (* = p< 0.05)**




| | Dosage 1 | Dosage 2 | Dosage 3 |
|---|---|---|---|
| Placebo | -4.3 | -6.0 | -8.3 |
| Cellfood | -11.8 | 3.0 | 0.1 |
| Switch | 6.2 | -7.7 | -4.4 |

During the first cycle it was clear that Switch™ was superior to both Cellfood® and the placebo regarding haemoglobin ($p<0.05$), red cells ($p<0.05$) and hematocrit ($p<0.05$). During cycle two, at a higher dosage, Cellfood® was more effective than Switch™ and placebo regarding all three of the above-mentioned variables of red blood cell count ($p<0.05$), heamatcorit ($p<0.05$) and haemoglobin ($p<0.05$). When considering the results of the haematology studies it is clear that Switch™ was more effective for the endurance runner at lower dosages while Cellfood® shows a higher degree of efficacy at a higher dosage, with the intermediate dosage being the most effective.

**4.5 Fasting Glucose**

Absolute pre- and post-test values can be observed in Table I and the relative changes are presented graphically in Figure 4.5.

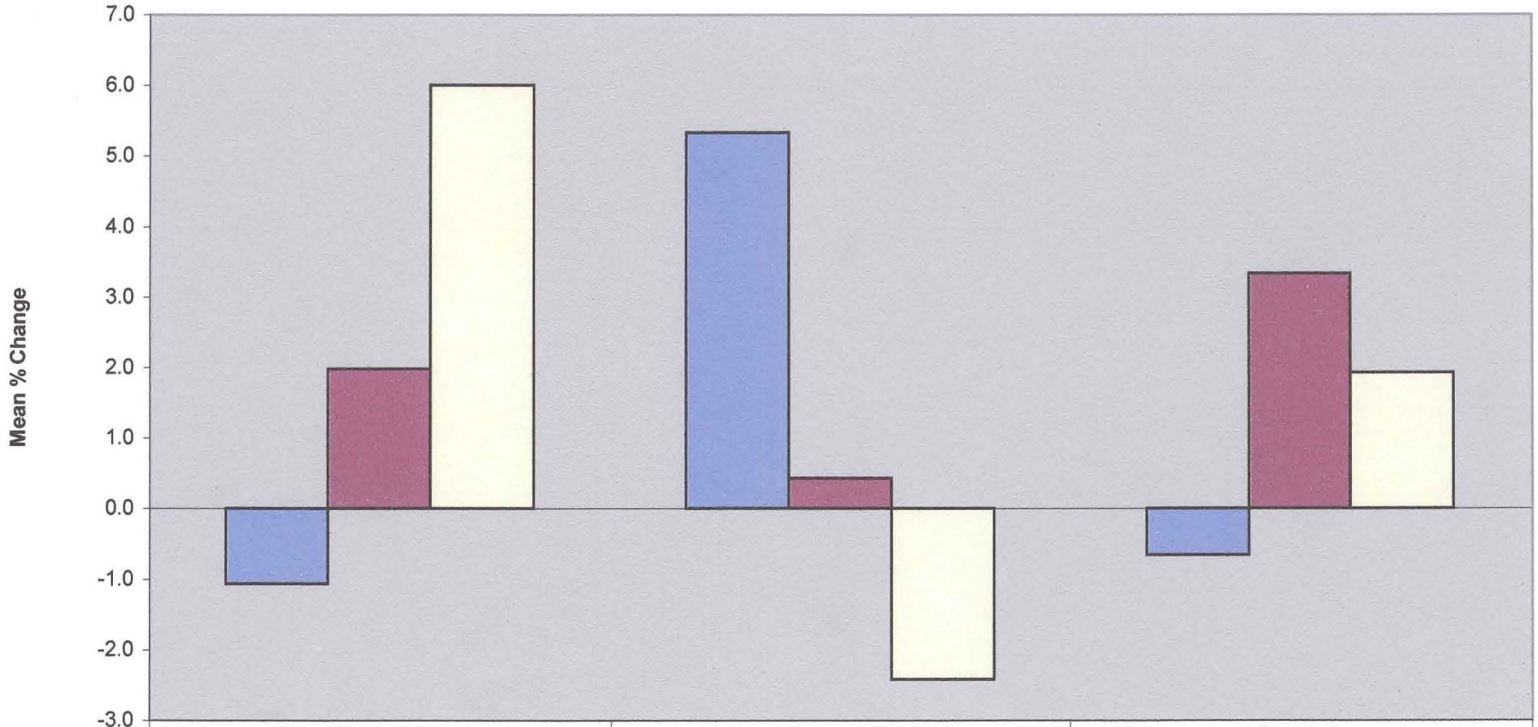
Cycle 1 (Low Dosage)
Both Cellfood® and Switch™ showed increases in fasting blood glucose with values of 2.0% and 6%, respectively. The placebo showed a decrease of 1.1%. There were no statistically significant differences ($p>0.05$) in these changes between groups.

Cycle 2 (Intermediate Dosage)
Both Cellfood® with 0.4% and placebo with 5.3% showed increases while Switch™ showed a decrease of 2.4%. There were, however, no statistically significant differences ($p>0.05$) in these changes between groups.

Cycle 3 (High Dosage)
Cellfood® showed an increase of 3.3% while Switch™ showed an increase of 1.9%. A decrease of 0.7% was observed in the placebo group. There were, however, no statistically significant differences ($p>0.05$) in these changes between groups.

**Discussion**
During prolonged exercise, glucose production may be reliant on gluconeogenesis because of hepatic glycogen depletion. This may cause the fall of glucose production below that required by the working muscle and other essential tissue such as the brain.

## FIGURE 4.5: FASTING GLUCOSE VALUES




| | Dosage 1 | Dosage 2 | Dosage 3 |
|---|---|---|---|
| Placebo | -1.1 | 5.3 | -0.7 |
| Cellfood | 2.0 | 0.4 | 3.3 |
| Switch | 6.0 | -2.4 | 1.9 |

Also in prolonged exercise leading to dehydration and hyperthermia, shunting of blood flow away from the liver and kidneys occurs. Thus, levels of gluconeogenic precursors (lactate, pyruvate, alanine) rise, and hepatic glucose production decreases. In this case of falling blood glucose, the exercise becomes subjectively more difficult because of CNS starvation and difficulty in oxidizing fats in muscle due to the absence of anaplerotic substrates (Brooks et al., 1996). A higher resting blood glucose level (within normal physiological range) would be beneficial in delivering energy in the transition from rest to exercise as well as shortening the process of ATP production via anaerobic glycolysis.

Switch™ had the best effect on the fasting blood glucose values during cycle 1 (lowest dosage) while Cellfood® had the most beneficial influence on the glucose values during cycle 3 (highest dosage). The glucose values correlated with the pattern regarding the optimal dosages noted thus far.

**4.6 Pulse Oximetry**

Absolute pre- and post-test values can be observed in Table II and the relative changes are presented graphically in Figure 4.6.

Cycle 1 (Low Dosage)

Switch™ was the only group that generally showed improved haemoglobin saturation levels across all the running speeds on the treadmill. Cellfood® only showed notable increases during the last two running (higher) speeds while at the other speeds, except 12 km/h, it showed decreased saturation levels There were, however, no statistically significant differences ($p>0.05$) in these changes between groups. Placebo showed decreases during two running speeds while there were increases during three of the speeds with no change at one of the running speeds.

Cycle 2 (Intermediate Dosage)

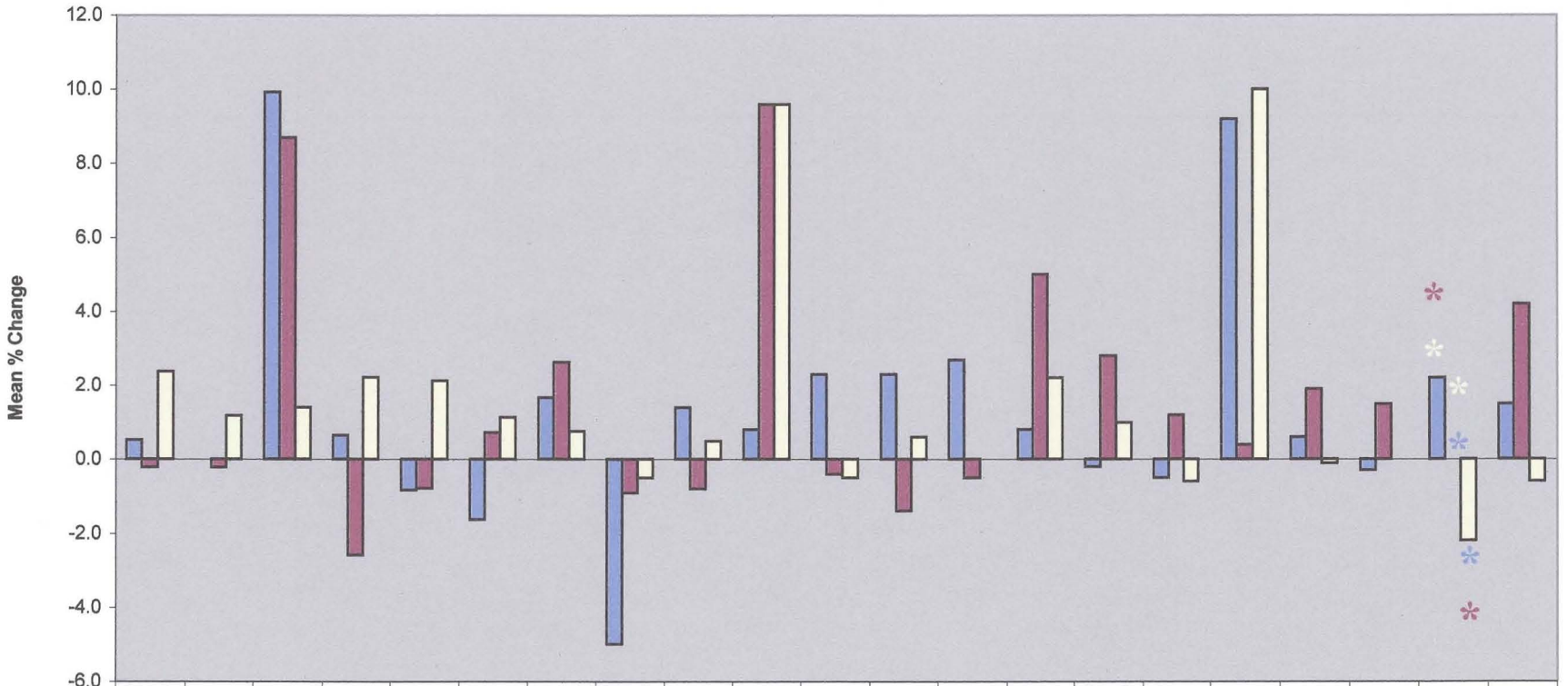
Switch™ showed increases in saturation levels on four of the seven running speeds, while Cellfood® only showed increases during two of the seven running speeds. There were no statistically significant differences ($p>0.05$) in these changes between groups

## TABLE II: PULSE OXIMETRY

*** = p< 0.05; % Δ = Relative Change; NS = Not Significant (p> 0.05)**

| VARIABLES | | | PL: PLACEBO (N=10) | | | | | CF: CELLFOOD (N=10) | | | | | SW: SWITCH (N=10) | | | | | SIGNIFICANCE | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RUNNING SPEED | Cycle | UNITS | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PL vs CF | PL vs SW | CF vs SW |
| 8km/h | 1 | %Sp02 | 94.1 | 2.2 | 94.6 | 1.3 | 0.5 | 94.6 | 1.4 | 94.4 | 1.4 | -0.2 | 92.5 | 5.2 | 94.7 | 1.6 | 2.4 | | | |
| 8km/h | 2 | %Sp02 | 92.5 | 5.2 | 87.9 | 21.1 | -5.0 | 94.1 | 2.2 | 93.3 | 2.8 | -0.9 | 94.6 | 1.4 | 94.1 | 1.5 | -0.5 | NS | | |
| 8km/h | 3 | %Sp02 | 94.6 | 1.4 | 94.4 | 1.3 | -0.2 | 92.5 | 5.2 | 95.1 | 1.5 | 2.8 | 94.1 | 2.2 | 95.0 | 1.2 | 1.0 | | | |
| 10km/h | 1 | %Sp02 | 94.2 | 1.4 | 94.2 | 1.5 | 0.0 | 94.5 | 1.8 | 94.3 | 1.6 | -0.2 | 92.6 | 3.9 | 93.7 | 1.8 | 1.2 | | | |
| 10km/h | 2 | %Sp02 | 92.6 | 3.9 | 93.9 | 2.6 | 1.4 | 94.2 | 1.4 | 93.4 | 2.2 | -0.8 | 94.5 | 1.8 | 95.0 | 1.2 | 0.5 | NS | | |
| 10km/h | 3 | %Sp02 | 94.5 | 1.8 | 94.0 | 1.7 | -0.5 | 92.6 | 3.9 | 93.7 | 2.0 | 1.2 | 94.2 | 1.4 | 93.6 | 1.3 | -0.6 | | | |
| 12km/h | 1 | %Sp02 | 84.6 | 28.7 | 93.0 | 3.5 | 9.9 | 85.1 | 26.8 | 92.5 | 2.2 | 8.7 | 92.2 | 3.0 | 93.5 | 2.7 | 1.4 | | | |
| 12km/h | 2 | %Sp02 | 92.2 | 3.0 | 92.9 | 3.3 | 0.8 | 84.6 | 28.7 | 92.7 | 1.8 | 9.6 | 85.1 | 26.8 | 93.3 | 1.4 | 9.6 | NS | | |
| 12km/h | 3 | %Sp02 | 85.1 | 26.8 | 92.9 | 1.1 | 9.2 | 92.2 | 3.0 | 92.6 | 2.1 | 0.4 | 84.6 | 28.7 | 93.1 | 1.2 | 10.0 | | | |
| 14km/h | 1 | %Sp02 | 91.8 | 1.7 | 92.4 | 3.4 | 0.7 | 92.9 | 2.2 | 90.5 | 2.9 | -2.6 | 90.3 | 5.1 | 92.3 | 2.5 | 2.2 | | | |
| 14km/h | 2 | %Sp02 | 90.3 | 5.1 | 92.4 | 2.1 | 2.3 | 91.8 | 1.7 | 91.4 | 2.7 | -0.4 | 92.9 | 2.2 | 92.4 | 1.6 | -0.5 | NS | | |
| 14km/h | 3 | %Sp02 | 92.9 | 2.2 | 93.5 | 1.4 | 0.6 | 90.3 | 5.1 | 92.0 | 2.3 | 1.9 | 91.8 | 1.7 | 91.7 | 2.6 | -0.1 | | | |
| 16km/h | 1 | %Sp02 | 91.0 | 2.6 | 90.3 | 4.0 | -0.8 | 92.0 | 2.8 | 91.3 | 1.8 | -0.8 | 89.9 | 2.8 | 91.8 | 2.6 | 2.1 | | | |
| 16km/h | 2 | %Sp02 | 89.9 | 2.8 | 92.0 | 2.3 | 2.3 | 91.0 | 2.6 | 89.7 | 2.9 | -1.4 | 92.0 | 2.8 | 92.6 | 2.4 | 0.6 | NS | | |
| 16km/h | 3 | %Sp02 | 92.0 | 2.8 | 91.7 | 1.3 | -0.3 | 89.9 | 2.8 | 91.2 | 2.5 | 1.5 | 91.0 | 2.6 | 91.0 | 2.2 | 0.0 | | | |
| 17km/h | 1 | %Sp02 | 92.0 | 4.0 | 90.5 | 4.4 | -1.6 | 91.0 | 2.8 | 91.7 | 2.3 | 0.7 | 88.0 | 2.7 | 89.0 | 2.4 | 1.1 | NS | | |
| 17km/h | 2 | %Sp02 | 88.0 | 2.7 | 90.4 | 1.3 | 2.7 | 92.0 | 4.0 | 91.5 | 3.5 | -0.5 | 91.0 | 2.8 | 91.0 | 1.9 | 0.0 | | | |
| 17km/h | 3 | %Sp02 | 91.0 | 2.8 | 93.0 | 1.0 | 2.2 | 88.0 | 2.7 | 88.0 | 1.0 | 0.0 | 92.0 | 4.0 | 91.0 | 0.0 | -2.2 | * | * | * |
| 18km/h | 1 | %Sp02 | 89.5 | 3.5 | 91.0 | 0.0 | 1.7 | 88.7 | 4.2 | 91.0 | 1.4 | 2.6 | 87.3 | 2.1 | 88.0 | 3.2 | 0.8 | | | |
| 18km/h | 2 | %Sp02 | 87.3 | 2.1 | 88.0 | 2.8 | 0.8 | 89.5 | 3.5 | 94.0 | 0.0 | 5.0 | 88.7 | 4.2 | 90.6 | 1.9 | 2.2 | NS | | |
| 18km/h | 3 | %Sp02 | 88.7 | 4.2 | 90.0 | 3.1 | 1.5 | 87.3 | 2.1 | 91.0 | 0.0 | 4.2 | 89.5 | 3.5 | 89.0 | 0.0 | -0.6 | | | |

## FIGURE 4.6: PULSE OXIMETRY (* = p < 0.05)




| | Dose 1: 8km/h | 10km/h | 12km/h | 14km/h | 16km/h | 17km/h | 18km/h | Dose 2: 8km/h | 10km/h | 12km/h | 14km/h | 16km/h | 17km/h | 18km/h | Dose 3: 8km/h | 10km/h | 12km/h | 14km/h | 16km/h | 17km/h | 18km/h |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Placebo | 0.5 | 0.0 | 9.9 | 0.7 | -0.8 | -1.6 | 1.7 | -5.0 | 1.4 | 0.8 | 2.3 | 2.3 | 2.7 | 0.8 | -0.2 | -0.5 | 9.2 | 0.6 | -0.3 | 2.2 | 1.5 |
| Cellfood | -0.2 | -0.2 | 8.7 | -2.6 | -0.8 | 0.7 | 2.6 | -0.9 | -0.8 | 9.6 | -0.4 | -1.4 | -0.5 | 5.0 | 2.8 | 1.2 | 0.4 | 1.9 | 1.5 | 0.0 | 4.2 |
| Switch | 2.4 | 1.2 | 1.4 | 2.2 | 2.1 | 1.1 | 0.8 | -0.5 | 0.5 | 9.6 | -0.5 | 0.6 | 0.0 | 2.2 | 1.0 | -0.6 | 10.0 | -0.1 | 0.0 | -2.2 | -0.6 |

Cycle 3 (High Dosage)

Cellfood® showed higher saturation levels during six of the seven running speeds while Switch™ only showed higher saturation levels during two of the seven running speeds. The only significant ($p>0.05$) changes were at 17 km/h were both Switch™ and placebo showed significantly greater changes than Cellfood®. The decrease with Switch™ also was significantly greater than the increase of placebo or Cellfood, which showed an anomalous trend of no change.

**Discussion**

One molecule of Hb is capable of maximally combining with four molecules of oxygen as follows:

$$\mathbf{Hb_4 + 4\ O_2 \leftrightarrow Hb_4\ (O_2)_4}$$

One gram of Hb becomes saturated with oxygen when it combines with 1.34ml of oxygen. Once the Hb saturation point and the Hb concentration in the blood is known one can calculate what is referred to as the oxygen capacity of Hb:

**$O_2$ capacity of Hb (ml $O_2$ / 100ml blood) = Hb concentration (grams Hb / 100ml blood) x (1.34 ml $O_2$/ gram Hb)**

At rest and at sea level, about 15 grams of Hb are present in every 100ml blood (for males, 16 grams per 100ml and for females, 14 grams per 100ml). Therefore under these conditions, the oxygen capacity of Hb is 15 x 1.34 =20.1ml $O_2$/ 100ml blood, or 20.1 volumes percent (volumes percent in this case refers to millilitres of $O_2$ per 100ml blood). With exercise the Hb concentration of blood increases by 5 – 10%. This is due, in part, to fluid shifts from the blood into the active muscle cells, and hemoconcentration results. A 10% hemoconcentration during exercise implies that there will be about 16.5 grams of Hb per 100ml of blood instead of 15 grams. The oxygen capacity of Hb would in this case increase from 20.1 to 22.1 volumes percent, a definite advantageous change. The last important concept regarding Hb is the percent saturation of Hb with oxygen. The percentage saturation of haemoglobin with oxygen ($\%SO_2$) was measured incrementally throughout the treadmill tests. These

values relate the amount of oxygen actually combined with haemoglobin (content) to the maximum amount of oxygen that could be combined with haemoglobin (capacity):

**$\%SO_2$ = ($O_2$ content of Hb/ $O_2$ capacity of Hb) x 100**

A saturation of 100% indicates that the oxygen actually combined with the Hb is equal to the oxygen capacity of Hb. The use of $\%SO_2$ takes into account individual variations in Hb concentrations (Fox et al., 1993).
When looking at the haemoglobin saturation values throughout the three cycles it is clear that Switch™ performed optimally during cycle 1 (lower dosage) and Cellfood® at its best during cycle 3 (higher dosages).

## 4.7 Rate of Perceived Exertion

Absolute pre- and post-test values can be observed in Table III and the relative changes are presented graphically in Figure 4.7.

Cycle 1 (Low Dosage)
Switch™ showed reduced rates of perceived exertion (RPE) values for all the running speeds during the treadmill test while Cellfood® only showed reduced values on the last three (faster) of the seven running speeds. There were, however, no statistically significant differences ($p>0.05$) in these changes between groups. Placebo showed increases in RPE during four running speeds with two decreases and one speed that showed no change.

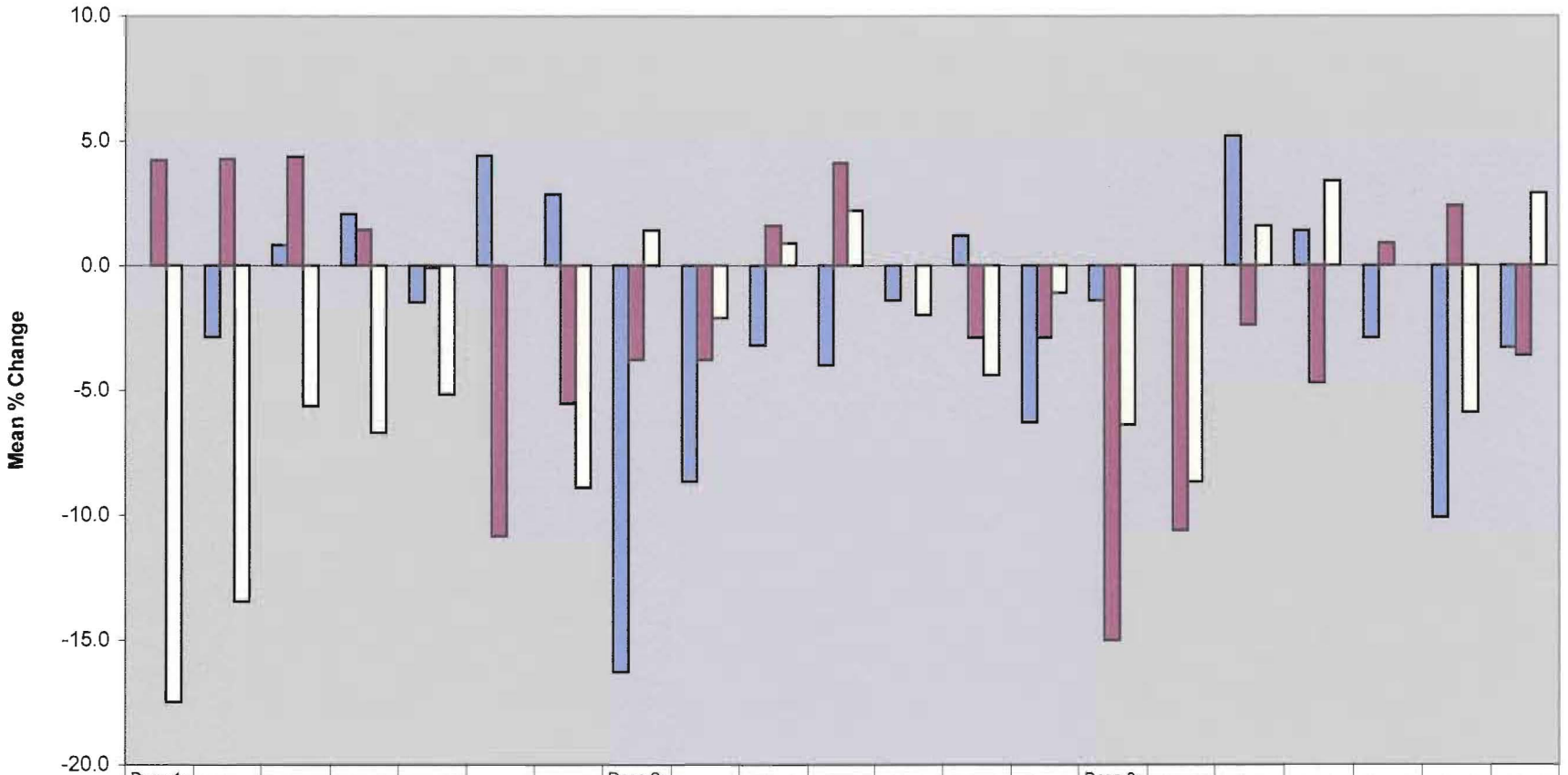
Cycle 2 (Intermediate Dosage)
Both Cellfood® and Switch™ showed reduced values on four of the seven running speeds. There were, however, no statistically significant differences ($p>0.05$) in these changes between groups. Placebo showed lower values on six of the seven running speeds, with only one increase.

## TABLE III: RATE OF PERCEIVED EXERTION

* = p< 0.05; % Δ = Relative Change; NS = Not Significant (p> 0.05)

| VARIABLES | | | PL: PLACEBO (N=10) | | | | CF: CELLFOOD (N=10) | | | | SW: SWITCH (N=10) | | | | SIGNIFICANCE | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RUNNING SPEED | Cycle | UNITS | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PL vs CF | PL vs SW | CF vs SW |
| 8km/h | 1 | | 7.8 | 1.3 | 7.8 | 1.4 | 0.0 | 7.1 | 1.1 | 7.4 | 1.3 | 4.2 | 8.0 | 1.6 | 6.6 | 1.7 | -17.5 | NS | | |
| 8km/h | 2 | | 8.0 | 1.6 | 6.7 | 0.5 | -16.3 | 7.8 | 1.3 | 7.5 | 2.0 | -3.8 | 7.1 | 1.1 | 7.2 | 1.3 | 1.4 | | | |
| 8km/h | 3 | | 7.1 | 1.1 | 7.0 | 1.9 | -1.4 | 8.0 | 1.6 | 6.8 | 1.3 | -15.0 | 7.8 | 1.3 | 7.3 | 1.2 | -6.4 | | | |
| 10km/h | 1 | | 10.4 | 1.7 | 10.1 | 1.3 | -2.9 | 9.4 | 1.5 | 9.8 | 1.5 | 4.3 | 10.4 | 1.4 | 9.0 | 1.9 | -13.5 | NS | | |
| 10km/h | 2 | | 10.4 | 1.4 | 9.5 | 0.8 | -8.7 | 10.4 | 1.7 | 10.0 | 2.6 | -3.8 | 9.4 | 1.5 | 9.2 | 1.6 | -2.1 | | | |
| 10km/h | 3 | | 9.4 | 1.5 | 9.4 | 1.3 | 0.0 | 10.4 | 1.4 | 9.3 | 1.4 | -10.6 | 10.4 | 1.7 | 9.5 | 1.3 | -8.7 | | | |
| 12km/h | 1 | | 12.3 | 2.2 | 12.4 | 1.2 | 0.8 | 11.5 | 1.1 | 12.0 | 1.4 | 4.3 | 12.4 | 1.3 | 11.7 | 2.2 | -5.6 | NS | | |
| 12km/h | 2 | | 12.4 | 1.3 | 12.0 | 1.2 | -3.2 | 12.3 | 2.2 | 12.5 | 2.6 | 1.6 | 11.5 | 1.1 | 11.6 | 1.4 | 0.9 | | | |
| 12km/h | 3 | | 11.5 | 1.1 | 12.1 | 2.0 | 5.2 | 12.4 | 1.3 | 12.1 | 0.9 | -2.4 | 12.3 | 2.2 | 12.5 | 1.4 | 1.6 | | | |
| 14km/h | 1 | | 14.5 | 2.6 | 14.8 | 1.2 | 2.1 | 13.9 | 1.4 | 14.1 | 2.1 | 1.4 | 14.9 | 2.1 | 13.9 | 2.2 | -6.7 | NS | | |
| 14km/h | 2 | | 14.9 | 2.1 | 14.3 | 1.6 | -4.0 | 14.5 | 2.6 | 15.1 | 3.0 | 4.1 | 13.9 | 1.4 | 14.2 | 1.5 | 2.2 | | | |
| 14km/h | 3 | | 13.9 | 1.4 | 14.1 | 2.3 | 1.4 | 14.9 | 2.1 | 14.2 | 0.9 | -4.7 | 14.5 | 2.6 | 15.0 | 1.6 | 3.4 | | | |
| 16km/h | 1 | | 17.0 | 2.8 | 16.8 | 0.9 | -1.5 | 15.9 | 0.8 | 15.9 | 2.5 | -0.1 | 16.6 | 1.7 | 15.7 | 2.3 | -5.2 | NS | | |
| 16km/h | 2 | | 16.6 | 1.7 | 16.3 | 1.7 | -1.4 | 17.0 | 2.8 | 17.0 | 2.4 | 0.0 | 15.9 | 0.8 | 15.6 | 0.8 | -2.0 | | | |
| 16km/h | 3 | | 15.9 | 0.8 | 15.4 | 2.4 | -2.9 | 16.6 | 1.7 | 16.7 | 1.5 | 0.9 | 17.0 | 2.8 | 17.0 | 1.7 | 0.0 | | | |
| 17km/h | 1 | | 17.0 | 2.0 | 17.8 | 0.5 | 4.4 | 17.6 | 1.1 | 15.7 | 1.5 | -10.8 | 17.0 | 1.4 | 17.0 | 2.0 | 0.0 | NS | | |
| 17km/h | 2 | | 17.0 | 1.4 | 17.2 | 1.5 | 1.2 | 17.0 | 2.0 | 16.5 | 3.5 | -2.9 | 17.6 | 1.1 | 16.8 | 0.8 | -4.4 | | | |
| 17km/h | 3 | | 17.6 | 1.1 | 15.8 | 1.3 | -10.1 | 17.0 | 1.4 | 17.4 | 0.5 | 2.4 | 17.0 | 2.0 | 16.0 | 0.0 | -5.9 | | | |
| 18km/h | 1 | | 17.5 | 0.7 | 18.0 | 0.0 | 2.9 | 18.0 | 1.0 | 17.0 | 1.4 | -5.6 | 18.7 | 1.5 | 17.0 | 0.8 | -8.9 | NS | | |
| 18km/h | 2 | | 18.7 | 1.5 | 17.5 | 0.7 | -6.3 | 17.5 | 0.7 | 17.0 | 0.0 | -2.9 | 18.0 | 1.0 | 17.8 | 1.3 | -1.1 | | | |
| 18km/h | 3 | | 18.0 | 1.0 | 17.4 | 1.5 | -3.3 | 18.7 | 1.5 | 18.0 | 0.0 | -3.6 | 17.5 | 0.7 | 18.0 | 0.0 | 2.9 | | | |

## FIGURE 4.7: RATE OF PERCEIVED EXERTION




| | Dose 1: 8km/h | 10km/h | 12km/h | 14km/h | 16km/h | 17km/h | 18km/h | Dose 2: 8km/h | 10km/h | 12km/h | 14km/h | 16km/h | 17km/h | 18km/h | Dose 3: 8km/h | 10km/h | 12km/h | 14km/h | 16km/h | 17km/h | 18km/h |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Placebo | 0.0 | -2.9 | 0.8 | 2.1 | -1.5 | 4.4 | 2.9 | -16.3 | -8.7 | -3.2 | -4.0 | -1.4 | 1.2 | -6.3 | -1.4 | 0.0 | 5.2 | 1.4 | -2.9 | -10.1 | -3.3 |
| Cellfood | 4.2 | 4.3 | 4.3 | 1.4 | -0.1 | -10.8 | -5.6 | -3.8 | -3.8 | 1.6 | 4.1 | 0.0 | -2.9 | -2.9 | -15.0 | -10.6 | -2.4 | -4.7 | 0.9 | 2.4 | -3.6 |
| Switch | -17.5 | -13.5 | -5.6 | -6.7 | -5.2 | 0.0 | -8.9 | 1.4 | -2.1 | 0.9 | 2.2 | -2.0 | -4.4 | -1.1 | -6.4 | -8.7 | 1.6 | 3.4 | 0.0 | -5.9 | 2.9 |

Cycle 3 (High Dosage)

Cellfood® showed reduced perceived exertion values on five of the seven running speeds. Switch™ only showed reduced values on three of the seven running speeds. There were, however, no statistically significant differences ($p>0.05$) in these changes between groups. Placebo showed increases on two of the running speeds, four speeds showed lower values, with one speeds showing no change.

**Discussion**

Rating of perceived exertion (RPE) has been found to be a valuable and reliable indicator in monitoring an individual's exercise tolerance. Borg's RPE scale was developed to allow the exerciser to subjectively rate their feelings during exercise, taking into account personal fitness level, environmental factors and general fatigue levels (Borg, 1973). The greatest value of the scale is it that provides exercisers of all fitness levels with easily understood guidelines regarding exercise intensity. It has been found that a cardio-respiratory training effect and the threshold for blood lactate accumulation are achieved at a rating of "somewhat hard" or "hard" which corresponds to a rating of 13 to 16 on the scale used during the study.

Switch™ showed the best results regarding the RPE scale during cycle 1 (low dosage) while Cellfood® was superior to both the Switch™ product and the placebo during cycle 3 (high dosage).

**4.8 Heart Rate Values**

Absolute pre- and post-test values can be observed in Table IV and the relative changes are presented graphically in Figure 4.8.

Cycle 1 (Low Dosage)

Both Cellfood® and Switch™ showed reduced heart rates on all the running speeds. There were, however, no statistically significant differences ($p>0.05$) in these changes between groups. Placebo showed lower heart rates at all the speeds except the last two running speeds.

Cycle 2 (Intermediate Dosage)

Both Cellfood® and Switch™ showed reduced heart rates on all the running speeds. There were, however, no statistically significant differences ($p>0.05$) in these changes between groups. Placebo showed lower heart rates at all the running speeds except the last (18km/h).

Cycle 3 (High Dosage)

Cellfood® showed reduced heart rate values on all of the running speeds while Switch™ only showed reduced heart rate values on the first two (8 and 10 km/h) running speeds. The reduction in heart rate at a running speed of 10 km/h in Switch™ was, however, significantly less ($p<0.05$) than in Cellfood® and placebo. Placebo showed lower heart rate values during all the running speeds of the treadmill test.

**Discussion**

Heart rate is one of the two important factors influencing cardiac output, the other being stroke volume.

**Q (litres per minute) = SV (stroke volume, litres per beat) x HR (beats per minute)**

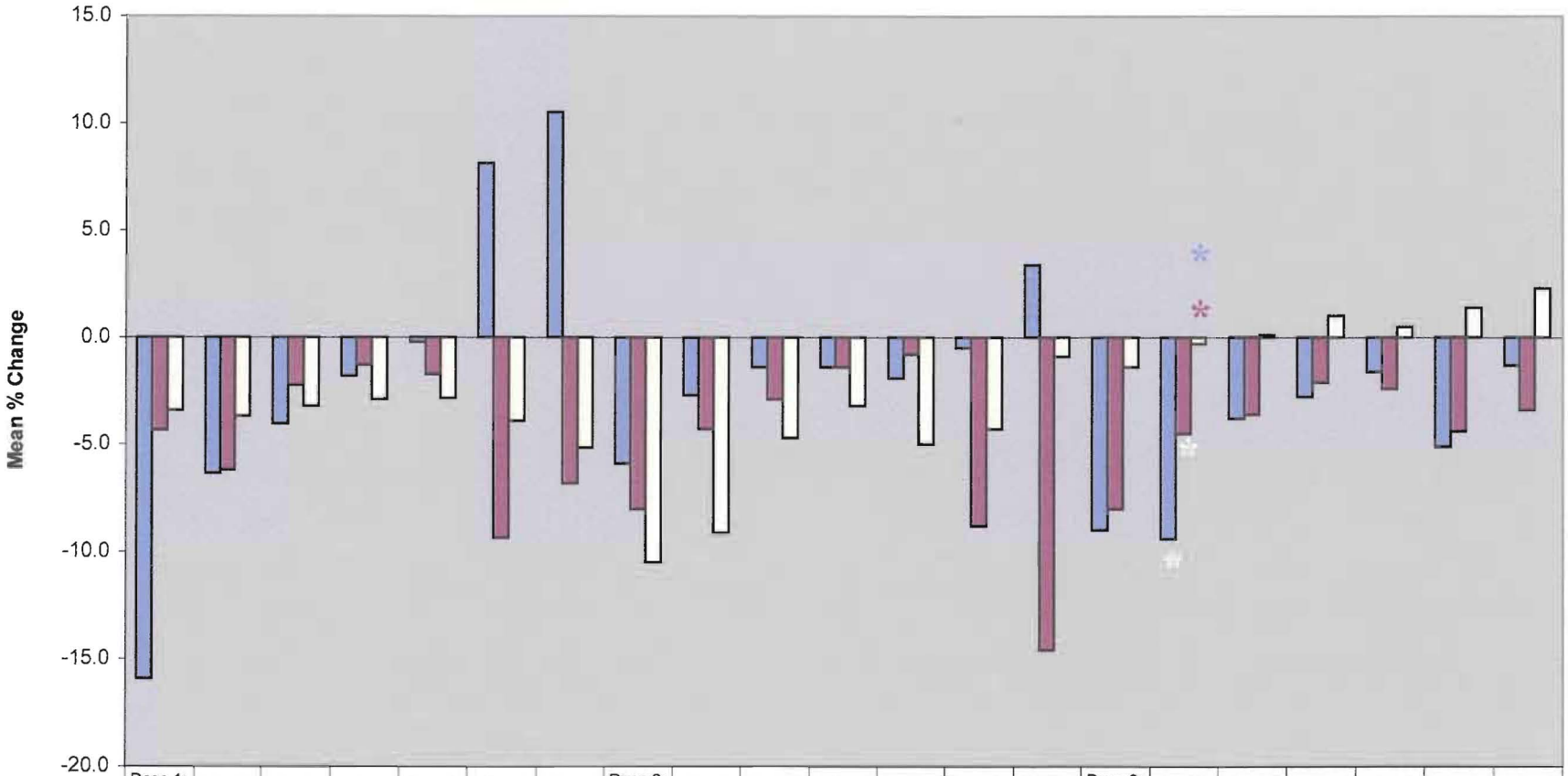
Cardiac output is defined as the amount of blood ejected per minute by the heart, specifically the left ventricle. At rest there is little difference in cardiac output between trained and untrained subjects, with average values ranging between 5 and 6 litres per minute. Maximal cardiac output in trained male subjects can reach values in excess of 30 litre per minute. Women tend to have a slightly higher cardiac output when performing at the same level of oxygen consumption. This difference amounts to between 1.5 and 1.75 litres per minute. This means that, the cardiac output will be 1.5 to 1.75 litres per minute higher on the average in woman than in men for a given oxygen consumption. The reason for this is probably compensatory due to the woman's lower oxygen-carrying capacity of blood, resulting from lower levels of haemoglobin. Also, the maximal cardiac output of both trained and untrained woman is generally lower than that of their male counterparts (Fox and Bowers, 1993). The increase in cardiac output and redistribution of blood flow that occur during exercise

## TABLE IV: HEART RATE VALUES

* = p< 0.05; % Δ = Relative Change; NS = Not Significant (p> 0.05)

| VARIABLES | | | PL: PLACEBO (N=10) | | | | | CF: CELLFOOD (N=10) | | | | | SW: SWITCH (N=10) | | | | | SIGNIFICANCE | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RUNNING SPEED | Cycle | UNITS | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PL vs CF | PL vs SW | CF vs SW |
| 8km/h | 1 | Beats/min | 125.6 | 8.4 | 105.6 | 31.8 | -15.9 | 124.5 | 9.2 | 119.1 | 12.6 | -4.3 | 123.1 | 17.8 | 118.9 | 7.4 | -3.4 | NS | | |
| 8km/h | 2 | Beats/min | 123.1 | 17.8 | 115.8 | 15.0 | -5.9 | 125.6 | 8.4 | 115.5 | 17.9 | -8.0 | 124.5 | 9.2 | 111.4 | 13.2 | -10.5 | | | |
| 8km/h | 3 | Beats/min | 124.5 | 9.2 | 113.3 | 12.0 | -9.0 | 123.1 | 17.8 | 113.2 | 12.2 | -8.0 | 125.6 | 8.4 | 123.9 | 10.8 | -1.4 | | | |
| 10km/h | 1 | Beats/min | 141.6 | 12.6 | 132.6 | 12.1 | -6.4 | 142.1 | 11.6 | 133.3 | 14.3 | -6.2 | 138.7 | 15.1 | 133.6 | 9.1 | -3.7 | NS | | |
| 10km/h | 2 | Beats/min | 38.7 | 15.1 | 134.9 | 9.3 | -2.7 | 141.6 | 12.6 | 135.5 | 14.4 | -4.3 | 142.1 | 11.6 | 129.2 | 13.4 | -9.1 | | | |
| 10km/h | 3 | Beats/min | 142.1 | 11.6 | 128.8 | 11.1 | -9.4 | 138.7 | 15.1 | 132.4 | 9.6 | -4.5 | 141.6 | 12.6 | 141.2 | 9.8 | -0.3 | NS | * | * |
| 12km/h | 1 | Beats/min | 155.8 | 14.5 | 149.5 | 9.8 | -4.0 | 151.6 | 7.4 | 148.2 | 14.7 | -2.2 | 152.0 | 15.6 | 147.1 | 12.4 | -3.2 | | | |
| 12km/h | 2 | Beats/min | 152.0 | 15.6 | 149.9 | 10.2 | -1.4 | 155.8 | 14.5 | 151.7 | 15.9 | -2.9 | 151.6 | 7.4 | 144.4 | 15.3 | -4.7 | NS | | |
| 12km/h | 3 | Beats/min | 151.6 | 7.4 | 145.9 | 13.4 | -3.8 | 152.0 | 15.6 | 146.6 | 11.1 | -3.6 | 155.8 | 14.5 | 156.0 | 12.0 | 0.1 | | | |
| 14km/h | 1 | Beats/min | 165.7 | 16.0 | 162.7 | 10.5 | -1.8 | 162.9 | 7.4 | 160.8 | 13.8 | -1.3 | 163.0 | 11.1 | 158.3 | 13.0 | -2.9 | | | |
| 14km/h | 2 | Beats/min | 163.0 | 11.1 | 160.7 | 9.9 | -1.4 | 165.7 | 16.0 | 163.4 | 17.0 | -1.4 | 162.9 | 7.4 | 157.7 | 15.0 | -3.2 | NS | | |
| 14km/h | 3 | Beats/min | 162.9 | 7.4 | 158.3 | 15.2 | -2.8 | 163.0 | 11.1 | 159.6 | 10.0 | -2.1 | 165.7 | 16.0 | 167.3 | 12.0 | 1.0 | | | |
| 16km/h | 1 | Beats/min | 171.9 | 14.9 | 171.5 | 7.1 | -0.2 | 173.1 | 9.3 | 170.1 | 14.9 | -1.7 | 173.2 | 11.5 | 168.3 | 15.4 | -2.8 | | | |
| 16km/h | 2 | Beats/min | 173.2 | 11.5 | 169.9 | 11.5 | -1.9 | 171.9 | 14.9 | 170.6 | 19.9 | -0.8 | 173.1 | 9.3 | 164.4 | 13.2 | -5.0 | NS | | |
| 16km/h | 3 | Beats/min | 173.1 | 9.3 | 170.3 | 12.4 | -1.6 | 173.2 | 11.5 | 169.1 | 11.4 | -2.4 | 171.9 | 14.9 | 172.8 | 8.2 | 0.5 | | | |
| 17km/h | 1 | Beats/min | 166.7 | 12.6 | 180.3 | 12.3 | 8.1 | 179.4 | 11.2 | 162.7 | 7.1 | -9.3 | 176.2 | 13.8 | 169.3 | 11.4 | -3.9 | | | |
| 17km/h | 2 | Beats/min | 176.2 | 13.8 | 175.4 | 15.0 | -0.5 | 166.7 | 12.6 | 152.0 | 21.2 | -8.8 | 179.4 | 11.2 | 171.8 | 10.6 | -4.3 | NS | | |
| 17km/h | 3 | Beats/min | 179.4 | 11.2 | 170.2 | 11.4 | -5.1 | 176.2 | 13.8 | 168.4 | 11.3 | -4.4 | 166.7 | 12.6 | 169.0 | 0.0 | 1.4 | | | |
| 18km/h | 1 | Beats/min | 171.0 | 0.0 | 189.0 | 5.2 | 10.5 | 180.3 | 10.6 | 168.0 | 11.3 | -6.8 | 179.0 | 14.0 | 169.8 | 7.0 | -5.2 | | | |
| 18km/h | 2 | Beats/min | 179.0 | 14.0 | 185.0 | 12.7 | 3.4 | 171.0 | 0.0 | 146.0 | 0.0 | -14.6 | 180.3 | 10.6 | 178.8 | 10.5 | -0.9 | NS | | |
| 18km/h | 3 | Beats/min | 180.3 | 10.6 | 178.0 | 12.0 | -1.3 | 179.0 | 14.0 | 173.0 | 0.0 | -3.4 | 171.0 | 0.0 | 175.0 | 0.0 | 2.3 | | | |

**FIGURE 4.8: HEART RATE VALUES (* = p< 0.05)**




| | Dose 1: 8km/h | 10km/h | 12km/h | 14km/h | 16km/h | 17km/h | 18km/h | Dose 2: 8km/h | 10km/h | 12km/h | 14km/h | 16km/h | 17km/h | 18km/h | Dose 3: 8km/h | 10km/h | 12km/h | 14km/h | 16km/h | 17km/h | 18km/h |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Placebo | -15.9 | -6.4 | -4.0 | -1.8 | -0.2 | 8.1 | 10.5 | -5.9 | -2.7 | -1.4 | -1.4 | -1.9 | -0.5 | 3.4 | -9.0 | -9.4 | -3.8 | -2.8 | -1.6 | -5.1 | -1.3 |
| Cellfood | -4.3 | -6.2 | -2.2 | -1.3 | -1.7 | -9.3 | -6.8 | -8.0 | -4.3 | -2.9 | -1.4 | -0.8 | -8.8 | -14.6 | -8.0 | -4.5 | -3.6 | -2.1 | -2.4 | -4.4 | -3.4 |
| Switch | -3.4 | -3.7 | -3.2 | -2.9 | -2.8 | -3.9 | -5.2 | -10.5 | -9.1 | -4.7 | -3.2 | -5.0 | -4.3 | -0.9 | -1.4 | -0.3 | 0.1 | 1.0 | 0.5 | 1.4 | 2.3 |

can best be summarized by developing the concept of the oxygen transport system. The components of the system and their interrelationship are as follows:

**$V0_2$ (oxygen transported) = SV x HR x a-$v0_2$ diff (arteriovenous oxygen difference)**

From the above equation we can derive that to maintain a certain $V0_2$ during exercise with lower comparative heart rates the subjects must either experience an increase in stroke volume or a increase in arterial oxygen content ($Ca0_2$).

Keeping in mind the higher cellular oxygen content supposedly delivered by both Switch™ and Cellfood® it explains why the subjects showed decreased comparative heart rates during the treadmill tests.

**4.9 Blood Lactate Concentrations**

Absolute pre- and post-test values can be observed in Table V and the relative changes are presented graphically in Figure 4.9.

Cycle 1 (Low Dosage)
Switch™ showed reduced lactate concentration values on all the running speeds while Cellfood® only showed reductions on the last two running speeds. There were, however, no statistically significant differences ($p>0.05$) in these changes between groups. Placebo showed higher values on the first two running speeds.

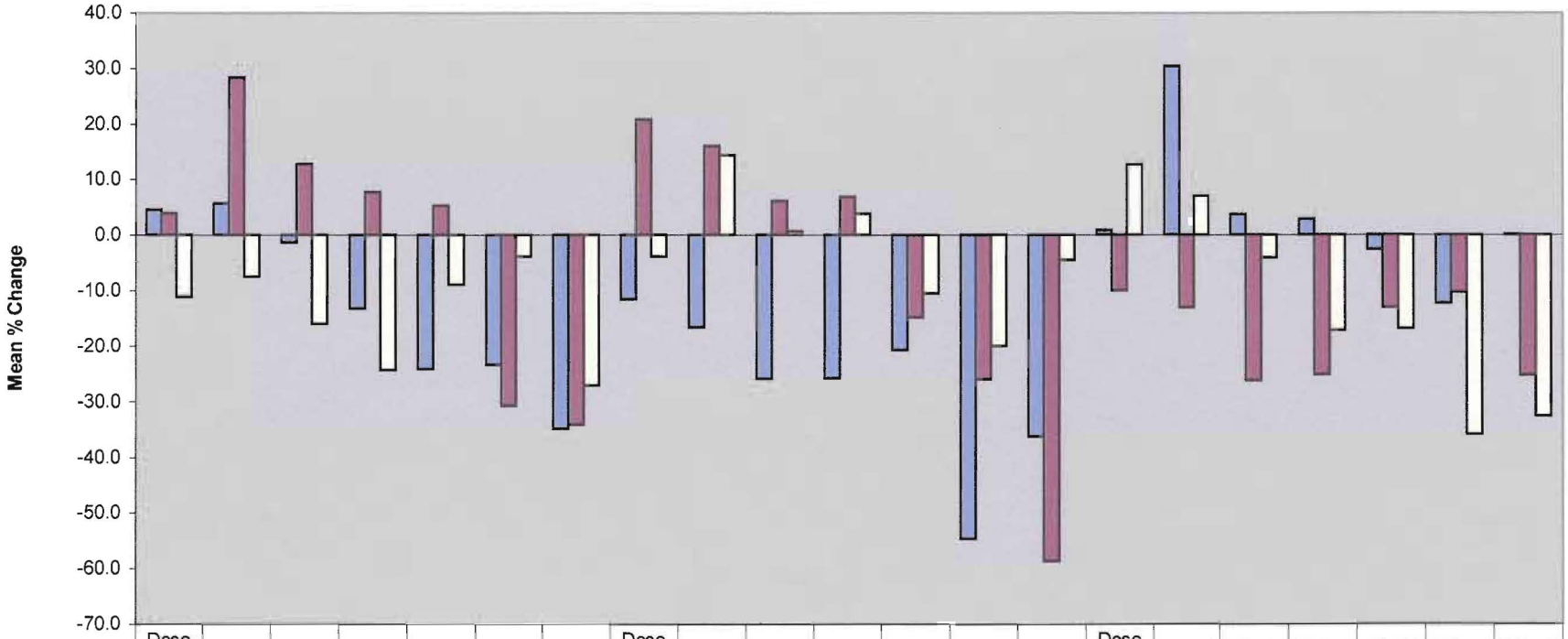
Cycle 2 (Intermediate Dosage)
Cellfood® showed reduced lactate values on the last three (higher) running speeds. Switch™ showed reduced lactate values on the initial and the last three (higher) running speeds. There were, however, no statistically significant differences ($p>0.05$) in these changes between groups. Placebo showed lower values on all the running speeds. The within-group ergolytic improvement from base-line values of 6.9% in lactate concentration at 14km/h observed in Cellfood® was statistically significant ($p<0.05$).

## TABLE V: BLOOD LACTATE VALUES

* = p< 0.05; % Δ = Relative Change; NS = Not Significant (p> 0.05)

| VARIABLES | | | PL: PLACEBO (N=10) | | | CF: CELLFOOD (N=10) | | | SW: SWITCH (N=10) | | | SIGNIFICANCE | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RUNNING SPEED | Cycle | UNITS | PRE TEST. X ± SD | POST-TEST X ± SD | %Δ | PRE-TEST. X ± SD | POST-TEST X ± SD | %Δ | PRE-TEST. X ± SD | POST-TEST X ± SD | %Δ | PL vs CF | PL vs SW | CF vs SW |
| 8km/h | 1 | mmol/L | 2.2 0.8 | 2.3 0.4 | 4.5 | 2.3 0.5 | 2.4 0.7 | 3.9 | 2.5 1.1 | 2.2 0.7 | -11.2 | NS | | |
| 8km/h | 2 | mmol/L | 2.5 1.1 | 2.2 0.6 | -11.6 | 2.2 0.8 | 2.7 0.3 | 20.8 | 2.3 0.5 | 2.2 0.6 | -3.9 | | | |
| 8km/h | 3 | mmol/L | 2.3 0.5 | 2.3 0.5 | 0.9 | 2.5 1.1 | 2.3 0.5 | -10.0 | 2.2 0.8 | 2.5 0.4 | 12.7 | | | |
| 10km/h | 1 | mmol/L | 2.1 0.8 | 2.2 0.5 | 5.7 | 1.9 0.7 | 2.5 1.1 | 28.4 | 2.7 1.0 | 2.5 0.6 | -7.4 | NS | | |
| 10km/h | 2 | mmol/L | 2.7 1.0 | 2.3 0.7 | -16.6 | 2.1 0.8 | 2.5 0.4 | 16.1 | 1.9 0.7 | 2.2 0.6 | 14.4 | | | |
| 10km/h | 3 | mmol/L | 1.9 0.7 | 2.5 0.4 | 30.4 | 2.7 1.0 | 2.3 0.6 | -13.0 | 2.1 0.8 | 2.3 0.5 | 7.1 | | | |
| 12km/h | 1 | mmol/L | 3.0 0.7 | 2.9 0.6 | -1.4 | 2.7 0.9 | 3.1 1.6 | 12.8 | 3.4 1.2 | 2.9 0.9 | -16.0 | NS | | |
| 12km/h | 2 | mmol/L | 3.4 1.2 | 2.5 0.6 | -25.9 | 3.0 0.7 | 3.1 0.8 | 6.1 | 2.7 0.9 | 2.8 0.6 | 0.7 | | | |
| 12km/h | 3 | mmol/L | 2.7 0.9 | 2.8 0.6 | 3.7 | 3.4 1.2 | 2.5 0.5 | -26.2 | 3.0 0.7 | 2.8 0.4 | -4.1 | | | |
| 14km/h | 1 | mmol/L | 4.4 0.9 | 3.8 0.6 | -13.3 * | 3.7 1.1 | 4.0 1.5 | 7.8 | 4.6 1.4 | 3.5 1.1 | -24.3 | NS | | |
| 14km/h | 2 | mmol/L | 4.6 1.4 | 3.4 1.2 | -25.8 | 4.4 0.9 | 4.7 1.1 | 6.9 * | 3.7 1.1 | 3.9 1.6 | 3.8 | | | |
| 14km/h | 3 | mmol/L | 3.7 1.1 | 3.8 1.2 | 2.9 | 4.6 1.4 | 3.5 0.9 | -25.2 | 4.4 0.9 | 3.6 0.6 | -17.2 * | | | |
| 16km/h | 1 | mmol/L | 6.4 1.7 | 4.9 1.0 | -24.1 | 5.0 1.4 | 5.3 1.5 | 5.3 | 5.5 1.4 | 5.0 1.3 | -8.9 | NS | | |
| 16km/h | 2 | mmol/L | 5.5 1.4 | 4.4 1.0 | -20.8 | 6.4 1.7 | 5.5 1.8 | -14.8 | 5.0 1.4 | 4.5 1.0 | -10.5 | | | |
| 16km/h | 3 | mmol/L | 5.0 1.4 | 4.9 1.6 | -2.6 | 5.5 1.4 | 4.8 1.1 | -13.1 | 6.4 1.7 | 5.3 1.3 | -16.8 | | | |
| 17km/h | 1 | mmol/L | 7.6 2.4 | 5.9 0.9 | -23.4 | 7.1 1.1 | 4.9 2.0 | -30.7 | 6.8 2.9 | 6.5 2.3 | -3.9 | NS | | |
| 17km/h | 2 | mmol/L | 6.8 2.9 | 3.1 1.9 | -54.7 | 7.6 2.4 | 5.7 2.6 | -26.0 | 7.1 1.1 | 5.7 1.9 | -20.0 | | | |
| 17km/h | 3 | mmol/L | 7.1 1.1 | 6.2 1.8 | -12.3 | 6.8 2.9 | 6.1 1.1 | -10.3 | 7.6 2.4 | 4.9 0.0 | -35.8 | | | |
| 18km/h | 1 | mmol/L | 9.2 2.8 | 6.0 | -34.8 | 7.4 1.5 | 4.9 0.4 | -34.1 | 9.5 4.6 | 6.9 3.0 | -27.1 | NS | | |
| 18km/h | 2 | mmol/L | 9.5 4.6 | 6.1 2.8 | -36.3 | 9.2 2.8 | 3.8 0.0 | -58.7 | 7.4 1.5 | 7.1 3.0 | -4.5 | | | |
| 18km/h | 3 | mmol/L | 7.4 1.5 | 7.4 1.9 | 0.1 | 9.5 4.6 | 7.1 0.0 | -25.3 | 9.2 2.8 | 6.2 0.0 | -32.6 | | | |

## FIGURE 4.9: BLOOD LACTATE VALUES




| | Dose 1: 8km/h | 10km/h | 12km/h | 14km/h | 16km/h | 17km/h | 18km/h | Dose 2: 8km/h | 10km/h | 12km/h | 14km/h | 16km/h | 17km/h | 18km/h | Dose 3: 8km/h | 10km/h | 12km/h | 14km/h | 16km/h | 17km/h | 18km/h |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Placebo | 4.5 | 5.7 | -1.4 | -13.3 | -24.1 | -23.4 | -34.8 | -11.6 | -16.6 | -25.9 | -25.8 | -20.8 | -54.7 | -36.3 | 0.9 | 30.4 | 3.7 | 2.9 | -2.6 | -12.3 | 0.1 |
| Cellfood | 3.9 | 28.4 | 12.8 | 7.8 | 5.3 | -30.7 | -34.1 | 20.8 | 16.1 | 6.1 | 6.9 | -14.8 | -26.0 | -58.7 | -10.0 | -13.0 | -26.2 | -25.2 | -13.1 | -10.3 | -25.3 |
| Switch | -11.2 | -7.4 | -16.0 | -24.3 | -8.9 | -3.9 | -27.1 | -3.9 | 14.4 | 0.7 | 3.8 | -10.5 | -20.0 | -4.5 | 12.7 | 7.1 | -4.1 | -17.2 | -16.8 | -35.8 | -32.6 |

Cycle 3 (High Dosage)

Cellfood® showed reduced lactate values on all of the running speeds during the test. Switch™ showed lower values on five of the seven running speeds. There were, however, no statistically significant differences ($p>0.05$) in these changes between groups. Placebo showed higher values on five of the seven running speeds, with two speeds showing lower values. The within-group ergogenic improvement from base-line values of 17.2% in lactate concentration at 14km/h observed in Switch™ was statistically significant ($p<0.05$)..

**Discussion**

Lactate is one of the by-products of glycolysis. It is both produced and used by the muscles. It's rate of production increases as the exercise rate increases and as more carbohydrate is used to fuel exercise (Noakes, 1992). Glycolysis refers to the process where carbohydrates are broken down to pyruvic acid or lactic acid (Meyer and Meij, 1996). Lactic acid does not necessarily accumulate at all levels of exercise. During light and moderate exercise the energy demands are adequately met by reactions that use oxygen. In biochemical terms, the ATP for muscular contraction is made available predominantly through energy generated by the oxidation of hydrogen. Any lactic acid formed during light exercise is rapidly oxidized. As such, the blood lactic acid levels remains fairly stable even though oxygen consumption increases. Lactic acid begins to accumulate and rise in an exponential fashion at about 55% of the healthy, untrained subject's maximal capacity for aerobic metabolism. The usual explanation for the increase in lactic acid is based on the assumption of a relative tissue hypoxia in heavy exercise (McArdle et al., 1991). For this reason it would be beneficial to the athlete if either one of the products could help the oxygen supply to the muscle and surrounding tissue, preventing or rather delaying the onset of hypoxia due to increased exercise intensity. Although the energy released during glycolysis is rapid and does not require oxygen, relatively little ATP is resynthezised in this manner. Consequently, aerobic (absence of hypoxia) reactions provide the important final stage for energy transfer, especially if vigorous exercise proceeds beyond several minutes. An untrained individual who fasted overnight and who has a sample of blood collected in the morning from an arm vein before any exercise, has a lactate level ranging from 0.44 to 1.7 mmol/L. Martin and Coe (1997) also found the equivalent of 0.3 to 0.6 mmol/L to be true for trained individuals, providing that they are not over-

trained. Within an hour after an intensive training session during which blood lactate levels reach the highest achievable values (15mmol/L), muscle lactate levels will return to normal (Noakes, 1992). Most of the lactic acid produced during vigorous exercise is removed by direct oxidation (55-70%) while the balance amount is converted to glycogen (<20%), protein constituents (5-10%) and other compounds (<10%) (Gupta et al., 1996). Lactic acid produced in working muscles is almost completely dissociated into $H^+$ and lactate within the range of physiological pH, which contributes to the metabolic acidosis (Hirokoba, 1992). Blood doping is one known method to try and lower lactate levels in endurance athletes. It is now clear that blood doping reduces blood lactate levels during exercise and alters the lactate turn point to higher running speeds. These effects are likely to be the more important explanations for the increased running performance after blood doping (Noakes, 1992).

L- Carnitine is a well-known supplement often used to try and lower lactate concentrations, it plays a role in regulating the balance between key chemicals in metabolic processes and is known to act as a buffer for pyruvate, thus reducing muscle lactate accumulation associated with fatigue (Armsey and Green, 1997).

It is clear when looking at the graphic presentation of the results that Switch™ was more effective during cycle 1, (lowest dosage) and Cellfood® was the most effective during cycle 3 (highest dosage) in keeping lactate production as low as possible.

## 4.10 Gas Analyses

Absolute pre- and post-test values can be observed in Table VI (A and B) and the relative changes are presented graphically in Figure 4.10-4.20

### 4.10.1 Respiratory Exchange Rate (Figure 4.10) and $VC0_2$ (Figure 4.11) (Table VI A)

Since the respiratory exchange ratio (RER) reflects the rate of carbon dioxide production to oxygen consumption it is an indication of the metabolic exchange of gases in the body tissues. Any change in either the $V0_2$ or $VC0_2$ would have a direct

influence on the RER. Essentially RER is a non-steady-state measurement that can vary from breath to breath as well as from time to time depending on physiological circumstances (Cooper and Storer, 2001).

Resting RER is typically 0.7-0.95, indicating that overall body metabolism utilizes a mixture of carbohydrate and fat. Resting RER is influenced by the nutritional state of the subject. When first measured breathing through a mouthpiece, RER tends to increase due to hyperventilation, which increases $VC0_2$ whilst having relatively little effect on $V0_2$.

With the onset of exercise, RER decreases. This transition phase occurs because of the important differences in the dynamic changes of $V0_2$ and $VC0_2$. Measured at the mouth, V02 increases more rapidly than $VC0_2$. This phenomenon is thought to be due to the greater solubility of $C0_2$, causing some of the $C0_2$ from increased muscle metabolism to load into body stores rather than to appear immediately in the exhaled breath. A reverse phenomenon is observed when exercise ends. In this situation the body continues to eliminate excess carbon dioxide until body stores have normalized. Consequently there is a transient increase in RER after exercise cessation. During incremental exercise, particularly after adjustment of body carbon dioxide stores, RER increases steadily. Above the metabolic threshold, when additional carbon dioxide is derived from bicarbonate buffering of lactic acid, RER increases more rapidly. End exercise RER has been advocated as a measure of maximal effort. Although there is some logic to this approach, it is not to be recommended. End-exercise RER can vary considerably between individuals and hyperventilation for various reasons can elevate RER independently of effort (Cooper and Storer, 2001).

Like oxygen consumption, carbon dioxide production increases during exercise because of increasing metabolic activity in the exercising muscles. The amount of carbon dioxide generated by the process is related to the oxygen consumption by the RER. Additional carbon dioxide is derived from bi-carbonate buffering of lactic acid at high work rates. In contrast to tissue oxygen supply, the actual cardiac output needed for $C0_2$ elimination is not critical. Rather, the quantity of ventilation relative to the $VC0_2$ determines arterial $PC0_2$. The tissue $PC0_2$ is defined by the arterial PC02, blood flow, and metabolic activity (Wasserman et al., 1986).

One must remain cognisant of the distinction between the terms carbon dioxide production and carbon dioxide output. Tissues might produce a certain amount of carbon dioxide but not all of this carbon dioxide is necessarily expelled through the lung or measured as carbon dioxide output. Carbon dioxide output should approximate tissue carbon dioxide production when the body is in steady state (Cooper and Storer, 2001).

Cycle 1 (Low Dosage)

At the end of this cycle Cellfood® showed a decrease of 0.4% in the RER at $V0_2max$, while Switch™ showed a increase of 5.8%. Corresponding with the changes in RER, Cellfood® showed a decrease of 7.4% in $VC0_2$ while Switch™ had an increase of 6.6%. Placebo showed an increase of 6.1% in RER and an increase of 8.1% in $VC0_2$. As explained above this relates to aerobic metabolism contributing to a larger portion of energy expenditure while using Cellfood®. It seems that the Switch™ product increased the contribution of anaerobic metabolism to the energy expenditure when used at this dosage. There were, however, no statistically significant differences ($p>0.05$) in the changes between groups.

Cycle 2 (Intermediate Dosage)

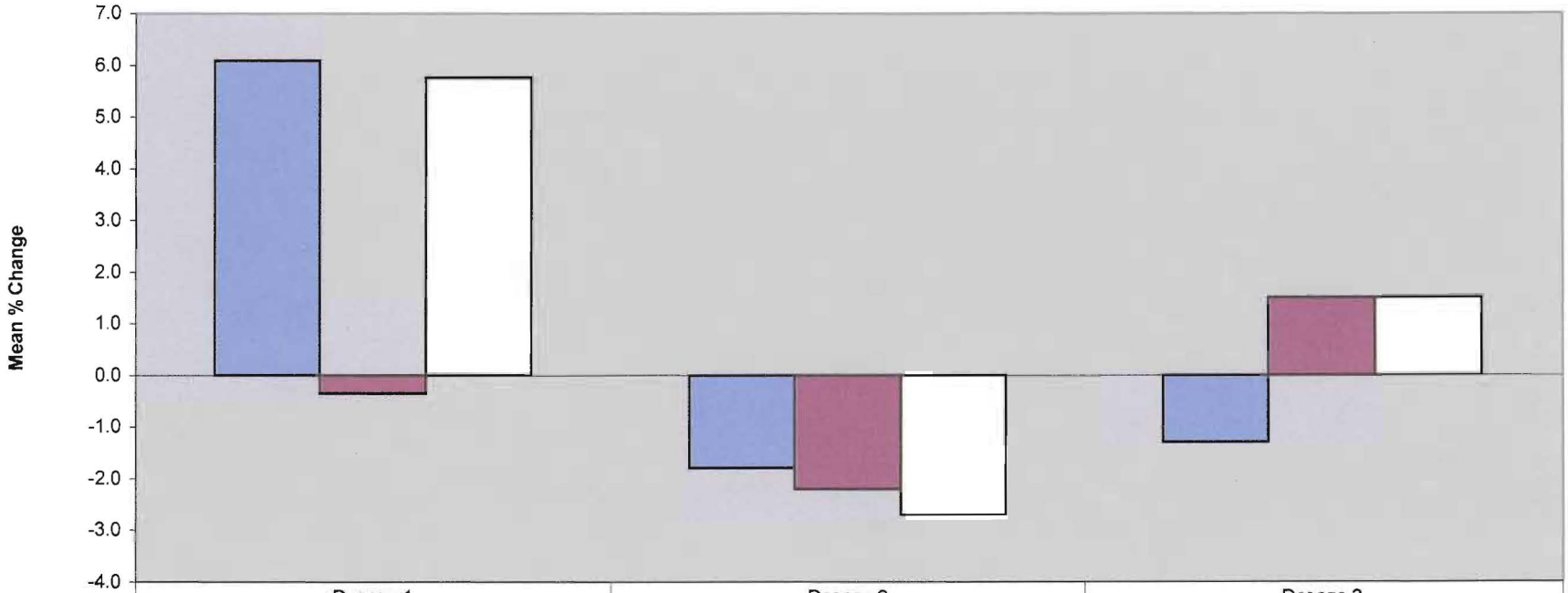
The Switch™ group showed decreases in both RER (2.7%) and $VC0_2$ (4.8%) indicating a bigger contribution by aerobic metabolism. The Cellfood® showed a decrease of 2.2% in the RER, which had to be related to the large increase in $V0_2$, during the cycle since the $VC0_2$ also increased (2.1%) for this group during this cycle. The bigger increase in the $V0_2$ compensated for the increase in carbon dioxide production leading to a decrease in the RER. The placebo showed a decrease of 1.8% in the RER while the $VC0_2$ showed no change from the previous cycle. It seems that both Cellfood® and Switch™ were effective at increasing the aerobic metabolism and its contribution to energy expenditure when used at this dosage. There were, however, no statistically significant differences ($p>0.05$) in the changes between groups.

## TABLE VI: GAS ANALYSES (A)

* = p< 0.05; % Δ = Relative Change; NS = Not Significant (p> 0.05)

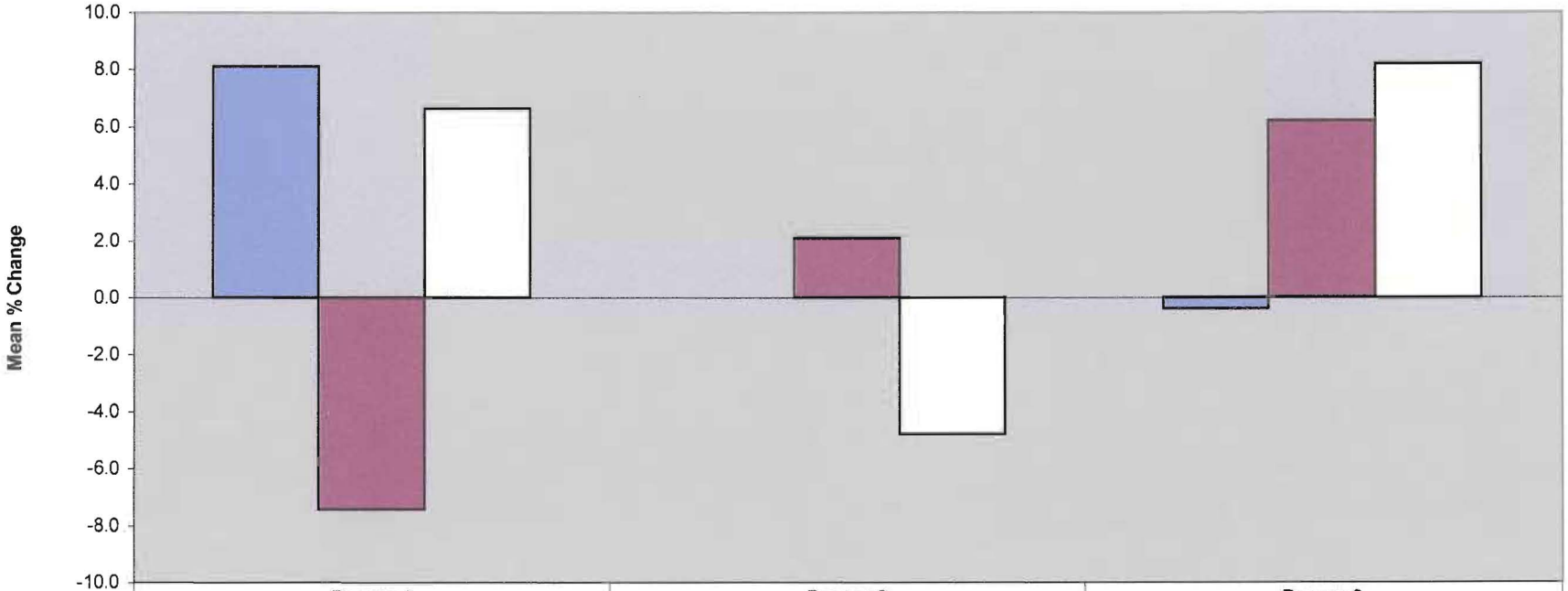
| VARIABLES | | | PL: PLACEBO (N=10) | | | | | CF: CELLFOOD (N=10) | | | | | SW: SWITCH (N=10) | | | | | SIGNIFICANCE | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GAS VALUES | Cycle | UNITS | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PL vs CF | PL vs SW | CF vs SW |
| RER | 1 | | 1.2 | 0.1 | 1.2 | 0.1 | **6.1** | 1.1 | 0.0 | 1.1 | 0.1 | **-0.4** | 1.1 | 0.1 | 1.2 | 0.1 | **5.8** | | | |
| RER | 2 | | 1.1 | 0.1 | 1.1 | 0.1 | **-1.8** | 1.2 | 0.1 | 1.1 | 0.1 | **-2.2** | 1.1 | 0.0 | 1.1 | 0.1 | **-2.7** | | NS | |
| RER | 3 | | 1.1 | 0.0 | 1.1 | 0.1 | **-1.3** | 1.1 | 0.1 | 1.2 | 0.1 | **1.5** | 1.2 | 0.1 | 1.2 | 0.1 | **1.5** | | | |
| $VC0_2$ | 1 | l/min | 3559.2 | 633.5 | 3847.6 | 753.4 | **8.1** | 3687.2 | 825.5 | 3413.4 | 758.5 | **-7.4** | 3635.5 | 776.0 | 3876.4 | 947.0 | **6.6** | | | |
| $VC0_2$ | 2 | l/min | 3635.5 | 776.0 | 3634.2 | 648.7 | **0.0** | 3559.2 | 633.5 | 3633.9 | 776.4 | **2.1** | 3687.2 | 825.5 | 3509.5 | 950.0 | **-4.8** | | NS | |
| $VC0_2$ | 3 | l/min | 3687.2 | 825.5 | 3671.3 | 982.2 | **-0.4** | 3635.5 | 776.0 | 3859.4 | 695.7 | **6.2** | 3559.2 | 633.5 | 3852.0 | 798.2 | **8.2** | | | |
| $VE/VC0_2$ | 1 | L | 28.0 | 16.1 | 27.6 | 1.8 | **-1.6** | 28.8 | 2.8 | 27.7 | 2.8 | **-3.7** | 29.4 | 2.1 | 28.2 | 2.5 | **-4.3** | | | |
| $VE/VC0_2$ | 2 | L | 29.4 | 2.1 | 29.1 | 2.1 | **-1.2** | 28.0 | 16.1 | 28.8 | 1.5 | **2.7** | 28.8 | 2.8 | 28.3 | 2.9 | **-1.6** | | NS | |
| $VE/VC0_2$ | 3 | L | 28.8 | 2.8 | 29.4 | 3.4 | **2.1** | 29.4 | 2.1 | 28.8 | 2.8 | **-2.0** | 28.0 | 16.1 | 27.6 | 2.0 | **-1.3** | | | |
| $etCO_2$ | 1 | mmHg | 39.1 | 2.3 | 41.1 | 3.1 | **5.1** | 39.8 | 5.3 | 39.2 | 3.2 | **-1.5** | 37.7 | 2.1 | 39.3 | 4.2 | **4.2** | | | |
| $etCO_2$ | 2 | mmHg | 37.7 | 2.1 | 38.6 | 2.8 | **2.4** | 39.1 | 2.3 | 38.3 | 2.3 | **-2.0** | 39.8 | 5.3 | 39.3 | 5.0 | **-1.3** | | NS | |
| $etCO_2$ | 3 | mmHg | 39.8 | 5.3 | 38.8 | 3.9 | **-2.5** | 37.7 | 2.1 | 38.9 | 3.6 | **3.2** | 39.1 | 2.3 | 39.8 | 3.4 | **1.8** | | | |
| $VE/VO_2$ | 1 | L | 32.3 | 2.8 | 33.6 | 3.5 | **4.2** | 32.4 | 2.8 | 31.0 | 3.4 | **-4.0 *** | 33.6 | 1.6 | 34.0 | 2.4 | **1.3** | | | |
| $VE/VO_2$ | 2 | L | 33.6 | 1.6 | 32.5 | 2.9 | **-3.1** | 32.3 | 2.8 | 32.3 | 3.2 | **0.2** | 32.4 | 2.8 | 31.0 | 2.4 | **-4.5 *** | | NS | |
| $VE/VO_2$ | 3 | L | 32.4 | 2.8 | 32.7 | 4.6 | **0.7** | 33.6 | 1.6 | 33.4 | 2.8 | **-0.5** | 32.3 | 2.8 | 32.2 | 2.8 | **-0.1** | | | |
| $etO_2$ | 1 | mmHg | 96.5 | 1.9 | 96.5 | 2.5 | **0.0** | 96.4 | 2.3 | 94.7 | 2.8 | **-1.8** | 97.2 | 1.5 | 96.6 | 2.1 | **-0.6** | | | |
| $etO_2$ | 2 | mmHg | 97.2 | 1.5 | 95.7 | 2.3 | **-1.5** | 96.5 | 1.9 | 95.7 | 2.6 | **-0.8** | 96.4 | 2.3 | 94.6 | 2.5 | **-1.9** | | NS | |
| $etO_2$ | 3 | mmHg | 96.4 | 2.3 | 95.8 | 4.0 | **-0.6** | 97.2 | 1.5 | 96.1 | 3.1 | **-1.1** | 96.5 | 1.9 | 96.3 | 2.3 | **-0.2** | | | |

## FIGURE 4.10: RESPIRATORY EXCHANGE RATIO




| | Dosage 1 | Dosage 2 | Dosage 3 |
|---|---|---|---|
| Placebo | 6.1 | -1.8 | -1.3 |
| Cellfood | -0.4 | -2.2 | 1.5 |
| Switch | 5.8 | -2.7 | 1.5 |

**FIGURE 4.11: $VC0_2$**




| | Dosage 1 | Dosage 2 | Dosage 3 |
|---|---|---|---|
| Placebo | 8.1 | 0.0 | -0.4 |
| Cellfood | -7.4 | 2.1 | 6.2 |
| Switch | 6.6 | -4.8 | 8.2 |

Cycle 3 (High Dosage)

During this cycle both the Cellfood® and Switch™ showed an increases of 1.5% in RER. Cellfood® showed an increase of 6.2% in $VC0_2$ while Switch™ showed an increase of 8.2%. Placebo showed a decrease of 1% in RER while the $VC0_2$ decreased with 0.4%. There were, however, no statistically significant differences ($p>0.05$) in the changes between groups.

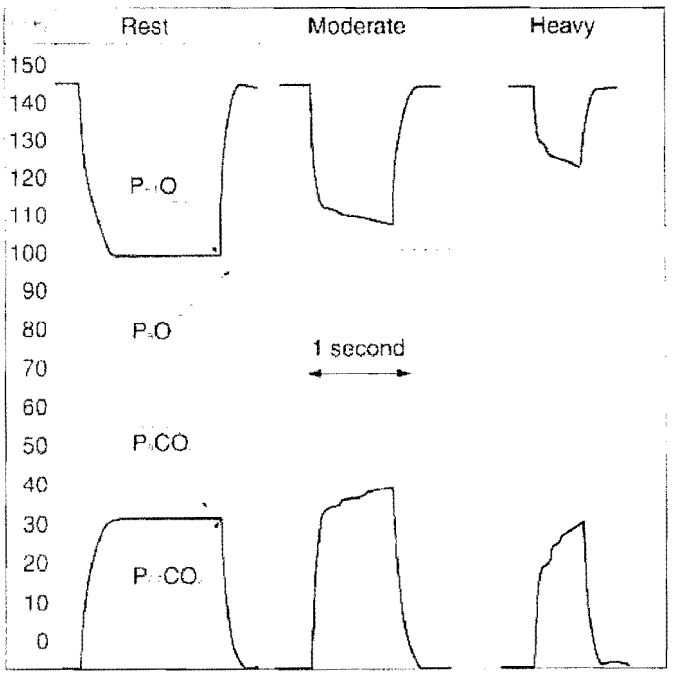
### 4.10.2 Breathing Equivalent for $C0_2$ (Figure 4.12) and End Tidal Partial Carbon Dioxide Pressure (Figure 4.13) (Table VI A)

Ventilatory equivalents are measures of breathing efficiency, which relate instantaneous minute ventilation to the metabolic rate of oxygen uptake or carbon dioxide output. Ventilatory equivalents are secondary variables derived as the ratios of instantaneous minute ventilation to oxygen uptake ($VE/V0_2$) or carbon dioxide output ($VE/VC0_2$). Being ratios of two flows, ventilatory equivalents have no units.

Resting ventilatory equivalents are variable, but generally 30-60. Ventilatory equivalents fall steadily during the early stages of incremental exercise.$VE/VC0_2$ does not begin to increase until VE becomes dissociated from $VC0_2$, i.e. when buffering mechanisms can no longer prevent a fall in blood pH and VE responds to carotid body stimulation. As long as the RER is less than 1.0, $VE/V0_2$ will be less than$VE/VC0_2$. Of particular importance are the plateau values that are on average 25 for $VE/V0_2$ and 28 for $VE/VC0_2$ for younger normal subjects. With advancing age, as the physiological dead space in the lung increases, the plateau values of the ventilatory equivalents are higher, e.g., 30 for $VE/V0_2$ and 33 for $VE/VC0_2$ (Cooper and Storer, 2001)

End tidal gas tensions are the partial pressures of oxygen and carbon dioxide observed at the end of each exhalation. The last gas exhaled from the lung is assumed to come from the alveolar compartment. Therefore, in the ideal lung, the end-tidal gas tensions would reflect the alveolar partial pressure of these gasses. The normal partial pressure profiles of exhaled oxygen and carbon dioxide are shown in accompanying sketch. The two profiles resemble “mirror images” of

each other and the relative magnitudes of the changes they reflect depend on the RER. The end-tidal partial pressures are often described as plateaus but in reality they are slopes. Towards the end of exhalation, the oxygen tension actually continues to decrease slowly whereas the carbon dioxide tension increases slowly. These changes, which are subtle at rest, represent the continuing gas exchange between the blood and the alveolar gas. During exercise, as the metabolic rate increases, these alveolar slopes become steeper (Cooper and Storer, 2001).

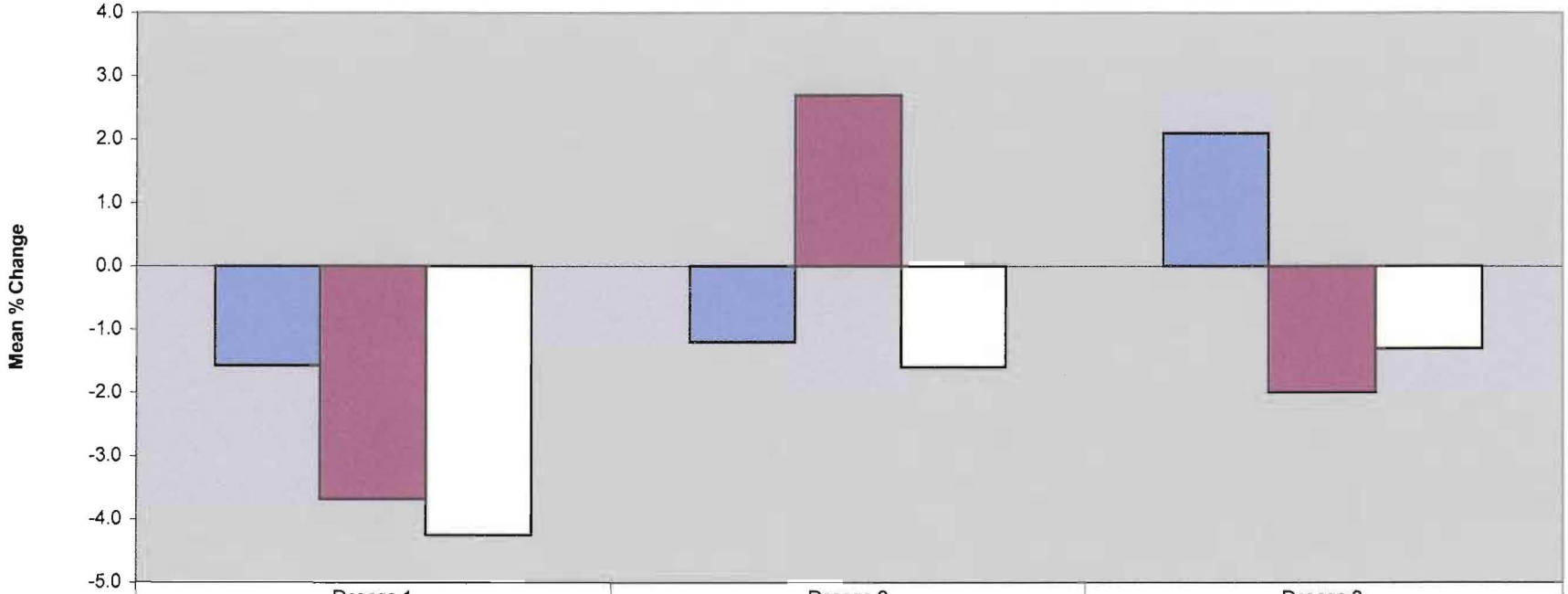



**Profiles of exhaled oxygen and carbon dioxide at rest and during moderate or high-intensity exercise (Cooper and Storer, 2001)**

Cycle 1 (Low Dosage)

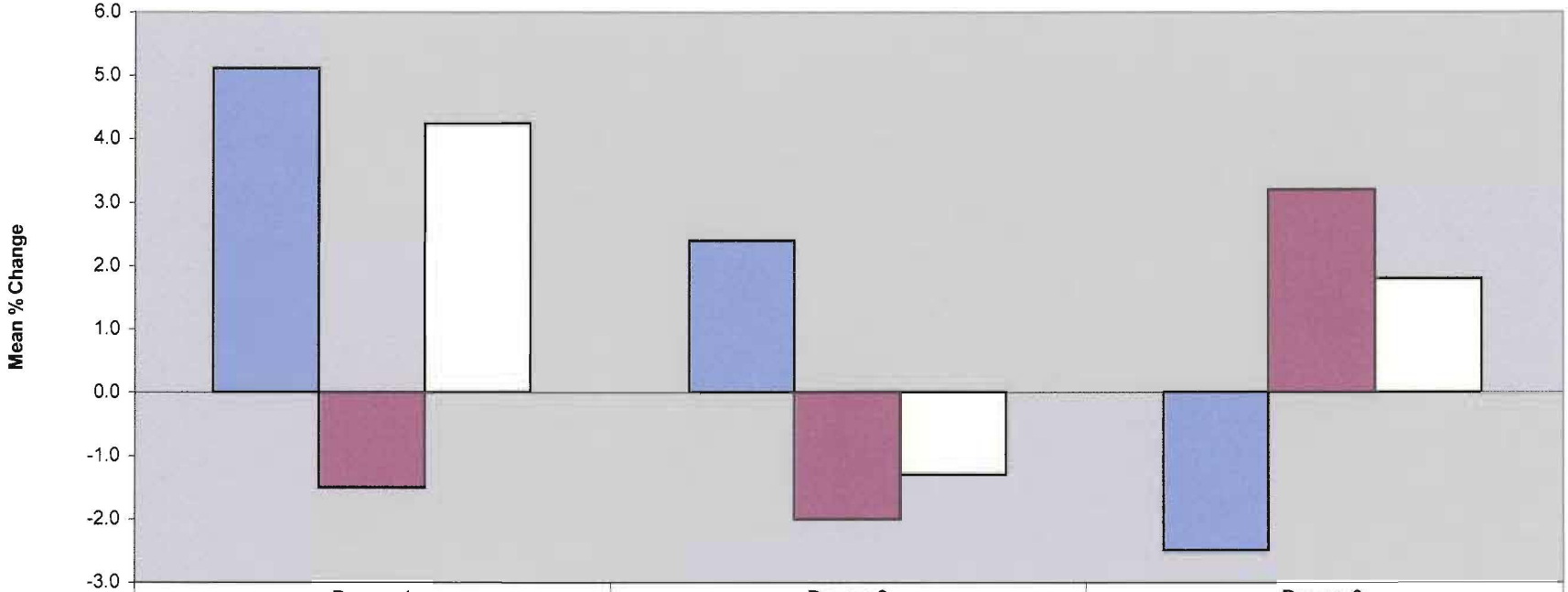
The ventilatory equivalent for carbon dioxide showed a decrease of 4.3% for Switch™ and a decrease of 3.7% for Cellfood®. The placebo showed a decrease of 1.6%. This indicates that Switch™ was most effective during this cycle, ensuring the best breathing efficiency. Switch™ showed an increase of 4.2% in the end tidal partial oxygen pressure while the Cellfood® showed a decrease of 1.5%. Placebo showed an increase of 5.1%. This indicates that Switch™ was the most effective during this cycle, ensuring the best breathing efficiency. There were, however, no statistically significant differences ($p>0.05$) in the changes between groups.

## FIGURE 4.12: BREATHING EQUIVALENT FOR $C0_2$




| | Dosage 1 | Dosage 2 | Dosage 3 |
|---|---|---|---|
| Placebo | -1.6 | -1.2 | 2.1 |
| Cellfood | -3.7 | 2.7 | -2.0 |
| Switch | -4.3 | -1.6 | -1.3 |

## FIGURE 4.13: END TIDAL PARTIAL CARBON DIOXIDE PRESSURE




| | Dosage 1 | Dosage 2 | Dosage 3 |
|---|---|---|---|
| Placebo | 5.1 | 2.4 | -2.5 |
| Cellfood | -1.5 | -2.0 | 3.2 |
| Switch | 4.2 | -1.3 | 1.8 |

Cycle 2 (Intermediate Dosage)

During this cycle Switch™ showed a decrease of 1.6% while Cellfood® showed an increase of 2.7% in the breathing equivalent for carbon dioxide. The placebo showed a decrease of 1.2%. This indicates that Switch™ was the most effective in improving the breathing efficiency during this cycle. Switch™ and Cellfood® showed decreases in end tidal partial carbon dioxide pressure (1.3% and 2.0% respectively). Placebo showed an increase of 2.4%. This indicates that neither Cellfood® nor Switch™ were very effective at this dosage. There were, however, no statistically significant differences ($p>0.05$) in the changes between groups.

Cycle 3 (High Dosage)

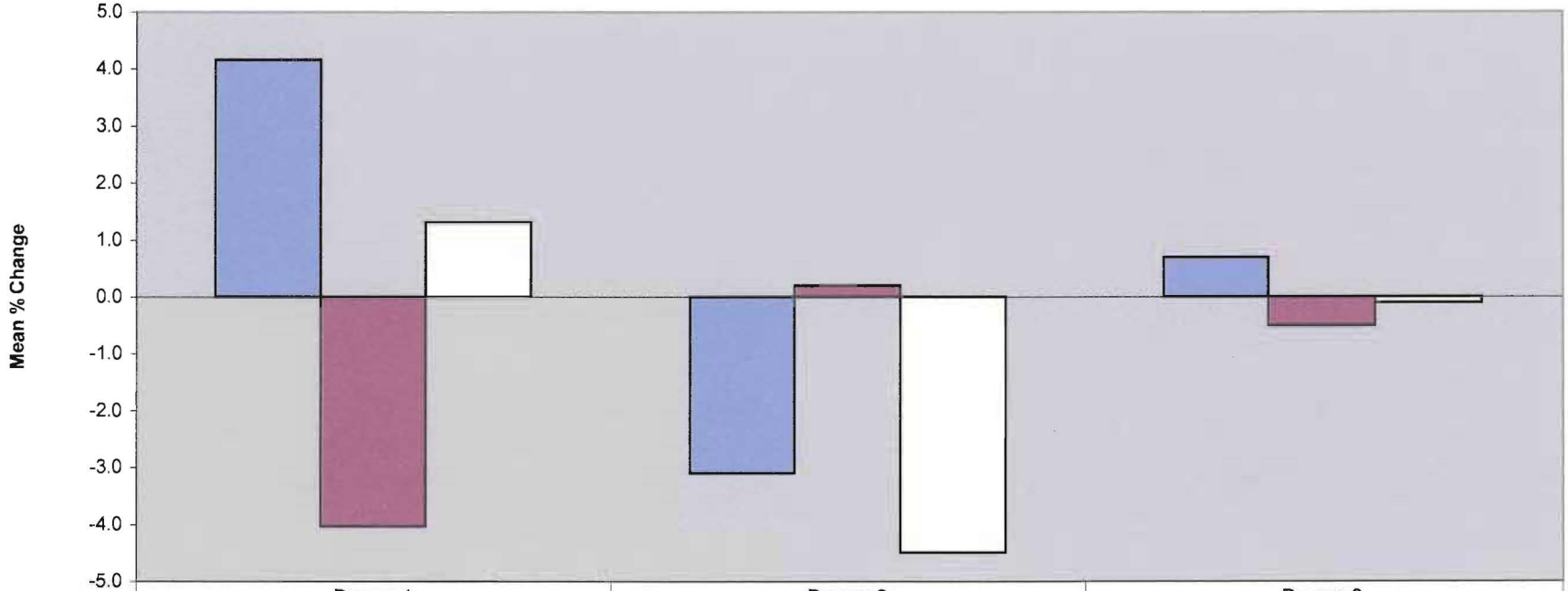
Cellfood® showed a decrease of 2% in the breathing equivalent for carbon dioxide, while Switch™ showed a decrease of 1.3%. Placebo showed an increase of 2.1%. This indicates that both Cellfood® and Switch™ were effective at improving breathing efficiency, but Cellfood® showed the best results during this cycle. Cellfood® showed an increase of 3.2% in the end tidal partial carbon dioxide pressure. Switch™ showed an increase of 1.8%. Placebo showed a decrease of 2.5%. This indicates that Cellfood® was the superior ergogenic aid when administered during the third cycle. There were, however, no statistically significant differences ($p>0.05$) in the changes between groups.

### 4.10.3 Breathing Equivalent for $0_2$ (Figure 4.14) and End Tidal Partial Oxygen Pressure (Figure 4.15) (Table VI A)

Cycle 1 (Low Dosage)

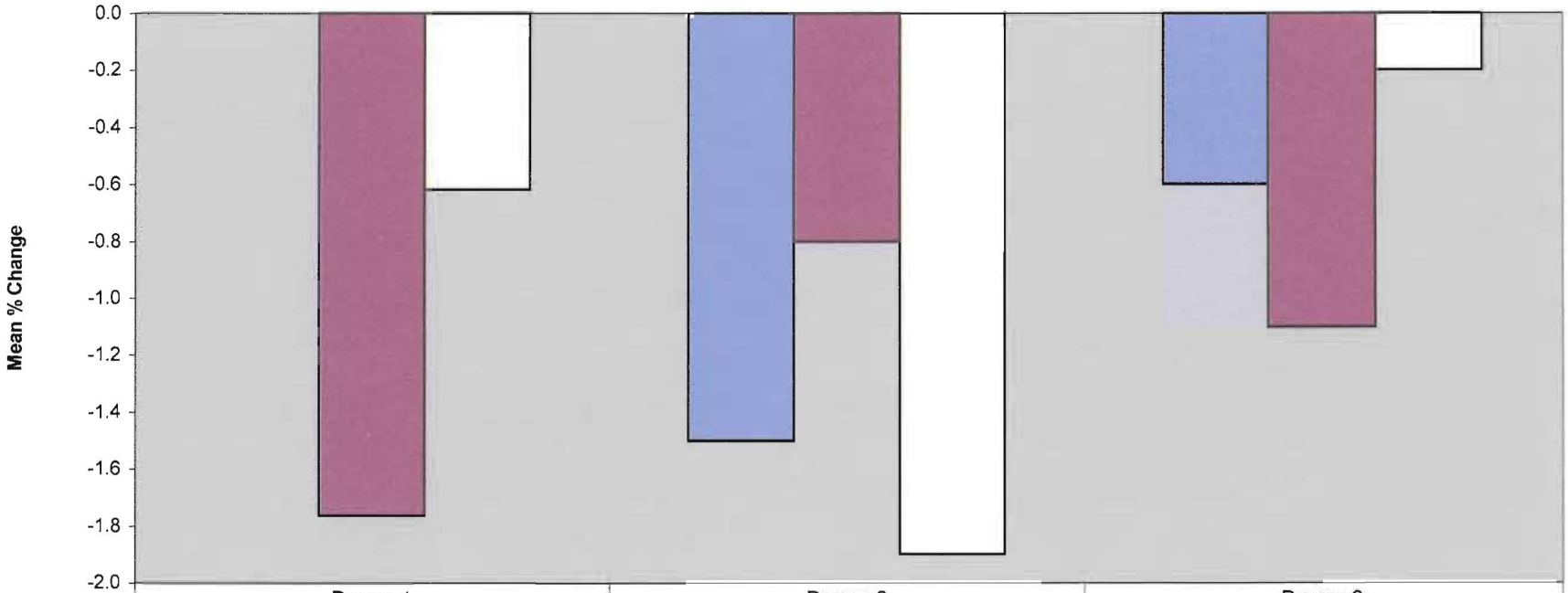
Cellfood® showed a decrease of 4% in the breathing equivalent for oxygen while Switch™ showed an increase of 1.3%. Placebo showed an increase of 4.2%. This indicates that Cellfood® was the most effective in improving breathing efficiency during this cycle. Cellfood® showed a decrease of 1.8% in the end tidal partial oxygen pressure. Switch™ showed a decrease of 0.6% while the placebo showed no changes when compared to the pre-test. These results confirms that Cellfood® was the most effective during this cycle. The within-group ergogenic improvement from base-line values of 4.0% in breathing equivalent observed in Cellfood® was statistically significant ($p<0.05$).

## FIGURE 4.14: BREATHING EQUIVALENT FOR $0_2$




| | Dosage 1 | Dosage 2 | Dosage 3 |
|---|---|---|---|
| Placebo | 4.2 | -3.1 | 0.7 |
| Cellfood | -4.0 | 0.2 | -0.5 |
| Switch | 1.3 | -4.5 | -0.1 |

## FIGURE 4.15: END TIDAL PARTIAL OXYGEN PRESSURE




| | Dosage 1 | Dosage 2 | Dosage 3 |
|---|---|---|---|
| Placebo | 0.0 | -1.5 | -0.6 |
| Cellfood | -1.8 | -0.8 | -1.1 |
| Switch | -0.6 | -1.9 | -0.2 |

Cycle 2 (Intermediate Dosage)

Switch™ showed a decrease of 4.5% in the breathing equivalent for oxygen. Cellfood® showed an increase of 0.2% while placebo showed a decrease of 3.1%. Switch™ was the most effective in improving the breathing efficiency during this cycle. Switch™ showed the greatest decrease in end tidal partial oxygen pressure at1.9%. Cellfood® showed a decrease of 0.8% and placebo showed a decrease of 1.5%. Overall, Switch™ had the most beneficial effect on the breathing efficiency during this cycle. There were, however, no statistically significant differences ($p>0.05$) in the changes between groups. The within-group ergogenic improvement from base-line values of 4.5% in breathing equivalent observed in Switch™ was statistically significant ($p<0.05$).

Cycle 3 (High Dosage)

Cellfood® showed a decrease of 0.5% in the breathing equivalent for oxygen, while Switch™ showed an increase of 0.2%. The placebo showed an increase of 0.7%. Cellfood® showed a decrease of 1.1% in the end tidal partial pressure for oxygen while Switch™ and placebo showed decreases of 0.2% and 0.6%, respectively. Cellfood® was the most effective in improving the breathing efficiency during this cycle. There were, however, no statistically significant differences ($p>0.05$) in the changes between groups.

### 4.10.4 Minute Ventilation (Figure 4.16), Tidal Volume (Figure 4.17) and Respiration Rate (Figure 4.18) (Table VI B)

Maximum minute ventilation is the highest value of ventilation which can be attained and measured during incremental exercise. With symptom-limited incremental exercise, minute ventilation typically increases from a resting value of 5-8 l/min up to 100-150 l/min. The response is non-linear. Every individual has a theoretical ventilatory capacity. This can be measured in the laboratory by performing a maximal voluntary ventilation (MVV) test. A normal individual uses

## TABLE VI: GAS ANALYSES (B)

* = p< 0.05; % Δ = Relative Change; NS = Not Significant (p> 0.05)

| VARIABLES | | | PL: PLACEBO (N=10) | | | | | CF: CELLFOOD (N=10) | | | | | SW: SWITCH (N=10) | | | | | SIGNIFICANCE | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GAS VALUES | Cycle | UNITS | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PRE-TEST. X ± SD | | POST-TEST X ± SD | | %Δ | PL vs CF | PL vs SW | Cf vs SW |
| Minute Volume | 1 | l/min | 100.1 | 19.9 | 106.9 | 26.2 | 6.9 | 105.1 | 20.3 | 94.3 | 17.6 | -10.2 | 106.7 | 22.1 | 108.2 | 22.7 | 1.4 | NS | | |
| Minute Volume | 2 | l/min | 106.7 | 22.1 | 105.3 | 17.9 | -1.3 | 100.1 | 19.9 | 104.7 | 23.3 | 4.6 | 105.1 | 20.3 | 97.4 | 22.8 | -7.3 | | | |
| Minute Volume | 3 | l/min | 105.1 | 20.3 | 107.7 | 31.6 | 2.5 | 106.7 | 22.1 | 111.4 | 23.3 | 4.4 | 100.1 | 19.9 | 106.7 | 23.6 | 6.6 | | | |
| Tidal Volume | 1 | ml | 1929.7 | 453.2 | 2068.8 | 489.1 | 7.2 | 2023.5 | 434.3 | 2059.4 | 313.5 | 1.8 | 2043.1 | 463.6 | 2165.6 | 497.8 | 6.0 | NS | | |
| Tidal Volume | 2 | ml | 2043.1 | 463.6 | 2208.7 | 565.6 | 8.1 | 1929.7 | 453.2 | 2072.2 | 421.1 | 7.4 | 2.23.5 | 434.3 | 2108.8 | 355.1 | 4.2 | | | |
| Tidal Volume | 3 | ml | 2023.5 | 434.3 | 2127.8 | 511.3 | 5.2 | 2043.1 | 463.6 | 2297.0 | 626.7 | 12.4 | 1929.7 | 453.2 | 2083.5 | 450.9 | 8.0 | | | |
| Respiration Rate | 1 | /min | 52.6 | 5.7 | 52.1 | 5.5 | -1.0 | 53.2 | 13.9 | 45.6 | 5.4 | -14.3 | 52.7 | 6.1 | 50.2 | 6.2 | -4.7 | NS | | |
| Respiration Rate | 2 | /min | 52.7 | 6.1 | 49.2 | 8.0 | -6.6 | 52.6 | 5.7 | 50.7 | 5.1 | -3.6 | 53.2 | 13.9 | 45.9 | 7.1 | -13.7 | | | |
| Respiration Rate | 3 | /min | 53.2 | 13.9 | 51.3 | 13.7 | -3.6 | 52.7 | 6.1 | 50.0 | 8.0 | -5.1 | 52.6 | 5.7 | 51.6 | 5.3 | -1.9 | | | |
| VO2max (absolute) | 1 | ml/min | 3101.9 | 564.8 | 3187.1 | 702.5 | 2.7 | 3262.4 | 701.2 | 3042.8 | 647.48 | -4.3 | 3178.5 | 689.1 | 3165.6 | 594.3 | -0.4 | NS | | |
| VO2max (absolute) | 2 | ml/min | 3178.5 | 689.1 | 3246.8 | 580.2 | 2.1 | 3101.9 | 564.8 | 3230.3 | 598.3 | 4.1 | 3262.4 | 701.2 | 3176.3 | 845.7 | -2.6 | | | |
| VO2max (absolute) | 3 | ml/min | 3262.4 | 701.2 | 3314.1 | 906.6 | 1.6 | 3178.5 | 689.1 | 3337.0 | 664.1 | 5.0 * | 3101.9 | 564.8 | 3294.4 | 598.4 | 6.2 | | | |
| VO2 max (relative) | 1 | ml/kg/min | 46.5 | 7.6 | 42.2 | 7.1 | -9.3 | 45.9 | 9.9 | 47.0 | 7.8 | 2.4 | 45.1 | 7.4 | 48.3 | 5.6 | 7.1 | NS | | |
| VO2 max (relative) | 2 | ml/kg/min | 45.1 | 7.4 | 46.6 | 8.0 | 3.2 | 46.5 | 7.6 | 45.5 | 7.8 | -2.1 | 45.9 | 9.9 | 46.9 | 7.3 | 2.1 | | | |
| VO2 max (relative) | 3 | ml/kg/min | 45.9 | 9.9 | 49.4 | 7.5 | 7.7 | 45.1 | 7.4 | 45.3 | 4.0 | 0.5 | 46.5 | 7.6 | 46.5 | 9.5 | -0.1 | | | |

50-75% of his or her ventilatory capacity at maximum exercise. Thus, a normal individual is not expected to exhibit ventilatory limitation. Athletes who have successfully extended their cardiovascular fitness use a higher proportion of their ventilatory capacity at maximum exercise (Cooper and Storer, 2001).

Tidal volume (VT) is the volume of a single breath. Normal VT varies according to body size and also varies from breath to breath. During exercise VT increases in a nonlinear fashion reaching a plateau value equal to approximately 50-60% of vital capacity at about 70% of $V0_2max$.

Respiration rate (RR) is the number of breaths taken per minute. A normal resting respiration rate is 8-12 breaths per minute. Characteristically RR increases steadily to a maximum value of between 30 and 40 per minute. RR rarely exceeds 50 per minute. However, some elite athletes may exhibit RR values as high as 80 per minute at maximum exercise (Cooper and Storer, 2001).

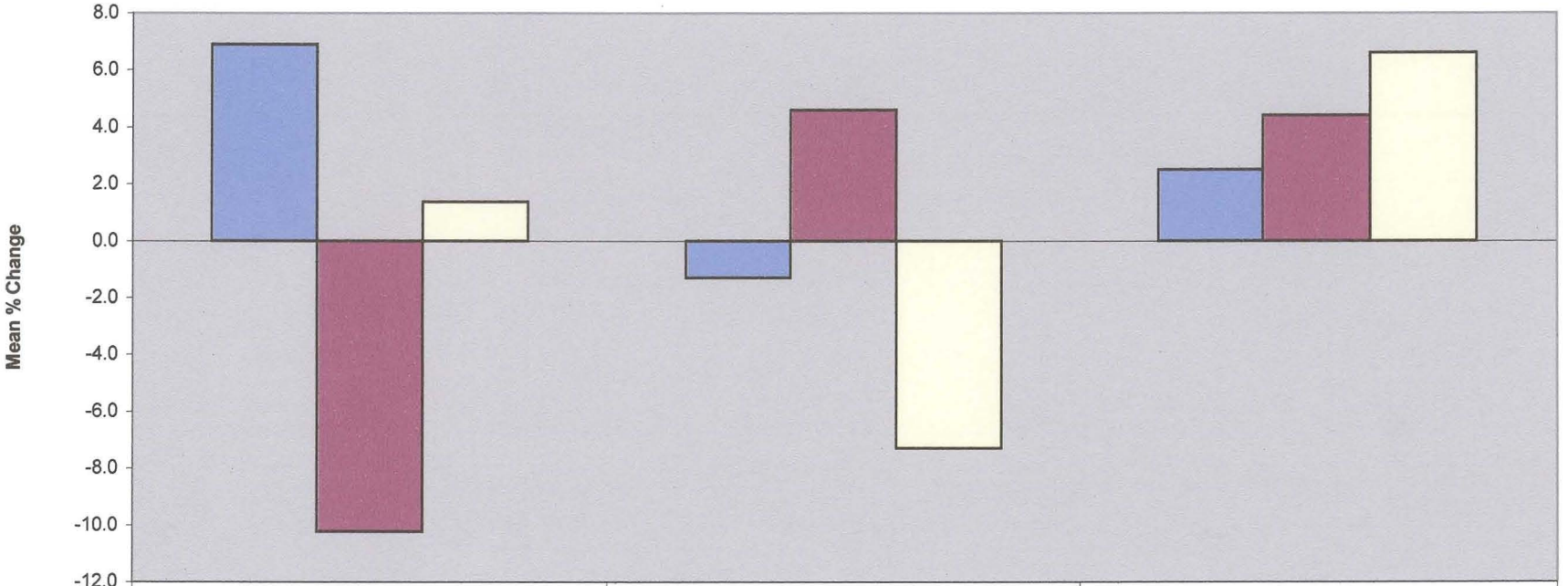
Cycle 1 (Low Dosage)

During this cycle Switch™ showed an increase of 1.4% in minute volume. This increase was possible due to an increase of 6% in tidal volume and a decrease of 4.7% in respiration rate. Cellfood® showed a decrease of 10.2% in minute volume. This was due to an increase of 1.8% in tidal volume but a decrease of 14.3% in respiration rate. The placebo showed an increase of 6.9% in minute volume. This increase was possible due to an increase of 7.2% in tidal volume and a decrease of 1% in the respiration rate. Switch™ was the more beneficial supplement during this cycle, but did not prove more beneficial than the placebo. There were, however, no statistically significant differences ($p>0.05$) in the changes between groups.

Cycle 2 (Intermediate Dosage)

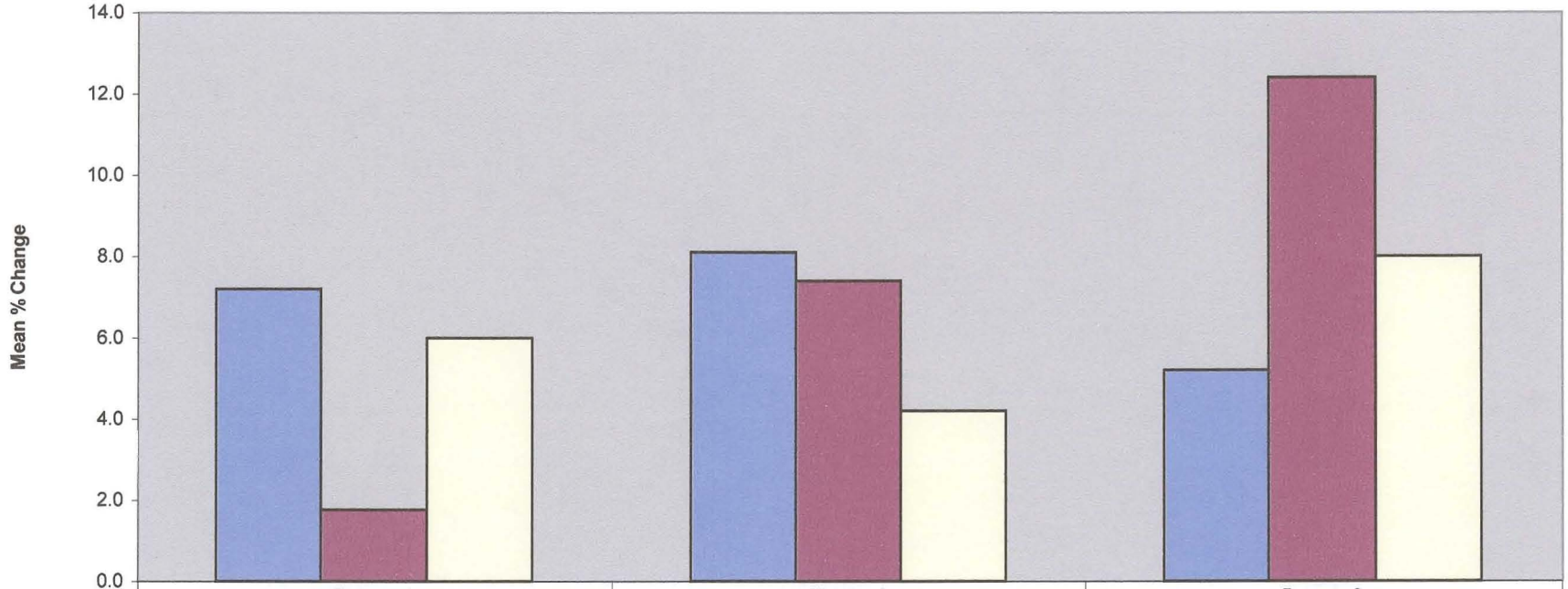
Cellfood® was the only group that showed an increase (4.6%) in minute volume during this cycle. This increase was possible due to an increase of 7.2% in tidal volume and a decrease of 3.6% in the respiration rate. Switch™ showed a decrease of 7.3% in minute volume. This was influenced by an increase of 4.2% in tidal volume but a decrease of 13.7% in the respiration rate. The placebo showed a

## FIGURE 4.16: MINUTE VENTILATION



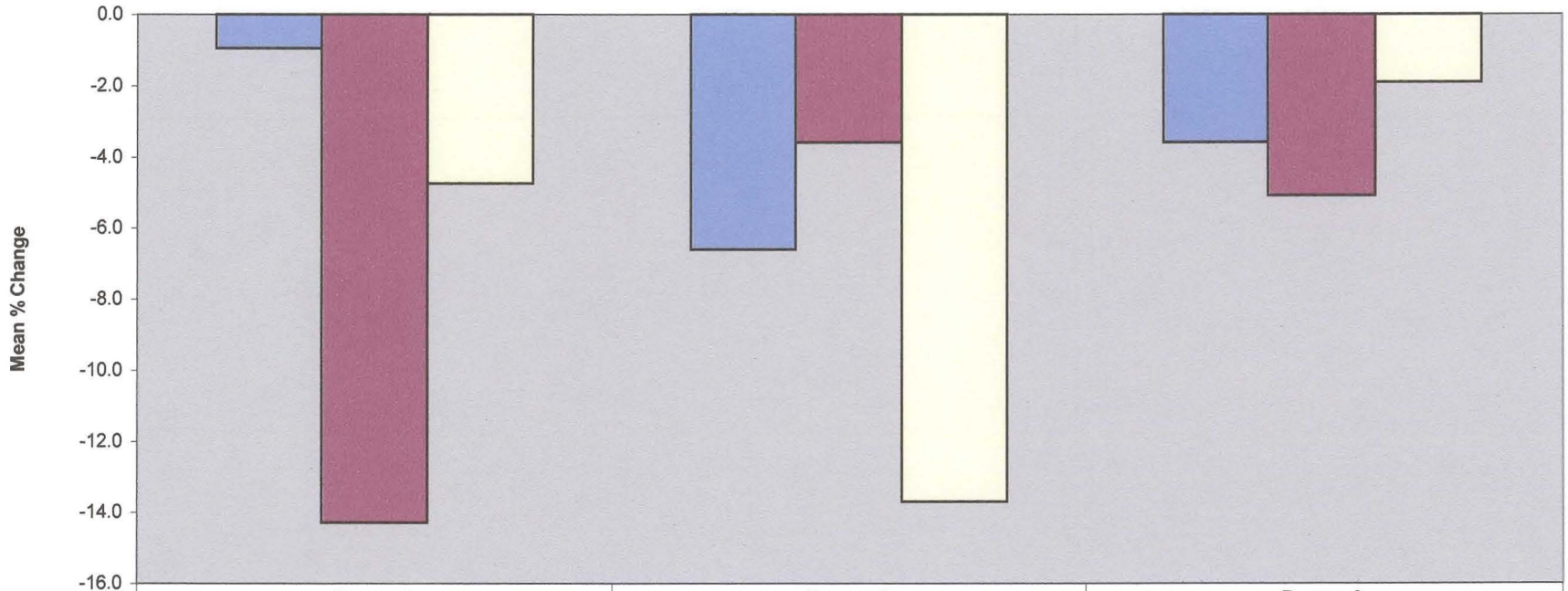

| | Dosage 1 | Dosage 2 | Dosage 3 |
|---|---|---|---|
| Placebo | 6.9 | -1.3 | 2.5 |
| Cellfood | -10.2 | 4.6 | 4.4 |
| Switch | 1.4 | -7.3 | 6.6 |

## FIGURE 4.17: TIDAL VOLUME




| | Dosage 1 | Dosage 2 | Dosage 3 |
|---|---|---|---|
| Placebo | 7.2 | 8.1 | 5.2 |
| Cellfood | 1.8 | 7.4 | 12.4 |
| Switch | 6.0 | 4.2 | 8.0 |

## FIGURE 4.18: RESPIRATION RATE




| | Dosage 1 | Dosage 2 | Dosage 3 |
|---|---|---|---|
| Placebo | -1.0 | -6.6 | -3.6 |
| Cellfood | -14.3 | -3.6 | -5.1 |
| Switch | -4.7 | -13.7 | -1.9 |

decrease of 1.3% in minute volume. This was influenced by an increase of 5.2% in tidal volume but a decrease of 3.6% in the respiration rate. Cellfood® was the most beneficial supplement during this cycle. There were, however, no statistically significant differences ($p>0.05$) in the changes between groups.

Cycle 3 (High Dosage)

Switch™ showed an increase of 6.6% in minute volume. This increase was established through an increase of 8.0% in tidal volume and a decrease of 1.9% in the respiration rate. Cellfood® showed an increase of 4.4% in minute volume. There was an increase of 12.4% in tidal volume and a decrease of 5.1% in the respiration rate. The placebo showed an increase of 2.5% in the minute volume through an increase of 5.2% in the tidal volume and a decrease of 3.6% in the respiration rate. Switch™ had the most beneficial effect on the minute volume during this cycle. There were, however, no statistically significant differences ($p>0.05$) in the changes between groups.

### 4.10.5 Maximal Oxygen Uptake ($V0_2$ max): Absolute (Figure 4.19) and relative (Figure 4.20) (Table VI B)

The components of the system and their interrelationship are as follows:

**$V0_2$ (oxygen transported) = SV x HR x a-$v0_2$ diff (arteriovenous oxygen difference)**

From the above equation we can derive that to maintain a certain $V0_2$ during exercise with lower comparative heart rates the subjects must either experience an increase in stroke volume or a increase in arteriovenous oxygen difference. Athletes who excel in endurance sports generally have a large capacity for aerobic energy transfer. The maximal oxygen consumption recorded for competitors in distance running are at most double those of sedentary men and woman. This is not to say that the $VO_2$ max is the only determinant of endurance performance. Other factors, principally those at local tissue level such as capillary density, enzymes, mitochondrial size and number, and muscle fibre type, exert a strong

influence on a muscle's capacity to sustain a high level of aerobic exercise (McArdle et al., 1996). The $VO_2$ max does, however, provide important information on the capacity of the long term energy system. In addition, this measure has significant physiological meaning in that attaining a high $VO_2$ max requires the integration of a high level of ventilatory, cardiovascular, and neuromuscular functions (McArdle et al., 1996). A healthy but sedentary adult male might have a $V0_2$ max of 35ml/kg/min. In a normal individual performing incremental exercise, $V0_2$ can increase by as much as sixteen-fold. $V0_2$ max is clearly related to the type of exercise performed. The prediction of normal $V0_2$ should therefore take into account exercise mode, gender, age, and body size (Cooper and Storer, 2001).

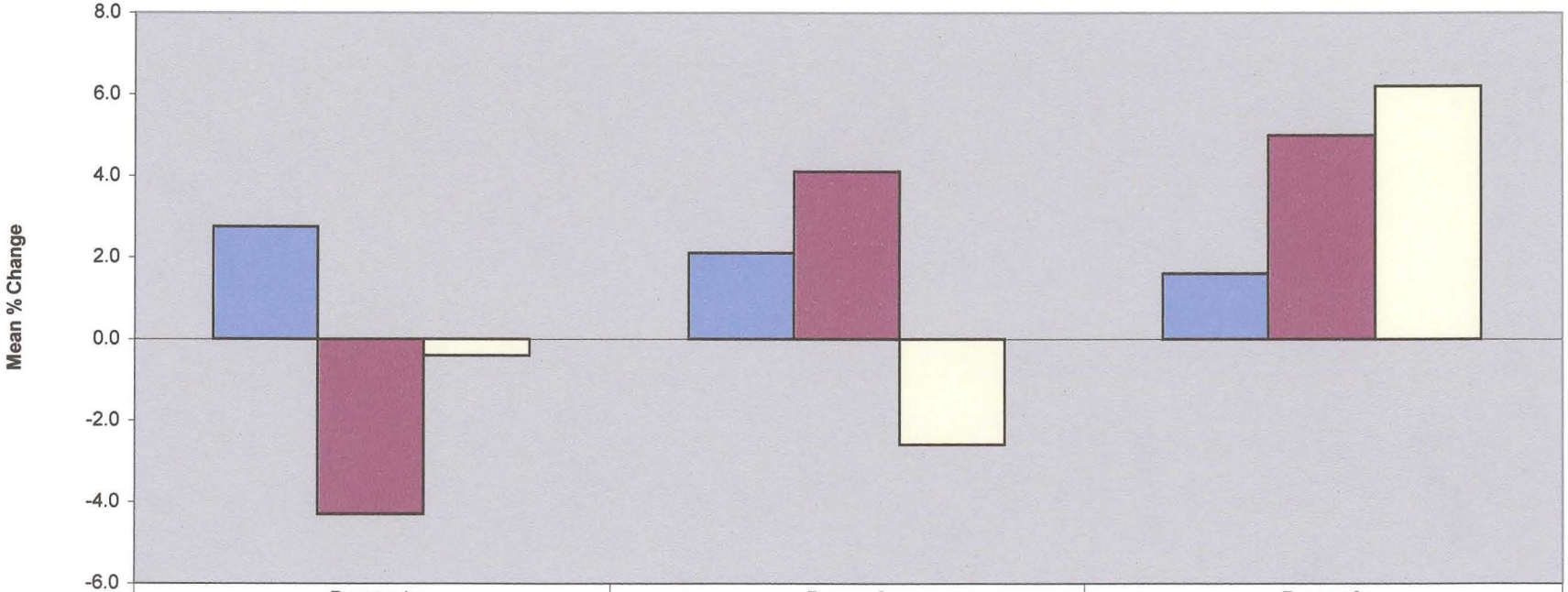
Cycle 1 (Low Dosage)

Switch™ showed a decrease of 0.4% in absolute $V0_2$max with an increase of 7.1% in relative $V0_2$ max. Cellfood® showed a decrease of 4.3% in absolute $V0_2$ max with an increase of 2.4% in relative $V0_2$ max. The placebo showed an increase of 2.7% in absolute $V0_2$ max and a decrease of 9.3% in relative $V0_2$ max. This indicates that neither Cellfood® nor Switch™ were effective in increasing the absolute $V0_2$ max although both supplements increased the relative oxygen consumption of the subjects. This is a anomalous trend that could only be explained when linking it to a decrease in body weight. There were, however, no statistically significant differences ($p>0.05$) in the changes between groups.

Cycle 2 (Intermediate Dosage)

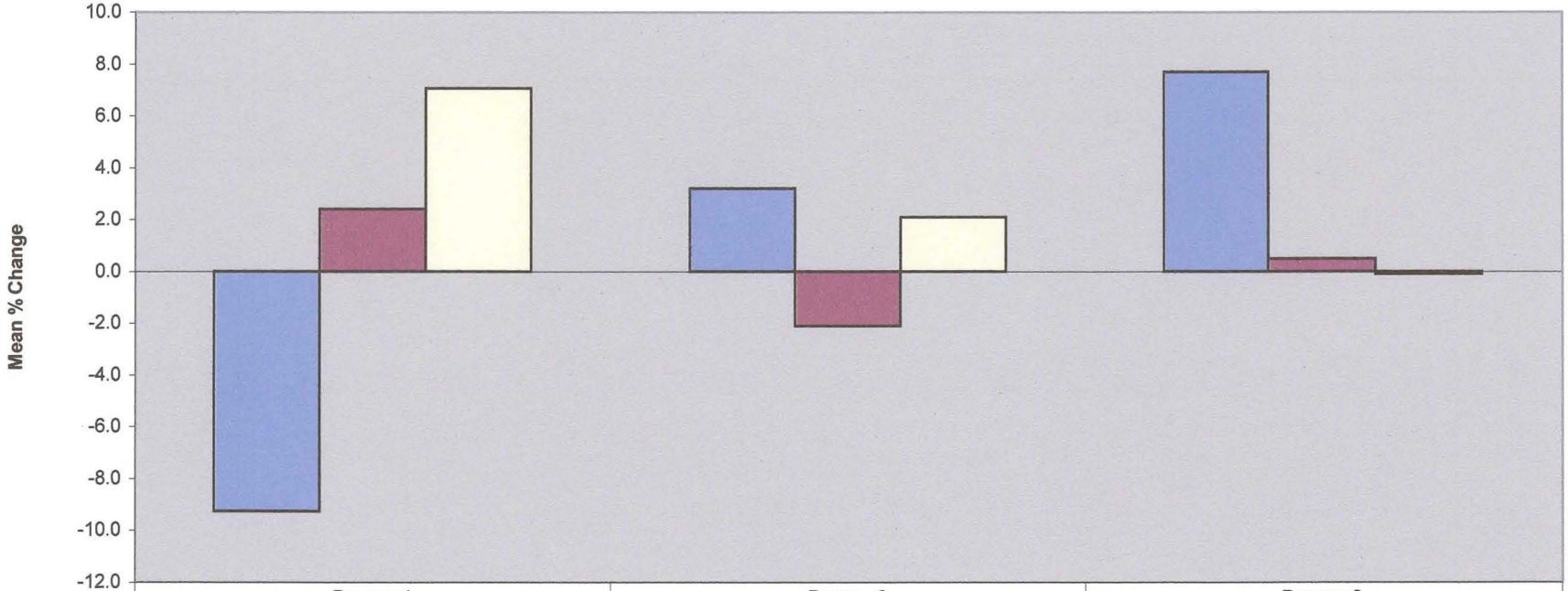
Cellfood® showed an increase of 4.1% in absolute $V0_2$ max but a decrease of 2.1% in the relative oxygen consumption. Switch™ showed a decrease of 2.6% in absolute $V0_2$ max but still an increase of 2.1% in the relative oxygen consumption. Placebo showed an increase of 2.1% in absolute $V0_2$ max with an increase of 7.7% in relative oxygen consumption. During this cycle Cellfood® was the most effective in increasing the absolute oxygen consumption. There were, however, no statistically significant differences ($p>0.05$) in the changes between groups.

## FIGURE 4.19: ABSOLUTE $V0_2$ MAX




| | Dosage 1 | Dosage 2 | Dosage 3 |
|---|---|---|---|
| Placebo | 2.7 | 2.1 | 1.6 |
| Cellfood | -4.3 | 4.1 | 5.0 |
| Switch | -0.4 | -2.6 | 6.2 |

## FIGURE 4.20: RELATIVE $V0_2$ MAX




| | Dosage 1 | Dosage 2 | Dosage 3 |
|---|---|---|---|
| Placebo | -9.3 | 3.2 | 7.7 |
| Cellfood | 2.4 | -2.1 | 0.5 |
| Switch | 7.1 | 2.1 | -0.1 |

Cycle 3 (High Dosage)

Switch™ showed an increase of 6.2% in absolute $V0_2$ max while the relative oxygen consumption decreased with 0.1%. Cellfood® showed an increase of 5.0% in absolute $V0_2$ max together with an increase of 0.5% in relative oxygen consumption. Placebo showed an increase of 1.6% in absolute $V0_2$ max, and an increase of 7.7% in relative oxygen consumption. Cellfood® was the most effective in increasing the absolute maximal oxygen consumption during this cycle. There were, however, no statistically significant differences ($p>0.05$) in the changes between groups. The within-group ergogenic improvement from base-line values of 5.0% in absolute $V0_2$max observed in Cellfood® was statistically significant ($p<0.05$).

## 4.11 Comparative Findings

In general, findings of this study showed that Cellfood® and Switch™ had ergogenic benefits in the following variables:

- Ferretin
- Haemoglobin
- Red blood cell count
- Hematocrit
- Glucose
- Pulse Oximetry
- RPE
- Heart Rate
- Lactate
- RER
- $VC0_2$
- $VE/VC0_2$
- $etC0_2$
- $VE/V0_2$
- $et0_2$
- VT
- RR

- Relative $V0_2max$

Considering that this was the first exercise-related study conducted on both Cellfood® and Switch™, directly comparative findings are not available. Therefore the only prudent approach is to integrate these findings with the literature by relating the performance of other ergogenic aids and methods that also claim similar benefits for those variables measured during this study.

**Haematology Related Ergogenic Aids**

- Iron Supplementation

  As the daily intake of iron, especially in females, is only marginally above that which is just sufficient to balance their normal daily iron losses, the additional iron losses caused by running may be sufficient to cause iron deficiency. Runners most likely to become iron deficient are those who run high weekly mileages; women runners who may loose large amounts of blood due to monthly menstruation; and those who eat iron-deficient diets. Foods that have a high iron content include liver, red meat, egg yolk, legumes, dark green leafy vegetables, molasses and whole grain. Vegetarians who eat no meat or eggs are considered to be particularly prone to iron deficiency. All these groups could benefit by eating more red meat, the dark meat of poultry, or liver, and by taking iron tablets orally if their blood haemoglobin levels are found to be sufficiently low to indicate that they might have iron-deficiency anaemia. Only if an athlete is found to have an iron-deficiency anaemia should iron therapy be considered. A drawback to iron therapy is that iron tablets tend to cause indigestion and constipation. Of the commercially available iron tablets, those least likely to cause problems are the "slow-release" forms and the iron chelates. Iron is best absorbed when taken with orange juice, this is due to the vitamin C present in the orange juice that aids in iron absorption (Noakes, 1992). Although neither Cellfood® nor Switch™ changed the ferretin values significantly, both of these supplements were effective in increasing the ferretin values of the athletes without any known detrimental side effects.

- Blood Doping

  Blood doping is one (illegal and dangerous) way of trying to increase the body's natural red blood cell counts. With the procedure, usually between 1 to 4 units of a person's own blood (autologos) are withdrawn, the plasma is removed and immediately reinfused, and the packed red cells are placed in frozen storage. To prevent a dramatic reduction in blood cell concentration, each unit of blood is withdrawn over a 3 to 8 week period because it generally takes this long for the person to re-establish normal red cell levels. The stored cells are reinfused 1 to 7 days before an endurance event. As a result, the red cell count and haemoglobin level of the blood is often elevated some 8 to 20%. Scientific studies of blood doping and endurance performance have produced conflicting results. Several studies have shown that blood doping increases endurance performance between 13% and 39% (measured by a treadmill run to exhaustion) and maximal oxygen consumption between 5% and 31% in both non-athletic and highly-trained endurance athletes (Belko, 1987; Ekblom et al., 1973; Ekblom et al., 1976). An equal number of studies (mostly from earlier literature), however, have found no effects of blood doping on endurance performance, maximal oxygen consumption, heart rate responses during exercise, or perceived exertion (Cunningham, 1978; Pate et al., 1979; Videman and Rytomaa, 1977). An examination of research design differences clarifies much of the conflicting evidence. Two critical factors became apparent: (1) when between 800 and 1200ml of blood, or its equivalent, is reinfused (as opposed to 450 to 500ml), aerobic capacity and endurance increases and (2) when 5 to 6 weeks elapse before reinfusion, "positive" results also are seen (Fox and Bowers, 1993).

- Erythropoietin

  Another technique for boosting red blood cells became apparent in the late 1980's. Erythropoietin (EPO), a hormone produced by the kidneys, stimulates the production of RBC's under conditions of hypoxia (chronic low oxygen tension in the blood) and anemia. It travels via the circulation to the bone marrow, where it stimulates the production of red cells. The rate of formation of new red cells, is in part determined by EPO. Injections

of EPO are very effective, athletes can expect enhancements in endurance performance of 5% or more (Sawka and Joyner et al., 1998; Birkeland et al., 2000). The benefits of this technique are similar to those achieved by blood doping. The non-therapeutic uses of EPO poses a significant health risk. The inappropriate use of EPO increases the thickness or viscosity of the blood so that the blood has difficulty passing through small blood vessels, in essence simulating the disease of erythrocythemia and polycythemia. When this increased viscosity effect is combined with the dehydration that is encountered in competitive athletics, the viscosity of the blood increases further, producing sludging of the blood in the vessels. At hematocrit above 55%, the blood viscosity increases exponentially, thereby substantially increasing the risk of a coronary artery occlusion or a cerebral artery occlusion. Similarly, occlusions can occur in other blood vessels producing other complications. With this in mind, it has been speculated that EPO may have contributed to the unusually high number of deaths that have occurred in competitive cyclists from the Netherlands and Belgium (MIMS, 1996; Fox and Bowers, 1993; McArdle et al., 1991; Noakes, 1992). Both Cellfood® and Switch™ were effective in increasing both red blood cell count and hematocrit values throughout the study. Theses increases never exceeded the normal physiological range and therefore is much safer than the previously mentioned techniques of blood doping and EPO.

**Metabolism Related Ergogenic Aids**

- Carbohydrate

Carbohydrate (CHO) loading is one of the more popular methods of nutritional modification used by endurance athletes to improve performance. It is also one of the most studied ergogenic aids for athletic performance (Walberg-Rankin, 1995). Although the judicious adherence to this dietary technique can significantly improve specific performances, there are also some negative aspects that could prove detrimental (McArdle et al., 1993). Reduction of body stores of carbohydrate and blood glucose is related to the perception of fatigue and the inability to maintain high-quality performance. This has been clearly shown with

aerobic, endurance events of moderate intensity of over 90 minutes duration. Carbohydrate intake may also have relevance for athletes involved in short, high-intensity events, especially if body weight control is an issue (Walberg-Rankin, 1995). The process of glycogen loading (carbohydrate loading) may be incorporated to elevate muscle glycogen stores above their normal resting levels prior to endurance competition (Fox and Bowers, 1993). Generally glycogen super-compensation is applicable where the athlete is continuously in motion for more than an hour at a time. Super-compensation may have value for events with an anaerobic component to the extent that lowered levels of glycogen can have adverse effects on lactate production (anaerobic power) (Fox and Bowers, 1993). Some recent studies further confirm that consumption of a high-carbohydrate diet for 2 or more days prior to an endurance event enhances performance relative to a low carbohydrate diet. For example, O'Keefe et al. (1989) found that 1 week on a 72% carbohydrate diet allowed cyclists to exercise at 80% of $V0_2$ max for 113 minutes, whereas they could only cycle 60 minutes when they consumed a 13% carbohydrate diet for the same period (Walberg-Rankin, 1995). Under circumstances where an athlete must perform multiple events in one day, super-compensation is appropriate. For these purposes one can simply increase the dietary intake of carbohydrates for 48 to 72 hours prior to competition. The practice of ingesting glucose 30 to 45 minutes before competition is not recommended. It can lead to a rapid fall in blood glucose levels with the onset of exercise and increase the rate of glycogen utilization. One other point of consideration is that with the storage of one gram of glucose about 2.7 grams of water will be taken into storage. Thus, with a storage of 700 gm of glucose an additional storage of about 1.9 kg of water will occur. An athlete should thus not be surprised to have a pre-competition weight gain, which may be an advantage or disadvantage depending on the event.

- Bicarbonate Loading ($NaHC0_3$)

  Blood doping is one known method to try and lower lactate levels in endurance athletes. It is now clear that blood doping reduces blood lactate

levels during exercise and alters the lactate turn point to higher running speeds. These effects are likely to be the more important explanations for the increased running performance after blood doping (Noakes, 1992). The ergogenic properties of $NaHC0_3$ ingestion have been the focus of various investigations (Verbitsky et al., 1997.; Matson and Tran, 1993). It has been shown that during short-term, high-intensity physical activity progressive metabolic acidosis due to lactic acid accumulation and a drop of pH takes place, in both the blood and working muscles (Verbitsky et al., 1997). The resultant accumulation of $H^+$ within the muscle directly inhibits the contractile process by inhibiting the release of $Ca^{2+}$ from the sarcoplasmic reticulum , as well as by reducing the activity of glycolytic enzymes, thus impairing the propagation of neural impulses. As exercise progresses, various buffering mechanisms function to neutralize this effect. Eventually, when the intracellular buffering capacity is exceeded, $H^+$ diffuse into the blood, causing a drop in extracellular pH. This, in turn, stimulates extracellular buffering mechanisms of which $HC0^-_3$ os one of the most effective constituents. It is thus expected that acute ingestion of $NaHC0_3$ should at this stage enhance the buffering capacity in the blood and hence delay exhaustion and improve performance (Verbitsky et al., 1997).

- L- Carnitine Loading

  L- Carnitine is a well-known supplement often used to try and lower lactate concentrations, it plays a role in regulating the balance between key chemicals in metabolic processes and is known to act as a buffer for pyruvate, thus reducing muscle lactate accumulation associated with fatigue (Armsey and Green, 1997). The possible mechanisms by which carnitine could have a positive effect include enhancing oxidation of fatty acids, a critical energy compound during exercise; preserving muscle glycogen during exercise, a factor potentially related to fatigue resistance; shifting fuel use towards glucose, thereby decreasing the oxygen requirement of exercise; improving resistance to muscle fatigue; and increasing the oxidative capacity of skeletal muscle (Phillips, 1997). It has been reported that after a period of carnitine supplementation, well-trained

subjects increased their maximal oxygen consumption. The key claim of this supplement is that it can enhance fat metabolism by increasing the transport of fat to its site of oxidation. Long-chain fatty acid oxidation in all tissues is carnitine dependent; therefore, hereditary and acquired carnitine deficiencies cause triglyceride to accumulate in the skeletal muscles, impair fatty acid utilization, and reduce exercise capacity. Carnitine supplementation can usually reverse these changes (Hawley, 1998). Neither Cellfood® nor Switch™ lowered lactate accumulation significantly during any cycles of the study, but it seems that when administered at the correct dosages, low dosage for Switch™ and the high dosage for Cellfood®, these supplements were effective in lowering lactate accumulation throughout the treadmill test.

**Oxygenation Related Ergogenic Aids**

- Oxygen Enriched Air

  It is common to observe athletes breathing oxygen-enriched or hyperoxic gas mixtures during times out, at half time, or following strenuous exercise. The belief is that this procedure significantly enhances the blood's oxygen carrying capacity and thus facilitates oxygen transport to the exercising muscles. The fact is however, that when healthy people breathe ambient air at sea level, the haemoglobin in arterial blood leaving the lungs is about 95 to 98% saturated with oxygen. Thus, breathing high concentrations of oxygen could increase oxygen transport by haemoglobin to only a small extent, i.e., about 1 ml of extra oxygen for every 100ml of whole blood. The oxygen dissolved in plasma when breathing a hyperoxic mixture would also increase slightly from its normal quantity of 0.3ml to about 0.7ml per 100ml of blood. Thus, the blood's oxygen-carrying capacity under hyperoxic conditions would be increased potentially by about 1.4ml of oxygen for every 100ml of blood, with 1.0ml extra attached to hemoglobin and 0.4ml extra dissolved in plasma (McArdle et al., 1996). Regardless, there is a rather large body of information indicating that breathing oxygen-enriched air (33 to 100% oxygen) has a beneficial effect

on exercise performance (Allen and Pandolf, 1977; Hughes et al., 1968; Miller, 1952). Oxygen breathing during both light and heavy exercise has resulted in reduced blood lactic acid levels, heart rates, ventilation volumes, and a significant increase in maximal oxygen consumption.

- $HB0_2$

  Hyperbaric oxygen is another method of oxygen therapy well known to sport. Professional athletes have reportedly received hyperbaric oxygen before sports participation, believing that performance would improve. Contradictory findings have been reported regarding the effect of a single hyperbaric oxygen treatment on aerobic performance. A Yugoslavian study (Staples and Clement, 1996), demonstrated that hyperbaric oxygen prior to treadmill running to volitional exhaustion increased peak running velocity and maximal oxygen consumption when measured 30 minutes and 3 hours post treatment. $HB0_2$ was administered for 60 minutes at 2.8 ATA. Enhanced performance and $V0_2$ max were attributed to additional oxygen storage in skeletal muscle. However to their knowledge, this link has yet to be definitely established (Delaney, 2001). In contrast, two recent studies (James et al., 1993; Potera, 1995), reported no change in submaximal and maximal exercise performance following hyperbaric oxygen therapy. Both Cellfood® and Switch™ were effective in increasing the haemoglobin concentration of the athletes throughout the study. These increases never exceeded the normal physiological ranges for the variable. The increased haemoglobin concentration together with an increase in haemoglobin saturation (although not significant at all running speeds) could benefit the athlete in an increased oxygen delivery throughout the body and working muscles.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

The primary aim of the study was to determine the efficacy of both Cellfood® and Switch™ as ergogenic aids for endurance athletes. In order to reach this goal a pre-test – post-test, double-blind cross-over, placebo controlled experimental design, was adopted for the study. Accordingly subjects were randomly assigned to either a placebo, Cellfood® or Switch™ group.

Each of the groups underwent a supplementation period comprising three four-week cycles of varying dosages, as recommended by the manufacturer. After each cycle the subjects stopped supplementation during a two-week washout period, prior to crossing over to an alternative supplementation and dosage cycle.

Accordingly the groups were arranged as follows over the duration of the study:

| **Cycle 1** | | |
|---|---|---|
| **Group** | **Product** | **Dosage** |
| **A** | Placebo | 28ml |
| **B** | Cellfood® | 28ml |
| **C** | Switch™ | 53.2ml |
| **Cycle 2** | | |
| **Group** | **Product** | **Dosage** |
| **A** | Cellfood® | 39.2ml |
| **B** | Switch™ | 78.4ml |
| **C** | Placebo | 39.2ml |
| **Cycle 3** | | |
| **Group** | **Product** | **Dosage** |
| **A** | Switch™ | 91.7ml |
| **B** | Placebo | 44.8ml |
| **C** | Cellfood® | 44.8ml |

Cellfood® is a proprietary super energized complex concentrate held in colloidal suspension. It is ingested orally in the form of fluid droplets added to water. It contains 78 trace elements and minerals, combined with 34 enzymes, 17 amino acids, dissolved and nascent oxygen, suspended in a solution of deteurium sulphate ($D_2SO_4$ ). Cellfood® is unique due to its ability to create nascent oxygen or "newly born" oxygen (Latin- Nascere). In biochemical terms nascent oxygen refers to this newly born single oxygen (elemental oxygen) that has not yet entered into biochemical reaction. Nascent oxygen is negatively charged ($O^-$) Free radicals on the other hand are positively charged ions of single oxygen ($O^+$). The opposite charge of these ions cause them to attract each other, forming a single pure oxygen molecule ($O_2$). Nascent oxygen "seeks out" and neutralizes dangerous free radicals, combining to form pure oxygen in the process.

Switch™ consists of the same ingredients as those found in Cellfood® but with two added substances mainly aimed at the mobilization of fat as energy source . The first substance being Citrin K and the second being L-Carnitine. Citrin-K is a herbal extract from the Garcinia Cambogia fruit plant and contributes 25% to the total Switch™ make up. L-Carnitine is a nutrient produced naturally in the liver and contributes 20% to the total Switch™ make up. A 100ml bottle of Switch™ contains about two months supply at 20 drops per serving. Each of these servings contains: 250mg Cellfood® proprietary blend; 110mg Citrin K; and 90mg L- Carnitine.

Cellfood® and Switch™ are liquid concentrates, taken by mixing a number of drops in a quarter of a glass of distilled of filtered water. Due to the oral ingestion of these aids one would have to classify them as nutritional aids, with hyper-oxygenation of the cellular environment as their proposed ergogenic mechanism of action.

The following dependent variables were measured:

- Haematology:
  - Ferretin values
  - Haemoglobin
  - Red blood cell count
  - Hematocrit
  - Fasting glucose

- Pulse oximetry
- Rate of perceived exertion
- Heart rate
- Capillary blood lactate concentrations
- Oxygen utilization and related spirometry:

  - RER
  - $VC0_2$
  - $VE/VC0_2$
  - $etC0_2$
  - $VE/V0_2$
  - $et0_2$
  - VE
  - VT
  - RR
  - $V0_2$ max (Absolute)
  - $V0_2$ max (Relative)

## 5.1 SPECIFIC RECOMMEDATIONS FOR PRACTICE

Based on the results of this study, endurance athletes who use Cellfood® or Switch™ with the aim of receiving an ergogenic effect should note that, when considering the efficacy of the products across all dosages:

**Cellfood® vs. Placebo**

Placebo was significantly ($p<0.05$) more effective than Cellfood® in the following variables measured:

- Haemoglobin concentration (first cycle, low dosage)
- Hematocrit (first cycle, low dosage)
- Haemoglobin saturation at 17km/h (third cycle, high dosage)
- Heart rate at 10km/h (third cycle, high dosage)

Cellfood® was no more effective ($p>0.05$) than placebo in the following variables measured:

- Red Blood Cell count
- RER
- VE
- $VC0_2$
- Absolute $V0_2max$
- Relative $V0_2max$

Cellfood® tended to be more effective than placebo, but not significantly so ($p>0.05$), in the following variables measured:

- Ferretin
- Glucose
- Pulse Oximetry
- RPE
- Heart Rate
- Lactate
- $VE/VC0_2$
- $etC0_2$
- $VE/V0_2$
- $et0_2$
- VT
- RR

Cellfood® was only significantly ($p<0.05$) more effective than placebo in the following variables measured during the following cycles:

- Haemoglobin (second cycle, intermediate dosage)
- Hematocrit (second cycle, intermediate dosage)

**Switch™ vs. Placebo**

Placebo was significantly ($p<0.05$) more effective than Switch™ in the following variables measured:

- Heamoglobin saturation at 17km/h (third cycle. high dosage)
- Heart rate at 10km/h (third cycle, high dosage)

Switch™ was no more effective ($p>0.05$) than placebo in the following variables measured:

- Ferretin
- $etC0_2$
- VE
- VT
- Absolute $V0_2max$

Switch™ tended to be more effective than placebo, but not significantly so ($p>0.05$), in the following variables measured:

- Glucose
- Pulse Oximetry
- RPE
- Heart Rate
- Lactate
- RER
- $VC0_2$
- $VE/VC0_2$

- $VE/V0_2$
- $et0_2$
- RR
- Relative $V0_2max$

Switch™ was only significantly ($p<0.05$) more effective than placebo in the following variables measured during the following cycles:

- Haemoglobin (first cycle, low dosage)
- Red Blood Cell Count (first cycle, low dosage)
- Hematocrit (first cycle, low dosage)

**Cellfood® vs. Switch™**

The only significant ($p<0.05$) differences between Cellfood™ and Switch™ were as follows:

- Cellfood® was significantly ($p<0.05$) more effective in increasing haemoglobin concentration than Switch™ during the second cycle at an intermediate dosage.
- Cellfood® was significantly ($p<0.05$) more efffective in increasing hematocrit than Switch™ during the second cycle at an intermediate dosage.
- Cellfood® was significantly ($p<0.05$) more efffective in increasing haemoglobin saturation at 17km/h than Switch™ during the third cycle at a high dosage.
- Cellfood® was significantly ($p<0.05$) more efffective in decreasing heart rate at 10km/h than Switch™ during the third cycle at a high dosage.
- Switch™ was significantly ($p<0.05$) more effective in increasing red blood cell count than Cellfood® during the first cycle at a low dosage.
- Switch™ was significantly ($p<0.05$) more effective in increasing hematocrit than Cellfood® during the first cycle at a low dosage.

- Switch™ was significantly ($p<0.05$) more effective in increasing haemoglobin concentration than Cellfood® during the first cycle at a low dosage.

In conclusion there are two notable observations to be made which may be considered limitations to the findings of this study. The treadmill testing protocol used during the study generally lasts maximally up to 20 minutes, depending on the fitness and potential of the athlete. A sub-maximal test protocol, of greater duration, with fat stores being the predominant energy source, could have provided a superior result for Switch™ due to it containing L-Carnitine and Citrin K, which aid in the mobilization of fat as energy source. In retrospect it appears as if the two-week wash-out period between cycles may not have been sufficient to negate the benefits experienced during the supplementation with the products. The possibility of a carry-over benefit of the preceding product to the subsequent cycle was a possibility. This may have unfounded some of the comparative between-group analyses.

## 5.2 FUTURE RESEARCH DIRECTIONS

Further research evaluating the efficacy of Cellfood® and Switch™ would be prudent in the following contexts:

- Pre-tests to confirm base-line values at the start of each new cycle;
- Wash-out periods of at least four weeks to ensure no carry-over benefits of subsequent products;
- Acute effects of Cellfood® and Switch™ on the performance of the endurance athlete;
- Possible advantages of Cellfood® and Switch™ for the anaerobic athlete;
- Dosage response of Cellfood® and Switch™ according to bodyweight.
- Determination of an upper "threshold" dosage, where-after the beneficial effects of these supplements may decline.
- Increased fat store utilization through the use of Switch™.

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UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

University of Pretoria

# INFORMED CONSENT

I, .....(full name of prospective participant), submit myself herewith to the services and facilities of the Sports Research Institute of the University of Pretoria (hereafter referred to as the UNIVERSITY), for the purpose of an official research project dealing with the use of Cellfood® and Switch® [manufactured by the Nu Science Corporation, Vitality Plus (Pty) Ltd and Oxygen for Life (Pty) Ltd] as potential ergogenic aids to endurance athletes.

I have been informed of the possible risks and benefits of participation and hereby declare that I participate in the said research project at my own risk.

I hereby declare that there is no information withheld by myself or by the parties listed above that could exclude me from participating in this research project and am aware that I may withdraw from the study at any time if I should wish.

I furthermore authorize the UNIVERSITY to publish and use any of my data forthcoming from the research project with my anonymity being guaranteed, and declare that I have no claim to any remuneration or compensation there from.

Signed at .....on this.....day of.....2000

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Signature of the prospective participant

Tel: (h)..... (w)..... .....
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WITNESSES:

1. .....

2. .....

APPENDIX B

**UNIVERSITY OF PRETORIA : RESEARCH PROJECT**

**INDIVIDUAL SCHEDULE FOR :**

| CYCLE : 1 | | SAMPLE : A | |
|---|---|---|---|
| DAY | | DATE | DROPS |
| 01 | TUE | 31 OCT | 4 |
| 02 | WED | 1 NOV | 5 |
| 03 | THU | 2 NOV | 6 |
| 04 | FRI | 3 NOV | 7 |
| 05 | SAT | 4 NOV | 8 |
| 06 | SUN | 5 NOV | 9 |
| 07 | MON | 6 NOV | 10 |
| 08 | TUE | 7 NOV | 11 |
| 09 | WED | 8 NOV | 11 |
| 10 | THU | 9 NOV | 11 |
| 11 | FRI | 10 NOV | 11 |
| 12 | SAT | 11 NOV | 11 |
| 13 | SUN | 12 NOV | 11 |
| 14 | MON | 13 NOV | 11 |
| 15 | TUE | 14 NOV | 11 |
| 16 | WED | 15 NOV | 11 |
| 17 | THU | 16 NOV | 11 |
| 18 | FRI | 17 NOV | 11 |
| 19 | SAT | 18 NOV | 11 |
| 20 | SUN | 19 NOV | 11 |
| 21 | MON | 20 NOV | 11 |
| 22 | TUE | 21 NOV | 11 |
| 23 | WED | 22 NOV | 11 |
| 24 | THU | 23 NOV | 11 |
| 25 | FRI | 24 NOV | 11 |
| 26 | SAT | 25 NOV | 11 |
| 27 | SUN | 26 NOV | 11 |
| 28 | MON | 27 NOV | 11 |
| 29 | TUE | 28 NOV | - |
| 30 | WED | 29 NOV | - |
| 31 | THU | 30 NOV | - |
| 32 | FRI | 1 DEC | - |
| 33 | SAT | 2 DEC | - |
| 34 | SUN | 3 DEC | - |
| 35 | MON | 4 DEC | - |
| 36 | TUE | 5 DEC | - |
| 37 | WED | 6 DEC | - |
| 38 | THU | 7 DEC | - |
| 39 | FRI | 8 DEC | - |
| 40 | SAT | 9 DEC | - |
| 41 | SUN | 10 DEC | - |
| 42 | MON | 11 DEC | - |

| CYCLE : 2 | | SAMPLE : B | |
|---|---|---|---|
| DAY | | DATE | DROPS |
| 43 | TUE | 12 DEC | 8 |
| 44 | WED | 13 DEC | 9 |
| 45 | THU | 14 DEC | 10 |
| 46 | FRI | 15 DEC | 11 |
| 47 | SAT | 16 DEC | 12 |
| 48 | SUN | 17 DEC | 13 |
| 49 | MON | 18 DEC | 14 |
| 50 | TUE | 19 DEC | 15 |
| 51 | WED | 20 DEC | 15 |
| 52 | THU | 21 DEC | 15 |
| 53 | FRI | 22 DEC | 15 |
| 54 | SAT | 23 DEC | 15 |
| 55 | SUN | 24 DEC | 15 |
| 56 | MON | 25 DEC | 15 |
| 57 | TUE | 26 DEC | 15 |
| 58 | WED | 27 DEC | 15 |
| 59 | THU | 28 DEC | 15 |
| 60 | FRI | 29 DEC | 15 |
| 61 | SAT | 30 DEC | 15 |
| 62 | SUN | 31 DEC | 15 |
| 63 | MON | 1 JAN | 15 |
| 64 | TUE | 2 JAN | 15 |
| 65 | WED | 3 JAN | 15 |
| 66 | THU | 4 JAN | 15 |
| 67 | FRI | 5 JAN | 15 |
| 68 | SAT | 6 JAN | 15 |
| 69 | SUN | 7 JAN | 15 |
| 70 | MON | 8 JAN | 15 |
| 71 | TUE | 9 JAN | - |
| 72 | WED | 10 JAN | - |
| 73 | THU | 11 JAN | - |
| 74 | FRI | 12 JAN | - |
| 75 | SAT | 13 JAN | - |
| 76 | SUN | 14 JAN | - |
| 77 | MON | 15 JAN | - |
| 78 | TUE | 16 JAN | - |
| 79 | WED | 17 JAN | - |
| 80 | THU | 18 JAN | - |
| 81 | FRI | 19 JAN | - |
| 82 | SAT | 20 JAN | - |
| 83 | SUN | 21 JAN | - |
| 84 | MON | 22 JAN | - |

| CYCLE : 3 | | SAMPLE : C | |
|---|---|---|---|
| DAY | | DATE | DROPS |
| 85 | TUE | 23 JAN | 20 |
| 86 | WED | 24 JAN | 22 |
| 87 | THU | 25 JAN | 24 |
| 88 | FRI | 26 JAN | 26 |
| 89 | SAT | 27 JAN | 28 |
| 90 | SUN | 28 JAN | 30 |
| 91 | MON | 29 JAN | 32 |
| 92 | TUE | 30 JAN | 35 |
| 93 | WED | 31 JAN | 35 |
| 94 | THU | 1 FEB | 35 |
| 95 | FRI | 2 FEB | 35 |
| 96 | SAT | 3 FEB | 35 |
| 97 | SUN | 4 FEB | 35 |
| 98 | MON | 5 FEB | 35 |
| 99 | TUE | 6 FEB | 35 |
| 100 | WED | 7 FEB | 35 |
| 101 | THU | 8 FEB | 35 |
| 102 | FRI | 9 FEB | 35 |
| 103 | SAT | 10 FEB | 35 |
| 104 | SUN | 11 FEB | 35 |
| 105 | MON | 12 FEB | 35 |
| 106 | TUE | 13 FEB | 35 |
| 107 | WED | 14 FEB | 35 |
| 108 | THU | 15 FEB | 35 |
| 109 | FRI | 16 FEB | 35 |
| 110 | SAT | 17 FEB | 35 |
| 111 | SUN | 18 FEB | 35 |
| 112 | MON | 19 FEB | 35 |
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**DIRECTIONS:**

**Upon waking, prepare ¼ glass of Distilled Water. Shake the Product Sample bottle, and carefully squeeze the prescribed number of DROPS allocated for that DAY and DATE into the water. When pressing the flip top open and closed, do this over the glass of water to prevent any possibility of the product staining clothing, etc.**

**Stop taking any product from DAYS 29 to 42; and from DAYS 71 to 84. The Project is completed after DAY 112. Please return any unused product after each Cycle. Once you have taken the product for a particular day, please cross it off the schedule.**