

**THE EFFECTS OF A SUPPLEMENTARY HIGH INTENSITY MUSCLE ENDURANCE
RESISTANCE TRAINING PROGRAMME ON COMRADES MARATHON
PERFORMANCE**

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Submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in
Human Movement Science in the Faculty of Science and Agriculture at the University
of Zululand

Date submitted: 15 January 2007

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DEDICATION

To all the Comrades Marathoners, who are the unsung heroes of sport.

ACKNOWLEDGEMENTS

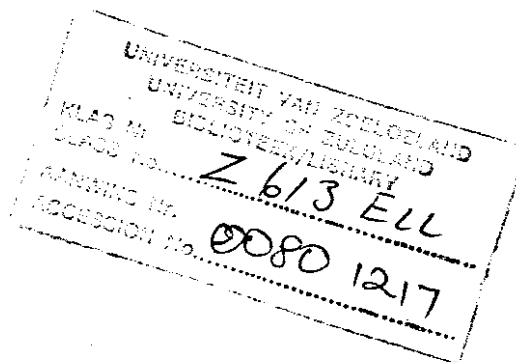
I would like to record my appreciation to the following people who assisted in various ways with this study:

A special tribute to the Almighty God;

thank you to my Mum, Dad, Noeleen, Cathy and Malcolm;

thank you to my promoter, Professor M.F. Coetsee, for his guidance, patience and constructive criticism, and to

Dr. C Roux for his interest, encouragement and support.




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TO WHOM IT MAY CONCERN

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

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ABSTRACT

In this study, the aim was to determine the effects of a high intensity muscle endurance resistance intervention programme as a supplement to normal running training for Comrades Marathoners. A sample voluntary population of 115 subjects were initially distributed at random into two groups of approximately equal size, namely the control (CT) group and the experimental (RST) group. Originally, the CT group constituted 57 subjects, whilst the RST group constituted 58 subjects. However, four subjects from the CT and one subject from the RST group failed to complete the pre-intervention test battery, thereby eliminating themselves from the study. The sample size was therefore reduced to 110 subjects, resulting in 53 subjects in the CT group and 57 in the RST group. Subjects were males between the ages of 25 to 50 years who had successfully completed a minimum of five Comrades Marathons (at least three up runs and two down runs). All subjects completed a PAR-Q as well as an informed consent form prior to participating in the pre-intervention test battery. The pre-and post-intervention test batteries comprised of physical characteristics measurements (age, body mass, height, body fat percentage and percentage of fat-free mass) and physical performance measurements (10km run, 400m-sprint, Wingate anaerobic cycle test, one-minute sit-up test, one-minute press-up test and lower back-leg dynamic strength test).

The pre-intervention test battery results indicated comparable, non-significant ($p > 0.05$) differences between the control and experimental groups' physical

characteristics and physical performance parameters. The statistical analyses of the control and experimental groups' previous Comrades Marathon completion times proved to be non-significantly ($p > 0.05$) different and therefore comparable. Subsequent to the pre-intervention test battery, the experimental group was subjected to the intervention programme for 34 weeks. The experimental group completed the intervention programme twice a week in addition to their normal marathon running training, whilst the control group continued with their normal Comrades Marathon running training. Thereafter both the groups underwent the post-intervention test battery.

The control group's post-intervention physical characteristics and physical performance parameters remained relatively similar, with non-significant ($p > 0.05$) differences. The control group's average 10km run time was non-significantly ($p > 0.05$) reduced by 2.1%. The experimental group experienced significant ($p < 0.05$) changes to both their physical characteristics and physical performance parameters. These changes included: a post-intervention decrease of percentage of body fat by 22.6%; an increase of percentage of fat-free mass by 4.8%; a reduction of 10km run time by 12.1%; a reduction of 400m-sprint time by 28.5%; an increase in Wingate anaerobic cycle test results by 16.3%; an improvement in one-minute sit-up test results by 27.8%; an improvement in one-minute press-up test results by 32.4%; an increase of lower body dynamic strength by 28.9%; and, most importantly, a reduction in their Comrades Marathon completion times by 9.2%. In addition to this, the intervention programme helped the experimental group to reduce their 21.1km and 42.2km

completion times. The intervention programme increased the structural/musculoskeletal joint integrity and stability of the members of the experimental group. It is proposed that the increased structural/musculoskeletal joint integrity and stability reduced the total incidence of overuse injury experienced by the experimental group by 43.3% as compared to the control group. In conclusion, the study demonstrated that the high intensity muscle endurance resistance programme that was used to supplement the primary running training of Comrades Marathon runners (experimental group) did help improve their Comrades Marathon completion times.

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CHAPTER ONE: INTRODUCTION

- 1.1 Introduction**
- 1.2 Aims of the study**
- 1.3 Objectives of the study**
- 1.4 Purpose of the study**
- 1.5 Null Hypotheses**
- 1.6 Assumptions**
- 1.7 Delimitations**
- 1.8 Limitations**
- 1.9 Definitions and abbreviations**
- 1.10 Summary**

CHAPTER ONE

INTRODUCTION

1.1 Introduction

A chilly 24th of May 1921 heralded the start of the Comrades Marathon legacy. Initially 30 entrants started the race from Pietermaritzburg Town Hall en route to complete the race in West Street, Durban. Bill Rowan was the first to complete this arduous journey in a time of eight hours and fifty-nine minutes. This race came about through the vision and persistence of Vic Clapham. Vic Clapham conceived the idea of commemorating those who had fallen during World War I by means of a race between Pietermaritzburg and Durban. Traditionally, a runner needed to complete the race within 11 hours. At the turn of the new millennium, however, the completion time was extended to 12 hours.

Walsh (2001) describes the Comrades Marathon as follows:

"The Comrades' marathon is the greatest ultra marathon race in the world. Annually thousands of Comrades runners stand packed and primed under a pale moon sky, ready to conquer this ultimate ultra marathon. The Comrades marathon's 87.6km route expands through the primeval valleys and burotic habitation, gentle, undulating farmlands, which roll off into a haze of hills, incorporating a certain charm. An epic battle plays off in these serene hills:

will the aspiring Comrades runner be victorious and tame this savage ultra marathon or would she destroy the entrapped chancier, who dares to challenge her majesty?"

Man's desire to achieve his optimal potential in athletic performance has initiated research in the field of ergogenics. Ergogenics refers to the application of a physical, nutritional, mechanical, psychological and pharmacological procedure or aid to improve work capacity or athletic performance (McArdle, et al., 1996). This inherent desire to improve has also played a part in motivating this study, which focuses on one of the disciplines of ergogenics, namely the application of a different training mode as a supplementary training technique to enhance a primary training mode, in this case as applied to the running training of Comrades Marathon runners – for the purpose of enhancing their performance.

1.2 Aim of the study

The investigation into the application of a high-intensity muscle endurance resistance training intervention programme as a supplement to the primary running training of Comrades Marathon runners is aimed at improving their running performance. Subjects of the experimental group adhered to a structured intervention exercise programme for an entire Comrades Marathon athletic training season comprised of 34 weeks. The findings of the study will not only improve the quality of life of endurance runners but promises to

benefit their performances in the Comrades Marathon as well as in other long distance endurance runs.

1.3 Objective of study

- ◆ To determine the effect of high intensity muscle endurance resistance training as a supplement to the primary running training of Comrades Marathon runners for an entire season.
- ◆ To determine whether this type of cross-training for endurance runners reduces risk of injury.

1.4 Purpose of the study

- ◆ To document the effects of a structured high intensity muscle endurance resistance training intervention programme as a supplement to a Comrades Marathon runner's primary run training, with the aim of improving Comrades Marathon running performance.
- ◆ To stimulate interest amongst Comrades Marathon runners to employ high intensity muscle endurance resistance training in order to supplement their run training.
- ◆ To document whether the intervention exercise programme reduces the incidence of injury that normally befalls Comrades Marathon runners.

1.5 Null Hypotheses

- Adherence to a high intensity muscle endurance resistance training intervention exercise programme as a supplement to the normal endurance running training of Comrades Marathon runners would not produce an improvement in their completion times.
- The physical characteristics of the experimental group after completion of the intervention exercise programme would not differ from that of the control group.
- Adherence to the high intensity muscle endurance resistance intervention exercise programme would not increase the experimental group's aerobic performance (10km run).
- Adherence to the high intensity muscle endurance resistance training intervention exercise programme would not increase the experimental group's short-term energy system performance (400m sprint-test).
- Adherence to the high intensity muscle endurance resistance training intervention exercise programme would not change the capacity of the immediate energy transfer system of the experimental group (Wingate anaerobic cycle test).
- Adherence to the high intensity muscle endurance resistance training intervention exercise programme would not change the abdominal muscular strength and endurance (one-minute sit-up test) of the experimental group.
- Adherence to the high intensity muscle endurance resistance training intervention exercise programme would not change upper body muscular

strength and endurance (one-minute press-up test) of the experimental group.

- Adherence to the high intensity muscle endurance resistance training intervention exercise programme would not change lower limb dynamic strength of the experimental group.
- Adherence to the high intensity muscle endurance resistance training intervention exercise programme would not reduce the incidence of injuries amongst the experimental group.

1.6 Assumptions

It was assumed that the subjects were always fully motivated and that they performed at their very best during all phases of the study.

1.7 Delimitations

The following delimitations were imposed on the study:

- The sample group was restricted to endurance runners who had previously successfully completed the Comrades Marathon in less than eleven hours.
- Endurance runners from athletic clubs in the surrounding areas of Durban were recruited to participate in the study.
- The sample group was comprised of male subjects.

- The sample group was limited to individuals between the ages of 25 to 50 years.
- The sample group was restricted to Comrades Marathon finishers who had officially completed a minimum of three up runs (from Durban to Pietermaritzburg) and two down runs (from Pietermaritzburg to Durban). This eliminated the possible effects of the learning curve that runners undergo during the initial few years of running the Comrades Marathon.
- The subjects had to continue with their regular Comrades Marathon running training as in previous years.

1.8 Limitations

- A key limitation was the issue of change in the health status of subjects and the way in which this influenced adherence to the exercise programme. Injuries sustained by runners during their training in preparation for the Comrades Marathon could affect their Comrades Marathon performance.
- Poor health or injuries sustained on the day of Comrades Marathon 2005 may have influenced subjects' performance.
- Environmental conditions have in the past influenced Comrades Marathon runners' performance. High humidity levels and temperatures do increase the loss of body fluids during the Comrades Marathon, resulting in dehydration. Rain on the day of the Comrades Marathon would also have an influence on the speed at which the runners run. Low temperatures on

the day of the Comrades Marathon can also adversely affect running performance.

- Although seasoned runners were eligible to participate in the study, the anxiety of completing the Comrades Marathon in a shorter period of time could affect the psychological state of runners during the race. Such an impeded psychological state would have a negative impact on the performance of Comrades Marathon runners.
- Lack of adherence to advice regarding nutritional and fluid supplementation could have had a negative effect on the performance of Comrades Marathon runners. The inability to individually monitor each runner's supplementation was also a limitation.

1.9 Definitions and Abbreviations

In this section the terms used in the study are defined.

Aerobic energy transfer system

This refers to a metabolic system involving a series of chemical reactions that require oxygen to break down food and produce adenosine triphosphate (Kent, 1994).

Anaerobic energy transfer system

This is a metabolic system that produces adenosine triphosphate without the need for oxygen (Kent, 1994).

Hyponatraemia

An abnormal, low concentration of sodium ions in the blood plasma, which may be caused by imbibing too much water, particularly after excessive sweating (Kent, 1994).

Fartlek running

This is a relatively unscientific blend of exercise and relief/recovery intervals, which is executed in an outdoor terrain (either cross country or road) (Beachle and Earle, 2000).

Lactic acid energy transfer system

An energy system in which adenosine triphosphate is manufactured from the breakdown of glucose into pyruvic acid, which is then converted to lactic acid in a process called anaerobic glycolysis (Kent, 1994).

Lactate threshold

The level of exercise at which the blood lactate level begins to increase (Kent, 1994).

Maximal oxygen consumption

The maximal amount of oxygen that a person can extract from the atmosphere and which can be transported to the tissues for their usage. Maximal oxygen consumption is quantitatively equivalent to the maximum amount of oxygen that can be consumed per unit time by an

individual during large muscle group activity of progressively increasing intensity that is continued until exhaustion (Kent, 1994).

Muscular strength

The muscular force or tension that a muscle group can exert on resistance in a maximal effort (Kent, 1994).

Muscular endurance

The ability of a muscle or a muscle group to perform repeated isotonic or isokinetic contractions, or sustain isometric contraction against a moderate resistance for an extended period of time (Kent, 1994).

Abbreviations used in the study are defined below in order to lend clarity to the concepts discussed.

CT

In this study CT will refer to the control group.

BMR

Basal metabolic rate (Kent, 1994).

PAR-Q

Physical activity readiness questionnaire (Kent, 1994).

RST

In this study RST will refer to the experimental group.

VO₂max

Maximal oxygen uptake (Kent, 1994).

1.10 Summary

The first chapter has served to clarify the need for this study and has defined the rationale of the study. The scope of the research has been clearly delimited and selected, relevant terms have been defined.

CHAPTER TWO: REVIEW OF LITERATURE

2.1 Introduction

2.2 Traditional Comrades Marathon training programme

2.2.1 Long slow distance running (LSD)

2.2.2 Fartlek run training

2.2.3 Hill training

2.2.4 Recovery runs

2.2.5 Physiological aerobic adaptations of the traditional Comrades Marathon training programme

2.3 Supplementary training

2.3.1 Resistance training

2.3.2 Speed run training

2.3.3 The effects of deep water running (DWR) on endurance running

2.3.4 The effects of plyometric training on endurance running

2.3.5 Conclusion of supplementary training on endurance running

2.4 Factors affecting the preparation of the Comrades Marathoner

2.4.1 Muscle injuries

2.4.2 Ligament injuries

2.4.3 Bone injuries

2.4.4 Overuse injuries

2.4.5 Upper respiratory tract infections

2.4.6 Environmental factors

**2.5 Factors affecting the performance of Comrades Marathoners
on race day**

2.5.1 Musculoskeletal injuries

2.5.2 Environmental conditions

2.5.3 Nutritional factors

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Introduction

Literature that relates to the study will be reviewed and discussed in this section. The successful completion of the Comrades Marathon requires completion of the mandatory preparatory fitness components that are necessary to attain an efficient level of running fitness and a strong musculoskeletal system, which prevents the incidence of injuries whilst simultaneously enhancing running biomechanics. This chapter attempts to examine the various training methods that assist endurance runners to successfully run the Comrades Marathon. Current discourse focusing on factors that affect the Comrade's marathoner's preparation as well as aspects that affect performance on race day will be examined. It is necessary, however, to first focus on the distinction between a marathon and the Comrades Marathon.

In order to complete a marathon, an endurance runner needs to run 42.2km over a specific route, whilst an endurance runner participating in the Comrades Marathon, more specifically needs to complete 87.6km on a route that stretches from Durban to Pietermaritzburg, or from Pietermaritzburg to Durban, in order to realise his/her goal. The Comrades Marathon is

considered to be a short ultra-marathon (Williamson, 2006). An ultra-marathon is any distance greater than 42.2km. The difference between the training of a marathoner and an ultra-marathoner lies in the frequency of the long slow distance runs. Ultra-marathoners generally do not run epic distances in their preparations for ultra-marathons. Instead, they complete numerous long slow distance runs varying from 21km to 35km to reach peak condition.

Williamson (2006) suggests that a marathoner needs to complete two ultra-marathon training runs (approximately 52km each) in preparation to complete the Comrades Marathon. Most marathoners complete the above stipulation in their normal marathon training by completing one ultra-marathon race and their club's Comrades Marathon route run.

2.2 Traditional Comrades Marathon training programme

Five percent of all Comrades Marathoners run within the seven hours and thirty minutes time limit that is required to secure a silver medal (Walsh, 2001). These Comrades Marathoners' training programmes vary considerably from the other 95% of the Comrades Marathoners, who meet the Bill Rowan (sub 9 hours), bronze (sub 11 hours) and Vic Chapman (sub 12 hours) time limits to secure the respective medals (Walsh, 2001). The cohort's completion times in this study varied between 10 and 11 hours. The training methods that these Comrades Marathoners adhered to were long,

slow distance (LSD), Fartlek, uphill and recovery runs. These four run training methods is referred to as the traditional Comrades Marathon training programme (Yeager, 2004). The different applications of these training methods by marathoners justify the different Comrades Marathon completion times. Bill Rowan medallists tend to apply each of these run training methods individually. However, there is a tendency among the slower Comrades Marathoners not to distinguish between the four training methods. The slower Comrades Marathoners tend to combine the different run training methods, which are practised with marginal variation in running speed (Fordyce, 1996). These runners divide their LSD run into sections. In each section they complete a different training method. The major criticism for this training method is the absence of appropriate effort during the application of each training method. The main objective of the traditional programme is to develop endurance. Marathoners adhering to the traditional programme are able to run the Comrades Marathon, but not race the Comrades Marathon. A description of each training method according to the traditional programme follows.

2.2.1 Long slow distance running (LSD)

The traditional programme's primary component is LSD. Long slow distance running can be described as continuous low intensity running for an extended period of time. This training method is a prerequisite for any endurance runner attempting to complete the Comrades Marathon because it allows the marathoner to train at nearly race pace for a prolonged period of time. This

training method places emphasis on raising the heart rate to levels of 60% to 80% of maximal heart rate, which equates to running speeds varying from 40% to 60% of VO_{2max} (Swain, 1994). Fordyce (1996) advises Comrades Marathoners to run their LSD slower than marathon race pace (approximately 60 to 75 seconds slower per kilometre) in order to increase muscle endurance.

Marathoners and ultra-marathoners must complete LSD runs varying from 32-35 km when preparing for the Comrades Marathon. Noakes (2001) is of the opinion that a marathoner's aerobic capacity is sufficiently developed by the time he/she has completed a distance 30-32km. Any additional distance beyond 32km is unlikely to bring further significant aerobic improvement. Further running will produce hypoglycaemia and muscle degeneration (Noakes, 2001). Hermansen, (1971) reported that trained marathoners are capable of running at 60-70% of their VO_{2max} for 32km without experiencing hypoglycaemia and that the minimal muscle degeneration which they experienced did not have a significant effect on their endurance running performance. However further running did produce hypoglycaemia and severe muscle degeneration that adversely affected their running performance (Hermansen, 1971).

A common practise employed amongst marathoners and ultra-marathoners is to complete a long slow distance run (of 32km) supplemented the next day with another long slow run (of 20km). According to Williamson (2006) the supplementation of two long slow distance runs on consecutive days,

educates the runner to continue running with tired legs (thereby increasing the marathoner's fatigue resistance and self-confidence). However it is advisable for endurance runners to rest for four to seven days after completing a long slow run (Walsh, 2001). This rest time allows the marathoner to recover adequately after the long run (both physiologically and psychologically).

Much research has been conducted on the impact of LSD on marathoners' performance. The limitations of LSD are:

- Chillag (1986) reports that frequent LSD is responsible for the following haematological disorders: gastrointestinal bleeding, runner's haematuria, runner's haemolysis, ammorhea and anaemia. All of these conditions adversely affect endurance running performance due to marathoners' inability to properly prepare for marathons or to perform optimally on race day.
- Frequent LSD produces type I muscle fibre and peripheral nerve degeneration. Sjostrom, et al. (1987) propose that the higher type I muscle fibre degeneration is due to the higher recruitment of these fibres during long slow distance running, consequently resulting in over-use muscle fibre strains. The peripheral nerve damage is attributed to the repetitive pounding of the marathoner's feet onto the ground. Kuiper (1996) and Krieder (1998) report that 10 – 20% of marathoners who complete frequent long slow distance running experience symptoms of over-training syndrome (muscle soreness, poor performance and muscle fatigue) which reaffirms the theory of Sjostrom, et al. (1987).

- Sjostrom, et al. (1987) claim that frequent LSD causes progressive muscle damage, which reduces the power output of the damaged muscles of the lower limb. The damaged musculature of the lower limb experience a reduction in capability to store and release elastic energy during the push-off stage of the running gait. This reduction in the force generated during the push-off stage produces a shorter stride length, which covers a smaller distance. In order for the marathoner to maintain a constant running speed, he or she would have to increase stride frequency. The increase in stride frequency, however, also increases energy consumption.
- Another of the negative effects of frequent long slow distance running is that marathoners and ultra-marathoners tend to become accustomed to slow running speeds in ultra marathon distances and therefore run all distances at the same ultra-marathon running speed (Higdon, 2006).

Methods of alleviating problems created by frequent slow long distance running:

- Periodisation of running programme into micro-cycles of eight weeks. In the first four weeks of the micro-cycle the runner must progressively increase the distance of long slow run to eventually reach a distance of 32km (e.g. week 1 – 15km, week 2 – 20km, week 3 – 25km and week 4 – 32km). Thereafter the runner must employ the same progressive decrease in distance from week five to eight. This will ensure adequate muscle recovery from these long runs (Higdon, 2006).
- Massage therapy for fatigued muscles (Fordyce, 1996).

- Rest (Noakes, 2001).
- Reduction in the volume and frequency of LSD. A comparative investigation by Dolegner, et al. (1994) with regard to the effects of varying the frequency and volume of long slow distance running on marathon performance, indicates that a 20% decrease in the volume and frequency of LSD with adequate rest produces similar marathon results as frequent running without rest.
- Shorter, faster run training methods to increase running speed. Berg, et al. (1989) report that the substitution of frequent LSD with interval run training enables trained marathoners to run at a higher percentage of $VO_2\text{max}$ for a longer period of time by increasing the lactate threshold, lactate removal rate and oxygen extraction from blood. These training adaptations enhance endurance running performance.

2.2.2 Fartlek run training

This is a relatively unscientific blend of exercise and relief/recovery intervals, which is executed in the outdoor terrain (either cross country or road). The runner may typically predetermine the route. However, the pace is varied spontaneously from fast running to slow jogging according to the terrain and the disposition of the runner (Beachle and Earle, 2000). The runner determines the training intensity (exercise interval) based on how he/she feels at that moment (rate of perceived exertion). As a result, the runner is able to manipulate the training session to incorporate as many exercise intervals and

recovery intervals as required. Exercise intervals may vary from 100m to one kilometre, whilst recovery intervals may vary from 400m to two kilometres (Williamson, 2006).

The regular application of this training method will enable the Comrades Marathoner to vary his running pace during the race, which will ensure a faster completion time. The alternation of fast/slow running speeds will assist the marathoner to make up lost time, or time spent walking or running at a slower pace. Towards the end of the Comrades Marathon a runner may need to run at a fast speed for one or two kilometres to ensure that he/she completes the marathon within a specific time limit. Fartlek training enables the marathoner to complete this task.

2.2.3 Hill training

Hill training can be divided into two categories, i.e. uphill run training and downhill run training. However the cohorts of this study only completed uphill run training.

2.2.3.1 Uphill run training

Uphill run training alternates a series of spurts of moderate to high paced running uphill, with low paced running down the hill. The duration of the session and distance of the hill that is covered depend on the runner.

Variation in the gradient of the hill determines the following benefits to the runner:

- The steeper the hill, the more emphasis falls on developing muscle strength;
- in the case of less steep hills, more emphasis is placed on developing speed;
- the longer the hill distance, the more emphasis is placed on developing muscle endurance and improving running biomechanics, and
- the shorter the hill, the more emphasis is placed on developing muscle power (Williamson, 2006).

Uphill run training empowers the Comrades Marathoner to run the uphill of the race at a steady pace, thereby preventing loss of time. This steady uphill running pace allows the Comrades Marathoner to maintain a constant running speed throughout the race. Fordyce (1996) and Noakes (2001) attribute regular uphill training to a successful Comrades Marathoners' performance. Common problems associated with uphill training are the increased incidence of running injuries (e.g. ankle sprains, knee damage and muscle spasms). Noakes (2001) attributes the prevalence of delayed onset of muscle soreness (DOMS) amongst marathoners (after the Comrades Marathon) to the absence of regular downhill run training. Comrades Marathoners in this category fail to adequately prepare for the large portion of downhill in the Comrades Marathon.

2.2.4 Recovery runs

Recovery runs should exist in every training schedule. These runs are performed at very a slow running pace over short distances, after a strenuous fast running session. The purpose of a recovery run is to increase blood circulation in order to remove metabolic waste products from the muscles and to transport nutrients to muscles, thereby allowing muscle rebuilding and strengthening to occur quicker. The benefit of a recovery run is best felt at the marathoner's next fast running session (Williamson, 2006). A common flaw amongst Comrades Marathoners is the failure to execute adequate numbers of recovery runs, therefore they experience over-training syndrome. Most Comrades Marathoners run slightly faster than their Comrades Marathon pace on all short runs (including the recovery runs) and slightly slower than marathon pace on long runs. Ideally they should be running significantly slower on long runs and much faster on short runs, except for their recovery runs, which must be run extremely slow (Fordyce, 1996).

Many runners' adapt their run training programme by changing the sequence of the different training sessions (Fordyce, 1996 & Williamson, 2006). The above run training methods allows the endurance runners to successfully complete the Comrades Marathon by improving their aerobic capacity. These aerobic capacity adaptations occur as a result of metabolic, cardiovascular and pulmonary changes. A discussion concerning the metabolic, cardiovascular and pulmonary changes is presented hereunder.

2.2.5 Physiological aerobic adaptations of the traditional Comrades Marathon programme

2.2.5.1 Metabolic Adaptations

The traditional Comrades Marathon training programme improves the marathoner's skeletal muscles' respiratory capacity. The aerobically trained skeletal muscles contain larger and more mitochondria than sedentary muscles. The aerobic training enlarges the mitochondrial structural machinery, which greatly increases the capacity of the sub-sarcolemmal and inter-myofibrillar muscle mitochondria to generate ATP aerobically (Martin, 1997). These changes enhance enzymatic activity, which facilitate rapid aerobic production of ATP. Endurance training increases a runners' capacity to utilize fatty acids more efficiently during sub-maximal running, as a result of:

- Increased blood flow within the muscle,
- More fat mobilizing and fat metabolising enzymes,
- Enhanced muscle mitochondrial respiratory capacity, and
- Blunted catecholamine release for the same absolute power output (Martin, 1997).

This enhanced fat catabolism benefits endurance runners by conserving the glycogen stores during ultra marathon running. Improvements in fatty acid beta-oxidation and respiratory ATP production contribute to maintaining cellular integrity and high level of function. The reduced carbohydrate use as

an energy fuel decreases muscle glycogen use and reduced production (and use) of plasma-borne glucose. Fatty acid oxidation combined with reduced carbohydrate metabolism contributes to blood glucose homeostasis and improved endurance capacity following endurance run training. Endurance run training stimulates metabolic adaptations in each muscle fibre type. The basic muscle fibre type does not change, rather the endurance run training maximises their existing aerobic potential. However, selective muscle hypertrophy does occur to some extent in endurance runners, thereby allowing them to possess more slow twitch fibres than fast twitch fibres. Slow twitch muscle fibres are predominately stimulated in aerobic type activity. As a result of an increased proportion of slow twitch muscle fibres possessed by endurance runners, they have a higher percentage of myoglobin (as slow twitch fibres have higher percentage of myoglobin molecules than fast twitch fibres). Myoglobin molecules have binding sites for oxygen, which increases the amount of oxygen available for aerobically generating ATP (McArdle, et al., 1996). Therefore a higher percentage of myoglobin enhances Comrades Marathon performance.

2.2.5.2 Cardiovascular Adaptations

Endurance run training produces significant dimensional and functional cardiovascular adaptations, which enhances cardiovascular function. The cardiovascular aerobic training-induced adaptations include:

- The marathoner's heart mass and volume generally increases with prolonged endurance run training. The enlarged size of the heart is reflected by an increase in the size of the left ventricle (consequent to the training induced plasma volume expansion) and the thickening of the ventricular walls (Hickson, 1985).
- The marathon runner's plasma volume increases, which enhances circulatory reserve and increases end-diastolic volume, stroke volume, oxygen transport and temperature regulation during exercise (Hagberg, 1998).
- Endurance runners experience an increase in stroke volume because of an increase in the internal left ventricle volume and mass, reduced cardiac stiffness, increased diastolic filling time (due to the training induced bradycardia), and the improved intrinsic cardiac contractile function (Krip, 1997).
- Regular aerobic activity also decreases the intrinsic stimulation of the sinoatrial node, producing bradycardial resting and submaximal heart rates (Schaefer, 1992).
- Regular marathon and ultra-marathon training increases the runner's cardiac output. Cardiac output is the product of stroke volume and heart rate. The increased maximal cardiac output is due to the training induced stroke volume, regardless of the bradycardia. Once trained marathoners have attained maximal cardiac output, they would need to increase their ability to extract oxygen from the blood. Failure to improve oxygen extraction would result in a limited availability of

oxygen to their working skeletal muscles during running (Ekblom, 1969).

2.2.5.3 Pulmonary Adaptations

Aerobic training stimulates significant adaptations in pulmonary ventilation during submaximal exercise. These adaptations are generally reflected by a reduced energy cost for respiration. Marathoners experience a reduced ventilatory equivalent for oxygen during submaximal exercise (Casaburi, 1987). The reduced ventilatory cost is attributed to greater ventilatory efficiency. This reduction of ventilatory musculature energy cost decreases the overall energy expenditure of endurance running, thus improving the marathoner's running economy. The reduced ventilatory cost is attributed to the marathoner's improved ability to extract oxygen more efficiently from haemoglobin and myoglobin, without requiring an increase in cardiac output. This reduced ventilatory musculature oxygen consumption enhances marathon running because it reduces the fatiguing effect of prolonged submaximal exercise on the ventilatory musculature and increases the availability of oxygen to the active skeletal muscles (McConnell and Semple, 1996).

Poorly trained Comrades Marathoners may experience inspiratory muscle fatigue during prolonged submaximal high intensity exercise. Poorly trained marathoners rely heavily on their cardiac output to increase the delivery of

oxygen to their working skeletal muscles. Increased cardiac output places stress on the cardio-respiratory system's functioning, which in turn requires increased ventilation. Increased ventilation causes a greater workload to be placed on the ventilatory muscles. This increases the energy cost of ventilation and increases the total energy cost of running, which reduces the exercise respiratory efficiency – that, in turn, leads to poor exercise performance. However, regular aerobic training increases the inspiratory muscle capacity to generate more force and sustain a given level of inspiratory pressure (Johnson, 1996). Johnson (1996) proposes that the following training adaptations benefit exercise performance in the following ways:

- Reduces overall exercise energy demand because of less respiratory work,
- Reduces lactate production by ventilatory muscles during high intensity, prolonged exercise, and,
- Enhances the ability of ventilatory muscles to mobilize circulating lactate as metabolic fuel.

2.3 Supplementary training

Run training in isolation accomplishes one of the prerequisites of the Comrades Marathon preparation. However the optimal Comrades Marathon performance requires the combination of speed, power, and muscle strength and endurance. Marathoners who were in search of the perfect Comrades

Marathon performance bear witness to the many benefits that can be gained from supplementary exercises (Fordyce, 1996; Higdon, 2006 & Williamson, 2006). The inclusion of supplementary training into a run training schedule adds variety, fun and enjoyment. It liberates the marathoner from the monotony of continuous running. Supplementary training such as resistance training has been instrumental in the development of specific muscle strength (Marcinik, et al., 1991 & Millet, et al., 2002), in rehabilitation of injuries and in the correction of muscle imbalances (Brukner and Khan, 2000 & Noakes, 2001). The discussion on supplementary training below serves to identify the various supplementary training methods, as well as their benefits to Comrades Marathoners. These supplementary training methods include resistance training, speed run training, deep water running and plyometric training.

2.3.1 Resistance training

The term resistance training includes body building, weight lifting, circuit training and weight training. Body building produces muscle hypertrophy, which increases the runner's body mass (something a Comrades Marathoner should not have in excess). An increase in a runner's body mass would require more energy to transport that body over the Comrades Marathon route. Energy expenditure investigations demonstrate that heavier runners (with greater body mass) expend more energy to run a given distance at a given velocity than runners with lower body mass (Passmore and Dumin,

1955). Generally, greater energy cost is incurred by heavier marathoners, inhibiting them from running at faster speeds for prolonged periods of time, thereby increasing their marathon and ultra-marathon completion times (Dennis and Noakes, 1999 & Saunders, et al., 2004). The objective of any marathoner is not to increase muscle bulk but rather to increase muscle strength and endurance.

Weight lifting concentrates on increasing the one repetition maximum (1RM) or the maximum amount of mass that can be lifted in a single attempt, whilst endurance running is concerned with a series of muscle movements performed at a steady rate over a prolonged time. Therefore weight lifting is of limited benefit to the Comrades Marathoner (Williamson, 2006).

Circuit training is a form of resistance strength training in which a series of exercises are performed using resistance strength training equipment in a predetermined sequence. In most circuit training programmes, eight to twelve different exercises are executed, usually at intensities equivalent to 40% to 60% of their 1RM (one repetition maximum) for the specific muscles. Brief workout bouts incorporating 20 repetitions of each exercise are alternated with predetermined rest periods, during which time the person moves to the next station (Allen, et al., 1976; Harris and Holly, 1987 & Haennel, et al., 1989).

Weight training is a type of strength training in which a series of exercises are performed using resistance strength training equipment. However, the rest

intervals between exercises are not limited by time, but rather by the person's perceived rate of exertion. Therefore the person could have unequal rest intervals in a single weight training session. In this study weight training will be referred to as resistance training. Marcinik, et al. (1991) and Millet, et al. (2002) report that circuit training and resistance training develops muscle strength and muscle endurance amongst trained marathoners and triathletes.

Traditionally, an endurance runner's performance was determined by running biomechanics, $VO_2\text{max}$ and lactate threshold (Tanaka & Swensen, 1998 & Jung, 2003). Improvements in the above mentioned areas were considered to have been achieved primarily by endurance run training. Therefore the effects of resistance training on marathoners' running biomechanics, $VO_2\text{max}$ and lactate thresholds will be discussed in an attempt to determine the effects of resistance training on endurance running.

2.3.1.1 The effects of resistance training on running biomechanics

All runners have their own distinctive running style. Running economy is typically described as the amount of energy required to run at a given sub maximal speed. Factors affecting a person's running economy are their particular running biomechanics, body mass and any abnormal musculoskeletal activity. Marathoners who possess a lower body mass expend less energy to run a given distance at a given speed and therefore consume less oxygen as compared to marathoners with high body mass who

require more energy to run the same distance at the same running speed, resulting in increased oxygen consumption (Passmore and Durnin, 1955 & Saunders, et al., 2004). Both VO_2max and running economy determines running performance, i.e. both have to be high for high performance. In a cohort of runners with similar VO_2max (50-55ml/kg/min), the running economy would be the determining factor. However, a runner with a VO_2max of 40 ml/kg/min with excellent running economy will never beat a runner with 60 ml/kg/min with poor running economy.

Many runners possess abnormal musculoskeletal activity, such as excessive pronation, excessive supination, leg length discrepancy, and a tendency for the upper body to lean forward, thus producing a crouched running appearance, rounded shoulders, small strides, etc. These abnormal musculoskeletal activities produce inefficient running biomechanics, which increase energy expenditure. Poor running biomechanics (e.g. excessive pronation, excessive supination, leg length discrepancy, upper body leaning forward producing a crouched running appearance, rounded shoulders, small strides, dropped head, rounded shoulders, externally rotated feet and a shuffling gait) increase the runner's energy expenditure, which produces slower running speeds (Hogbrog, 1952; Heinert, 1988 & Hauswirth, 1999). Slower running speeds produce slow race completion times. Efficient running biomechanics allow the runner to expend less energy per stride, thereby producing an energy-sparing effect. This conserved energy is used to help the runner to run faster (Nelson and Gregor, 1976; Heinert, 1988; Minetti, 1994; & Hauswirth, 1999). Improving a runner's inefficient biomechanics

decreases energy consumption, which in turn produces better running performance.

Abnormal musculoskeletal activity producing poor or inefficient running biomechanics is often related to muscle imbalances and muscle asymmetry. Regular endurance running tends to strengthen and shorten gluteus muscle, hamstrings and calf muscles (Williamson, 2006). This creates muscle asymmetry, which produces inefficient running biomechanics, consequently increasing energy expenditure. Correcting these muscle imbalances to their appropriate agonist/antagonist muscle ratio would include strengthening and stretching the effected muscles, thereby leading to efficient running biomechanics. Efficient running biomechanics require less energy expenditure, which allows for greater speed and reduced susceptibility to injury.

Resistance training has been shown to improve running economy in trained endurance runners. There are several proposed mechanisms that promise to improve running economy.

- Fordyce (1996); Brukner and Khan (2000) and Noakes (2001) advocate the principle that resistance strength training helps runners to maintain an efficient running posture. These structural strengthening exercises assist runners to acquire better muscle symmetry. The symmetrical muscle balance induces a more effective agonist/antagonist muscle relationship, which leads to better or more efficient running biomechanics (Brukner and Khan, 2000). Johnson, et

al. (1995) have reported that core and upper body strength training delay the onset of fatigue in the upper limbs, upper body and postural musculature during endurance running, thereby maintaining efficient running biomechanics, which facilitates faster running performances. Resistance strengthening of surrounding musculature (agonist, antagonist and stabilizer muscles) of joints enhances their co-activation and contraction, which improves running biomechanics and eventually produces faster running (Kyrolainen, et al., 2001).

- Dolezal and Potteiger (1998) & Jung (2003) propose that resistance training improves a marathoner's running economy by increasing the force generated by the muscles, which allows the runner to complete a given distance quicker at the same frequency. Dolezal and Potteiger (1998) hypothesize that the key component to improved running economy is the ability to store and recover elastic energy from muscle contractions, which increase the force generated by the muscles. The greater force generated per stride produces an optimal stride length, which allows the runner to complete a given distance quicker at the same stride frequency, subsequently reducing his energy expenditure, thus leading to running biomechanical efficiency.
- Kyrolainen, et al. (1991); Johnston, et al. (1997); Paavolainen, et al. (1999) and Chtara, et al., (2005) claim that resistance training enhances running economy due to the improvements in neuromuscular characteristics. The term neuromuscular characteristics, refers to interaction between the nervous system and the muscular system.

Resistance training elicits more efficient neural activation of muscle fibres, which produce more forceful muscle activity (muscle contraction). The more efficient neural activation of muscle fibres produce quicker nerve firing, motor unit recruitment and motor unit synchronization, which facilitate stronger more forceful muscle contraction.

- Saunders et al. (2004) theorize that resistance training increases muscle strength and endurance of the lower limb, which increases the dynamic stability of the lower limb joints, thereby decreasing the amount of energy expended to brake on the landing of the foot during the end of the swing phase. The conserved elastic braking energy is stored and added to the muscle contraction to generate a stronger elastic force during the push-off phase. This stronger elastic force produces a longer, but optimal stride length, which covers a greater distance – thereby allowing the marathoner to cover a greater distance in one stride at a less energy cost.

The above literature indicates that resistance training does improve running economy, which improves endurance running (Dolezal and Pottegier, 1998; Johnson, et al., 1995; Fordyce, 1996; Brukner and Khan, 2000; Noakes, 2001 & Saunders, et al., 2004). However the literature review also identifies the absence of research examining the effects of resistance training on the actual running economy of marathoners during a marathon. The literature search identifies studies examining the effects of resistance training on trained marathoners' running economy measured on laboratory treadmill test

(Johnson, et al., 1995; Kyrolainen, et al., 2001 & Chtara, et al., 2005). These results were then inferred to marathon running. This finding helps to demonstrate the significance of the current study, which examines the effect of supplementary resistance training on the Comrades Marathon performance.

2.3.1.2 The effects of resistance training on maximal oxygen consumption (VO_{2max})

Maximal oxygen consumption refers to the greatest rate at which the body can consume and utilize oxygen, which linearly increases with progressive exercise intensity. Maximal oxygen consumption is recognized as one of the primary predictors of successful endurance running (Bassett and Howley, 2000). Much controversy reigns in regards to the use of VO_{2max} as a predictor of endurance running performance. The different perspectives will be presented for better comprehension of the matter.

Recreational and trained marathoners and ultra-marathoners race pace are usually 50-70% of their VO_{2max} respectively. Very rarely marathoners are capable of running a marathon at 90% of their VO_{2max} . Elite marathoners and ultra-marathoners race speed usually vary between 75%-85% of their VO_{2max} (approximately 3min/km) for the marathon and slightly slower for the ultra-marathon (3:40min/km) (Swain, 1994 & Noakes, 2001). Elite marathoners are able to run these fast speeds (a higher percent of their

VO₂max) because their speed at 100% of their VO₂max is considerably faster than their marathon and ultra-marathon race speed. Studies conducted on heterogeneous running groups (different running abilities) have demonstrated that VO₂max could predict their endurance running performance (Hill and Lupton, 1923 & Taylor, et al., 1955). However in reality, marathoners' with similar marathon completion times have different VO₂max values. This suggests that VO₂max is not a good predictor of endurance running performance amongst homogenous running groups (Coetzer, et al., 1993 & Abe, et al., 1998). Noakes (2001) claims that all marathoners' race performance are influenced by other factors (such as running economy, lactate threshold and fatigue resistance), which eventually determine the winners of the race. Marathoners' who have lower VO₂max values (67ml/kg/min) with better running economy can better a marathoner with a higher VO₂max (70ml/kg/min). Efficient running biomechanics enables a marathoner with a lower VO₂max to run at a steady rate (pace) for longer.

Literature indicates VO₂max improvements are unlikely to occur in aerobically trained marathoners from resistance training (Hickson, 1980; Evans, 1995 & Balabaninis, et al., 2003). The various reasons for the insignificant impact that resistance training has on a marathoner's VO₂max are presented below.

- Hickson, (1980) hypothesizes that resistance training of trained marathoners is bound to be unsuccessful in an attempt to increase their VO₂max due to the insignificant stimulus produced by resistance training in challenging the oxidative system. Comparative studies that

measured the energy expenditures during a single resistance training session and during a walk on a treadmill recorded equivalent energy values (Hurley, et al., 1984 & Beckham and Earnest, 2000). Hurley, et al. (1984) and Beckham and Earnest (2000) reaffirm Hickson's (1980) hypothesis that the lack of improvement in VO_2max occurs because a single resistance training session elicits oxygen consumption values that are less than the recommended value of 50% of maximal oxygen consumption capacity (by Balady, et al., 2001). This insignificant stimulus is inadequate in challenging the trained marathoner's oxidative system.

- Evans (1995) and Balabaninis, et al. (2003) have documented that concurrent resistance training and endurance running do not increase nor decrease VO_2max values because endurance running and resistance training produce different muscular adaptations. Tanaka and Swensen (1998) have documented the fact that endurance running decreases glycolytic enzyme activity but increases intramuscular substrate stores; it also increases oxidative enzyme activities, and increases capillary and mitochondrial density. In contrast, resistance training decreases mitochondrial density, marginally impacts on capillary density, metabolic activity and intramuscular substrate stores, but increases muscle glycogen stores.
- Initially exercise scientists believed that endurance running converted the intermediate fast twitch type IIa muscle fibers to type I slow twitch muscle fibers (Jansen and Kaijser, 1977 & Jansen, 1978). Subsequent research (Tanaka & Swensen, 1998) documented that endurance

running converted fast twitch type IIb muscle fibres to smaller intermediate fast twitch type IIa. The smaller intermediate fast twitch type IIa muscle fibres reduced the intensity of the muscle contraction of these muscle fibres. Harber, et al. (2004) hypothesise that endurance running does not convert fast twitch type IIb to slow twitch type I and/or to intermediate fast twitch type IIa muscle fibres. Rather, endurance running amplifies the slow twitch fibre characteristics of intermediate fast twitch type IIa muscle fibres. In reality muscle fibre histochemical and anatomical analysis reveals no transformation of type IIa intermediate fast twitch muscle fibres to slow twitch type I muscle fibres. Conversely, researchers initially believed that chronic resistance training converted slow twitch type I muscle fibres to intermediate fast twitch type IIa (DeLorme and Watkins, 1951 & Jacobs, 1987). This transformation of fibre typing would have increased the intensity of the muscle contraction, which would have generated a stronger force by the converted muscle fibres. Subsequent research reported that resistance training does not convert slow twitch type I muscle fibres to intermediate fast twitch type IIa. Resistance training increases the fast twitch characteristics of the intermediate fast twitch type IIa muscle fibres (Trappe, et al. 2000). The above histochemical and anatomical anaerobic training adaptations increased the overall fast twitch characteristics of the muscle. Resistance training cannot transform slow twitch type I muscle fibres to fast twitch type IIb muscle fibres and thereby cannot decrease VO_{2max} . Neither can endurance running transform, fast twitch types

IIb to slow twitch type I muscle fibres and thereby decrease muscle strength and anaerobic power. The possible reason for the poor muscle strength and anaerobic power amongst marathoners is that they exclusively endurance run train and do not cross (resistance) train. A similar argument can be presented for the poor aerobic capacity of resistance trained athletes, who exclusively resistance train and do not cross (endurance) train.

When resistance training was performed in conjunction with endurance run training, $VO_2\text{max}$ has not been shown to improve beyond values achieved by endurance run training alone (Evans, 1995 & Balabaninis, et al., 2003). Combining resistance training with endurance running has shown to attenuate only muscle strength and anaerobic power. Although resistance training is ineffective in producing $VO_2\text{max}$ gains for marathoners, results consistently indicated that $VO_2\text{max}$ is not decreased when resistance training is combined with endurance running.

2.3.1.3 The effects of resistance training on lactate threshold

Lactate threshold refers to the point at which blood lactate accumulates above resting values during exercise. It is commonly accepted that lactate threshold is an important factor in predicting marathon performance. Farrell, et al. (1979) claim that blood lactate threshold is a more reliable indicator of marathon running performance than $VO_2\text{max}$. Farrell, et al. (1979) compared

the correlation value of trained marathoners' VO_2max to their marathon velocity ($r=0.83$) and to the correlation value of these trained marathoners' blood lactate threshold to their marathon velocity ($r=0.91$). The statistical data analysis revealed that lactate threshold is more closely correlated to marathon velocity, and therefore is a more reliable predictor of marathon running performance.

Marathoners select a race pace which utilizes energy and produces appreciable amounts of lactate just below the lactate threshold. This amount of lactate produced is readily removed from the muscle cells, thereby allowing the marathoner to continue running at the given speed for a prolonged period of time (MacDougall, 1998). Therefore, if marathoners could increase their lactate threshold, they would be able to run at faster speeds for a prolonged period of time. Marathoners' with high lactate thresholds are capable of running at a higher percentage of their VO_2max before lactate production rate exceeds lactate removal rate (Coetzer, et al., 1993). Black, South African marathoners' currently dominate the South African marathon running events. Coetzer, et al. (1993) completed an investigative study to determine the reason for black marathoners' superiority by critically evaluating 9 elite Caucasian South African marathoners and 11 black South African marathoners. All marathoners shared similar VO_2max values, training volumes and type I fibre distribution, except that the black marathoners were capable of running at a higher percentage ($> 80\%$) of their VO_2max for longer periods of time with minimal lactate accumulation. Coetzer, et al. (1993) hypothesise that the black South African marathoners' superior running

abilities were associated with their lower blood lactate concentration due to their higher lactate thresholds and quicker lactate removal rates during high intensity running as well as their better running economy. This information serves to indicate the importance of lactate threshold to marathon and ultra-marathon running.

A few studies have been conducted to primarily investigate the impact of resistance training on lactate threshold. The investigation of Marcinik, et al. (1985) on a heterogeneous group (varying fitness) documented that subjects were able to train at a 12% higher percentage of their VO_{2max} before reaching lactate threshold after resistance training. Marcinik, et al. (1985) proposed the following explanation:

- The resistance training increased the capability of the muscle fibres to produce more absolute force – therefore the fibres would work at a lower percentage of their new absolute maximum strength during endurance exercise as compared to their pre-training status. This decrease in effort may produce a decrease in anaerobic energy production, resulting in a decrease in blood lactate accumulation. The decrease in relative force production per fibre during endurance exercise (decrease in relative workload) may decrease blood flow occlusion, which effects lactate production and removal.

Subsequent investigations (Bishop, et al., 1999; Hoff, et al., 1999 & Paavolainen, et al., 1999) on the effects of resistance training on lactate threshold of homogenous groups (trained athletes with similar fitness levels)

proved to contrast with the findings of Marcinik, et al. (1985). Bishop, et al. (1999); Hoff, et al. (1999) & Paavolainen, et al. (1999) suggest that reasons for the lactate threshold improvement in of the study of Marcinik, et al. (1985) was due to the fact that it was an untrained heterogeneous group that was investigated. These untrained subjects possessed greater opportunity for improvement as compared to the homogenous groups of trained athletes.

However, all of the evidence (in Marcinik, et al., 1985; Bishop, et al., 1999; Hoff, et al., 1999 & Paavolainen, et al., 1999) indicates that resistance training does not decrease blood lactate threshold and therefore does not decrease endurance running efficiency. Further research should be conducted to conclusively document the effects of resistance training on lactate thresholds of trained marathoners and other sport athletes. Research has, however, been conducted to determine the effects of resistance training on trained marathoners' running economy, VO_2max and blood lactate thresholds measured in laboratory treadmill tests. This data was then inferred to marathon and ultra-marathon performance.

2.3.2 Speed run training

The traditional Comrades Marathon-training programme employed by most South African marathoners enables them to complete the Comrades Marathon, but not to race the Comrades Marathon. The primary reason why marathoners who adhere to the traditional Comrades Marathon training

programme cannot race the Comrades Marathon is because they don't complete an adequate amount of speed run training. Training methods of the traditional Comrades Marathon programme includes LSD, Fartlek, uphill run training and recovery runs (Yeager, 2004). The primary objective of LSD is to enable the marathoners to run long distance, slowly. Emphasis is placed on endurance but not speed. Although Fartlek training is a type of speed training, its unstructured protocol makes it less effective as compared to interval run training, tempo running and fast continuous running. The runner's perceived rate of effort determines the intensity and distance of each exercise interval, which marginalizes the aerobic training benefits. Runners employing Fartlek training do not stress their oxidative system maximally to obtain maximal benefit as compared to interval training. Uphill training adequately prepares marathoners to run uphill sections of the Comrades Marathon. However the Comrades Marathon contains large distances of downhill running, which according to research causes injuries to marathoners (Dutto and Braun, 2004 & Takahashi, et al., 2006). Noakes (2001) reports that most South African Comrades Marathoners' training programmes lack sufficient downhill run training, which prepares them inadequately – thereby incurring injury during the downhill running in the Comrades Marathon.

The above limitations indicate the need for marathoners to complete adequate supplementary speed run training in order to race the Comrades Marathon. The physiological rationale of how speed run training is able to improve Comrades Marathon performance is considered next.

2.3.2.1 How does speed run training improve Comrades Marathon performance?

Marathoners who attempt to complete the Comrades Marathon generally have a strong aerobic base and all their aerobic training induced adaptations usually derived from long slow distance running. Further continuous long slow distance running marginally improves these trained runners' cardio-respiratory fitness. Legaz, et al. (2006) documents that older seasoned marathoners with many years (minimum of 5 years) of endurance run training, who continue long slow distance running do not gain further improvement in their running performance and VO_{2max} . These older, seasoned marathoners have already attained the aerobic induced training adaptations over the previous years of endurance training. Novice marathoners who have few years (three years and less) of aerobic training need to perform long slow distance runs to improve their endurance running performance. These novice marathoners have not completely attained their aerobic training induced adaptations. Legaz, et al. (2006) suggest that further improvement amongst seasoned, older marathoners is dependant on changing their running training methods and techniques. In order for trained older marathoners to further improve their cardio-respiratory fitness, it is recommended that they complete speed run training (Noakes, 2001 & Hidgon, 2006). Marathoners run short distances (3-15km) at very fast running speeds, which are at a higher percentage of their VO_{2max} . Generally trained marathoners' running speeds over these short distances (3-15km) are quicker than their marathon and ultra-marathon race speeds (Noakes, 2001).

Speed run training methods include interval training, downhill, tempo and fast continuous running. Interval training involves the systematic alternation of fast paced running exercise intervals with slower paced recovery intervals. The intensity of the exercise and recovery intervals are specific and must be adhered to in order to achieve desired outcomes. Downhill training comprises of a series of fast downhill runs (exercise interval) alternating with slow uphill runs (recovery intervals). The commonality of interval and downhill training methods is the series of alternate exercise and recovery intervals. Tempo running involves fast running at a pace 5 to 10 seconds faster per kilometre than the marathoner's 10km race pace, over a distance varying from 5 to 8km. Fast continuous running involves running at marathon race pace distances varying from 15 to 25km. The relationship between the first type of speed run training (interval training and downhill training) and the second type of speed run training (tempo and fast continuous running) is the effect that the first type has on the second type. Interval training and downhill training enables the marathoner to run the tempo and fast continuous runs at a faster running speed (at a higher percent of $VO_2\text{max}$). The faster running speed of the tempo and fast continuous runs facilitates a quicker marathon and ultra-marathon race pace.

Running at a higher percentage of one's maximal oxygen consumption increases the amount oxygen being consumed. Therefore runners experience a decreased availability of oxygen supply to the working muscles. There are two mechanisms available to increase the availability of oxygen for consumption during exercise, namely an increase in cardiac output and an

increase in the extraction of oxygen from blood thereby increasing the a-vO₂ difference (McArdle, et al., 2001). This important relationship between cardiac output and a-vO₂ difference and aerobic capacity is summarised by Fick's equation, namely:

Maximal oxygen uptake= Maximal cardiac output x Maximal a-vO₂ difference

During endurance running, maximal oxygen consumption is limited by the availability of the cardio-respiratory system to deliver oxygen to the exercise muscles. Thus the delivery of oxygen and not the skeletal muscle extraction is considered as the primary limiting factor of maximal oxygen consumption during endurance running (Bassett and Howley, 2000). Therefore improvement in cardiac output increases maximal oxygen consumption. Long slow distance running increases cardiac output. This is a common aerobic adaptation of trained marathoners who have frequently completed long slow distance runs and is the primary reason for novice marathoners to complete regular long slow distance runs. However, Legaz, et al. (2006) postulate that trained marathoners who continue LSD training reach a plateau, or marginally improve their cardiac output. Rietjens, et al. (2002) document that years (minimum of five) of continuous LSD training do not continually improve trained marathoners' haematological status (oxygen carrying capacity). Cardiac output is a product of stroke volume and heart rate. Therefore Rietjens, et al. (2002) propose that trained marathoners should attempt to increase their ability to extract more oxygen from their relative constant supply of oxygenated blood in order to increase their maximal oxygen consumption.

An average of 5ml of oxygen is extracted from the 20ml of oxygenated arterial blood (50ml per litre) at rest. This represents a-vO₂ difference of 5ml of oxygen: thus 75% of the blood's original oxygen load remains bound to the haemoglobin and myoglobin. However during fast running of short distances (at a high percentage of VO₂max) the a-vO₂ difference increases to enable more oxygen to be extracted from the haemoglobin and myoglobin. The relatively large volume of oxygen still attached to haemoglobin provides an automatic reserve for muscle cells to immediately extract more oxygen should the metabolic demand suddenly increase. During fast short distance running, the need for oxygen increases in conjunction with a reduction in PO₂, which allows for more oxygen to be released from haemoglobin (Hickson, 1981 & Holloszy and Coyle, 1984). During vigorous exercise at high percent of maximal oxygen consumption, arterial PO₂ can be reduced to 15mmHg, thereby allowing only 5ml of oxygen to remain attached to haemoglobin. As a result the a-vO₂ difference increases to 15ml of oxygen per 100ml of blood.

The training methods that stimulate the body to extract more oxygen from the haemoglobin and myoglobin molecules at low arterial PO₂ is speed run training. Coetzer, et al. (1993) postulates that marathoners who regularly run fast, short distances at 80% (or higher) of their VO₂max improve their fatigue resistance. In a comparative investigation by Coetzer et al. (1993) aimed at determining the reason why elite black South African marathoners perform better than Caucasian South African marathoners, the most significant reason turned out to be that the black runners, in regular speed run training, performed at 80% (and higher) of their VO₂max. This suggests that

marathoners' who are able to increase a-vO₂ difference will enhance their maximal oxygen consumption and marathon running performance. In order for comrade marathoners to race the Comrades Marathon, they will need to supplement their run training with speed run training. A description of each type of speed run training follows.

2.3.2.2 Interval run training

Interval training is a systematic form of training that alternates spurts of high paced running (the work/exercise interval) with periods of low paced running (relief/recovery interval) in one exercise session. The optimal spacing of the exercise interval and recovery interval enables runners to run at very fast speeds for a short duration of time that they would not be capable of running continuously in a single run training session. Literature documents that interval training improves marathoners' VO₂max (Baquet, et al., 2004) lactate threshold (Esfarjani and Laursen, 2006) and running economy (Berg, et al., 1989 & Franch, et al., 1998). The physiological rationale of how interval training improves endurance running is dealt with next.

Each exercise interval produces appreciable amounts of lactate that is rapidly removed during the recovery interval before the start of the next exercise interval. The active recovery interval improves the rate of the lactate removal process from the skeletal muscles by ensuring a high blood circulation. Repeated attempts of progressively overloading the skeletal muscle lactate

threshold of marathoners, in accordance to the progressive overload principle of conditioning, induces a new higher lactate threshold and a faster lactate removal rate. This new lactate threshold and faster removal rate allows marathoners to run at a higher percentage of their VO_{2max} for an extended period of time, thereby increasing their fatigue resistance to lactate accumulation as well as their ability to run at an even higher percentage of VO_{2max} for each exercise interval (McArdle, et al., 1996).

This oxygen demand is met by two physiological mechanisms: cardiac output and a- vO_2 difference. When a marathoner is unable to deliver adequate amounts of oxygen to the active skeletal muscles, he/she would need to extract more oxygen from haemoglobin and myoglobin in order to provide oxygen to his/her working muscles (McArdle, et al., 2001).

Interval training enables a Comrades Marathoner to run at fast running speeds for short durations and distances of the race, thereby improving Comrades Marathon performance. These fast short distance bouts can be matched to the exercise intervals of interval training, but should be used only if terrain or tactics require this method – otherwise proper pacing is always better. Similarly, when a Comrades Marathoner is required to increase his/her running speed at the end of the race, he or she would be able to accomplish this task. Marathoners and ultra-marathoners preparing for the Comrades Marathon usually complete exercise interval distances varying between 800m–1500m. Comparative investigations by Berg, et al. (1989) and Franch, et al. (1998) document that the substitution of frequent long slow

distance runs with interval training proves to be beneficial to trained marathoners, by increasing their ability to run at a higher percentage of their VO₂max for longer periods. Generally marathoners and ultra-marathoners ignore this training method due to its exhaustive nature.

2.3.2.3 Downhill run training

Downhill run training is equally as important as uphill run training – and both are integral to a successful Comrades Marathoner's performance. The nature of this training method is fast downhill running (exercise interval) and slow uphill running (recovery interval). A runner should execute six to eight exercise and recovery intervals per session for maximum benefit (Williamson, 2006). Regular downhill run training increases the force of the eccentric contractibility of the hamstring muscles, thereby preventing and/or alleviating delayed onset of muscle soreness (DOMS). Noakes (2001) attributes the prevalence of post-marathon DOMS amongst Comrades Marathoners (who adhere to the traditional Comrades Marathon programme) to the absence of regular downhill run training. For this reason, Comrades Marathoners need to complete downhill run training in order to enhance their Comrades Marathon performance. Comrades Marathoners who regularly do downhill training are able to maintain a steady running pace during the downhill running sections for the marathon, which consequently enhance their Comrades Marathon performance.

2.3.2.4 Tempo run training

Tempo run training was developed in Russia in an attempt to simulate race conditions without the stress of a full-blown marathon. Tempo runs are run at a pace five to ten seconds faster per kilometre than a marathoner's 10km race pace (Williamson, 2006). This training method warrants running distances varying between 5 to 8 kilometres. Tempo runs should be done once every four to six weeks. Completion of tempo runs enables marathoners to increase their running speed, muscle strength, muscle endurance, as well as to pre-condition their mental state to cope with the stress of race day. An ideal setting to complete a tempo run is in the club time trial.

2.3.2.5 Fast continuous running

Fast continuous runs can be described as running shorter distances than race distance but at race pace. Marathoners intending to complete a marathon should, in the initial stages, first complete 15km at marathon race pace and then gradually progress to a maximum distance of 25km (Williamson, 2006). Fast continuous running prepares the Comrades Marathoner to cope with the stress and emotional turmoil of race day conditions. An additional benefit is the effective pace judgement that is gained for use on the race day. Fast continuous run training enables Comrades Marathoners to run distances varying from 15-25km in the Comrades Marathon at standard marathon pace, which will enhance their performance.

2.3.3 The effects of deep water running (DWR) on endurance running

Deep water running requires the runner to be immersed in water in a vertical plane while simultaneously driving with his/her arms and legs. The aquatic environment provides the following resistive forces: buoyancy (resistance to the participant's movements directed to the bottom of the pool), gravity (resistance to the participant's movement directed to the surface of the water) and water resistance (any horizontal movements). Further resistance can be added by the use of boards and floats. The most serious and dedicated runners all too often push their bodies to their maximum limit when running. This effort increases the risk of over-training syndrome and overuse injuries. There is much controversy about the claims that DWR enhances marathon running. The conflicting literature is, however, presented here in order to obtain a comprehensive knowledge of the effects of DWR on endurance running (Svedenhag and Seger, 1992; Eyestone, et al. 1993; Wilber, et al. 1996; Bushman, et al. 1997; and Demaere and Ruby, 1997).

Voyatzis (2005) claim that DWR is the best cross-training alternative choice for marathoners as DWR mimics the actual running motion. Deep water running increases blood circulation, range of motion of joints involved in the running action, muscle strength and muscle endurance and decreases risk of injury. The inclusion of DWR to the training schedule of marathoners adds variety and removes the monotony of land-based running. Voyatzis (2005) claims that DRW reduces the ventilatory equivalent for oxygen during submaximal exercises: thereby reducing the energy expenditure. Voyatzis,

(2005) proposes that the reduction in energy expenditure of the runner's ventilatory equivalent enables a marathoner to complete a given distance at a given velocity, thereby improving running economy.

Wilber, et al. (1996) and Bushman, et al. (1997) postulate that, DWR is an effective training alternative to land-based run training in order to maintain cardio-respiratory fitness. In a comparative investigation of trained marathoners, in which DWR and land-based run training were compared, Wilber, et al. (1996) reports that DWR elicits similar training induced aerobic adaptations of blood glucose, blood lactate, plasma nor-epinephrine and body composition over a six week period to land-based run training. Equivalent post-intervention VO_{2max} , 5km time trial and blood lactate threshold measures were recorded after trained marathoners implemented a four-week DWR programme as a substitute for the land-based run training programme to their pre-intervention measures (Bushman, et al., 1997).

However Svedenhag and Seger, (1992); Eyestone, et al. (1993) and Demaere and Ruby (1997) report that the substitution of land-based run training with DWR is not beneficial to marathoners, because it adversely affects VO_{2max} , respiratory exchange ratio, carbohydrate oxidation and lipid oxidation. The reversal of the above aerobic induced training adaptations are indicative of a reduction in aerobic fitness. The above information suggests that DWR does not maintain marathoners' aerobic fitness, nor has it the potential to enhance their endurance running.

The possible explanation for the different findings between the two opposing views is the number of weeks that trained marathoners were subjected to the DWR intervention programme. In the studies claiming that DWR is an acceptable substitute for land-based running, marathoners completed six weeks of the intervention programme (Wilber, et al., 1996 & Bushman, et al., 1997). On the other hand, in the studies claiming that DWR is not an adequate substitute for land-based running, marathoners only completed a four-week programme (Svedenhag and Seger, 1992; Eyestone, et al. 1993 and Demaere and Ruby 1997). This difference in methodology between the studies could possibly justify the different findings.

It may be concluded that further research that examines the effects of deep water running as a supplement to endurance run training needs to be completed in order to determine the impact of this training method.

2.3.4 The effects of plyometric training on endurance running

Plyometrics is described as a form of training that consists of hops, bounds and jumps, which concentrate on increasing the elasticity of muscles. The enhanced elasticity of muscles is a result of a series of eccentric (stretch) muscle contractions followed by a series of concentric (shortening) muscle contractions. This series of stretch (eccentric) and shortening (concentric) muscle contractions enhances the elastic force generated during the push-off

stage of swing phase. The combination of dynamic muscle actions is believed to activate the stretch reflex in such a way that more than the usual number of motor units are recruited, thereby developing muscle power (Kent, 1994).

Plyometric training generally increases muscle strength and explosive power (Prentice, 2004). Prentice (2004) attributes the increased muscle strength and explosive power to the enhanced elastic strength. The greater elastic strength is a direct result of the stronger eccentric muscle contractions produced by plyometric training.

Spurrs, et al. (2003) and Turner, et al. (2003) postulate that plyometric training supplementing endurance running improved endurance running performance. Spurrs, et al. (2003) and Turner, et al. (2003) postulate that plyometric training enhances the stretch shortening cycle of running. In order to gain a more comprehensive understanding of how plyometric training improves running, the stretch shortening cycle of running will be explained. The stretch shortening cycle theory proposes that running, in reality, is a series of bounces in which muscles, tendons and ligaments alternately store and release the elastic energy absorbed as the feet touch the ground. When running on flat surfaces, the lower limb muscles contract before the foot lands on the ground (heel strike). The muscle contraction is just adequate to keep the tendons stretched when the foot is on the ground, thereby storing elastic energy for the next stride. As a result, the muscles shorten (concentrically

contract) relatively little and thereby use only little energy (Roberts, et al., 1997). Most of the effort of running is done passively in the elasticity of the muscles and tendons. However, when running uphill, the muscles are concentrically contracted more and substantially more muscle fibres are recruited to produce the equivalent force as when running on flat surfaces.

Spurrs, et al. (2003) and Turner, et al. (2003) propose that plyometric training increases the stored and elastic energy of muscle contractions, which increase the force generated by the muscles. The greater force generated per stride produces an optimal stride length, which allows the runner to complete a given distance quicker at the same stride frequency, subsequently reducing his energy expenditure, thus leading to biomechanical running efficiency. Improved running economy allows marathoners to run longer distances in the Comrades Marathon at a lower energy cost. The conserved energy could be used to increase running speed, which would result in a faster Comrades Marathon completion time.

Further research on the effects of plyometric training as a supplement to endurance running needs to be documented in order to determine the impact of this training method and to validate the explanation (as proposed above) of how plyometric training improves running economy.

2.3.5 Conclusion of supplementary training on endurance running

The literature analysis on the effects of supplementary training on marathon and ultra-marathon performance indicates possible benefits to endurance runners. Resistance training concurrent to endurance running improves marathoners' running economy, which enhances their running. Concurrent resistance training does not decrease trained marathoners' VO_2max and blood lactate threshold and therefore does not hinder endurance running. Supplementary speed run training may empower Comrades Marathoners to run at faster running speeds for short durations and/or distances during the race, which will improve completion time. Supplementary plyometric training and DWR does demonstrate the potential to enhance endurance running. However, more research is required to conclusively document the effects of these supplementary training methods on marathon and ultra-marathon performance. The literature search also indicates the absence of research investigating the effects of supplementary training methods (resistance, plyometrics and DWR) on actual marathon and ultra-marathon performance.

2.4 Factors affecting the preparation of the Comrades Marathoner

The primary factor influencing a Comrades Marathoner's preparation is injury. Another factor that influences a Comrades Marathoner's preparation is the environmental conditions. Injuries affect the Comrades Marathoner's training preparation, because the recovery period of these injuries reduces the amount of time available for the marathoner to train. As a result inadequately

trained marathoners are often forced to attempt to run the Comrades Marathon. The lack of sufficient training adversely affects the runner's Comrades Marathon performance. The injuries that commonly affect the marathoner's preparations include:

- Muscle injuries,
- Ligament injuries,
- Bone injuries,
- Overuse injuries, and
- Upper respiratory tract conditions.

2.4.1 Muscle injuries

Skeletal muscle injuries are categorized into acute and chronic injuries.

2.4.1.1 Acute muscle injuries (strains)

A strain is often described as a pull or tear. It is an injury to any portion of the musculotendinous unit that includes the muscle, musculotendinous junction, tendon and its osseous insertion. Sometimes runners are suddenly overcome by immense agonizing pain in a specific muscle and thereafter immediately suffer loss of muscle function. The affected muscle goes into spasm, and becomes tender and inflamed, with skin discolouration. Acute muscle strains are a result of a combination of muscle strength imbalance between

agonist/antagonist muscles, forceful eccentric muscle contractions exceeding the tensile strength of the muscle (Garrett, 1990), muscle fatigue, inflexibility of the affected muscles and/or inadequate warm-up (Noakes, 2001). Tendons are considerably stronger than the muscles they serve, which makes them more resilient to injury. Therefore muscle strains are common to the muscle belly, musculotendinous junction or osseous attachment before the actual tendon becomes strained (Van Heerden, 1996).

Strains range from minute tears to complete discontinuity of the musculotendinous junction. Muscle strains are graded in three categories according to the severity of the injury and the resultant joint instability. A grade one strain involves minor stretching or tearing with minimal disruption in the continuity of the affected muscle. This grade one (mild) strain is characterised by minimal loss of function, no joint instability, slight pain, but allows running. A grade two (moderate) strain is characterised by tearing of the muscle with a partial break in its continuity. These moderate strains display varying degrees of pain and swelling, as well as joint instability, depending on the portion of fibres torn or ruptured. A grade three (severe) strain involves a complete rupture and break in the continuity of the muscle. Injuries in this third category are characterised by severe pain during the course of the trauma, major loss of function, marked instability, tenderness and swelling (Van Heerden, 1996). The treatment for acute muscle strains includes rest, prescription of anti-inflammatory medication and symmetrically stretching and strengthening of the affected agonist/antagonist muscle group (both concentrically and eccentrically). The treatment of acute muscle strains

requires rest, which reduces the time available for the marathoner to adequately train for the Comrades Marathon.

2.4.1.2 Chronic muscle strains (muscle knots)

Nikolaou, et al. (1987) suggest that the causes of chronic muscle strains are repeated acute injuries that are improperly managed or that allow the runner to resume training before complete recovery has occurred. This weakness is exposed during repeated bouts of fast running, when the eccentric loading exceeds the muscle's eccentric strength. This causes a small section of the muscle to become strained and to develop an inflammatory response. This initial tear is too minute to produce significant discomfort. However, once this minute strain has occurred, a cycle of repair and re-injury and re-inflammation develops that leads ultimately to a larger tender knot, comprising more muscle fibres surrounded by scar tissue (Nikolaou, et al., 1987). Chronic muscle strains are the most common injuries amongst marathoners and ultra-marathoners, usually occurring in the hamstrings, quadriceps and calf muscles. The characteristic feature of this injury is a gradual onset of pain. Fordyce (1996) and Noakes (2001) claim that the most effective treatment is a physiotherapeutic manoeuvre known as cross friction massage. Severe chronic muscle strains may inhibit the strongest endurance runner from training, until appropriate treatment of rest, stretching and cross friction massage has been completed.

2.4.2 Ligament injuries

A sprain is an injury to the ligaments of a joint when they are forced to lengthen beyond their normal anatomical capacity. Ligament sprains are graded in three categories according to the severity of the injury and the resultant joint instability. A grade one (mild) sprain involves minor stretching or tearing of the ligament with minimal disruption in the continuity. These mild sprains are characterised by minimal loss of function, no joint instability, slight pain, but allows running. A grade two sprain is characterised by tearing of a ligament producing a partial break in its continuity. Grade two (moderate) sprains display varying degrees of pain, swelling and joint instability, depending on the portion of fibres torn or ruptured. A grade three (severe) sprain involves a complete rupture and break in the continuity of the ligament. These injuries are characterised by severe pain during the course of the trauma, major loss of function, marked instability, tenderness and swelling (Van Heerden, 1996). Common ligament injuries experienced by endurance runners are ankle, anterior cruciate ligament, medial collateral ligament and lateral collateral ligament sprains. Initial treatment involves rest and prescription of anti-inflammatory medication. Subsequent to this initial treatment the marathoner should undergo rehabilitation that will focus on stabilizing the affected joint and its proprioception.

2.4.2.1 Ankle sprains

Ankle sprains comprise of inversion and eversion sprains.

2.4.2.1.1 Inversion ankle sprains

Inversion sprains occur when the foot is in an inverted, planterflexed and internally rotated position. It results in injury to the lateral ligaments (anterior talofibular, calcaneofibular and posterior talofibular ligaments) (Kent, 1994 & Bahr and Maehlum, 2004). These sprains are more common than eversion sprains. The majority of lateral ankle sprains occur at the moment when the foot makes contact with the ground at the termination of the swing phase in running or walking. At the heel strike, the ankle joint is planterflexed and the foot is supinated. As inversion proceeds, the strength of the peroneal muscle may be overcome and force falls upon the lateral ankle ligaments (Brukner and Khan, 2000).

2.4.2.1.2 Eversion ankle sprains

Eversion sprains occur when the sole of the foot is directed away from the body and the foot is flexed. Eversion ankle sprains produce damage to the deltoid ligaments of the ankle (Brukner and Khan, 2000).

The general treatment of ankle sprains include rest, stabilisation of the sub-talar joint, proprioception and change of running shoes to those that provide more stability of the sub-talar joint. Proprioceptive rehabilitation is essential to re-educate the nerves to adequately stimulate the muscles to prevent recurrent ankle injury (Bahr and Maehlum, 2004 & Prentice, 2004).

2.4.2.2 Anterior cruciate ligament (ACL) sprains

Anterior cruciate ligament attaches from the anterior tibial plateau and runs posteriorly to the lateral femoral epicondyle. Its primary function is to prevent anterior translation of the tibia. It also serves as a secondary stabilizer preventing internal and external rotation of the tibia (Marieb, 2004). The ACL can be injured via several mechanisms:

- One common mechanism involves a non-contact twisting motion in which the foot is planted and the runner is attempting to change direction creating deceleration, valgus stress and external rotation of the knee (Prentice, 2004).
- Another mechanism involves a valgus stress and internal rotation of the knee (Bahr and Maehlum, 2004).
- It is possible that the ACL can be sprained with contact involving a valgus force (Prentice, 2004).

Successful treatment of ACL injuries involves stabilisation of the knee joint, which employs closed chained isokinetic strengthening and proprioceptive

rehabilitation (Morris, et al., 1983 & Davimes and Levinrad, 1990). Intervention programmes employed to effectively prevent ACL injuries include verbal cues (Henning and Griffis, 1990), proprioceptive training (Caraffa, et al., 1996), plyometric training (Hewett, et al., 1996) and resistance weight training combined with proprioception (Hewett, 2000). Hewett, (2000) reports that the combination of weight training and proprioception training reduces the incidence of ACL injury by 50%. The duration of the rehabilitation of ACL injuries varies from 8-15 sessions (depending on severity), which approximates to 4-8 weeks. Once rehabilitation has been completed, the runner may begin run training at a low intensity and then gradually increase intensity. The rehabilitation of ACL injuries is time consuming and limits the time available for the marathoner to adequately train for the Comrades Marathon.

2.4.2.3 Medial collateral ligament (MCL) sprains

The medial collateral ligament runs from the medial femoral epicondyle to the tibial shaft and becomes fused with medial meniscus. Its major purpose is to protect the knee from valgus and external rotating forces (Marieb, 2004). The MCL is taut at full extension and relaxes between 20°-30° of flexion and then comes under tension again between 60°-70° of flexion although a portion of the ligament is taut throughout the range of motion (Jenkins, 1985). A MCL sprain occurs from contact of a valgus force applied to the lateral aspect of the knee, which exceeds the ligament's strength. Grade one and two MCL

sprains usually undergo rehabilitation that emphasises joint stabilisation. Rehabilitation of MCL sprains includes closed chain strengthening and proprioceptive exercises. Closed chain strengthening is a conservative approach, which serves a dual purpose, namely to prevent damage to the ACL and strengthen both the MCL and ACL (Prentice, 2004). Bahr and Maehlum (2004) report that the approximate training time lost during treatment of a MCL injury varies from 2-8 weeks, depending on the severity of the injury.

2.4.2.4 Lateral collateral ligament (LCL) sprains

Lateral collateral ligament attaches from the lateral femoral epicondyle to the fibula head. The LCL functions with ITB, popliteous tendon, arcuate ligament complex and the biceps femoris tendon to support the lateral aspect of the knee. The LCL is taut during knee extension but relaxed during knee flexion (Marieb, 2004). Lateral collateral ligament injuries are a result of contact varus forces applied to the medial aspect of the knee, which exceeds the ligament's strength. A non-contact varus force may be applied during running when weight is moved away from the site of injury, creating stress on the lateral structures producing a LCL sprain (Irrgang, et al., 1995). Grade one and two LCL sprains may be treated symptomatically and running may be resumed as soon as pain subsides and full weight bearing can be tolerated. Grade three LCL sprains may be managed non-operatively by means of bracing for six weeks, limited to 0°-90° motion, during which running is

prohibited. Rehabilitation of LCL sprains involves stabilisation of the knee. Similar stabilisation techniques of MCL sprains can be applied to LCL sprains (Bahr and Maehlum, 2004).

2.4.3 Bone injuries

The two most common bone injuries amongst runners are bone strains of the tibia and fibula and stress fractures.

2.4.3.1 Tibia and fibula strains

The location of the bone strain can occur in one of the following sites: posterior tibia, anterior tibia and medial tibia. Bone strains typically develop through four stages. Stage one is characterised by a vague poorly localized pain in the calf muscle. The pain is only noticed after running. As the runner continues to train without appropriate treatment, the pain becomes more noticeable during running (grade two). The pain progressively becomes severe which makes training impossible (grade three). If the strain progresses further it results in a stress fracture (grade four). The factors influencing the onset of bone strains are sudden increases in run speed and mileage; increased body mass in marathoners; inappropriate shoes that do not absorb the impact of running on hard surfaces, and inadequate rest (Noakes, 2001). Treatment of the above condition includes rest, symmetrical strengthening and stretching of respective muscles, a change to shoes that

absorb more impact, and a change of running terrain (to softer surfaces) (Bahr and Maehlum, 2004).

2.4.3.2 Bone stress fractures

Runners experience bone stress fractures due to accumulative repetitive minor trauma experienced over many weeks of running. Typically symptoms of stress fracture include a rapid onset of localized pain over the affected bone. Pain is usually bearable during inactivity but becomes severe during an attempt to run. Treatment of bone stress fractures is mainly centred on rest, which varies from six to eighteen weeks, depending on the site of injury. Sometimes the runner may be compelled to wear a plaster of Paris cast or air cast. Rehabilitation prior to return to running includes deep water running and isokinetic and isotonic strengthening regimes (Prentice, 2004).

2.4.4 Overuse injuries

Marathoners and ultra-marathoners are consistently advised about the perils that endurance running poses to their well-being. Cardiologists envision endurance running as mass suicide (Burch, 1979), whilst orthopaedic surgeons consider endurance running as an outrageous threat to the musculoskeletal system's integrity (Sonstegard, et al., 1978). In spite of these medical warnings, runners continue with their passion for running, which

places them under great risk of developing injury. Literature has identified over-training syndrome as the primary culprit of overuse injuries (Maughan and Miller, 1983; Wen, et al., 1997; Steinacker, et al., 2001 & Walsh, 2001). There is much controversy concerning over-training syndrome, over-training, over-use syndrome and over-straining. Therefore, these terms will be defined to lend clarity.

- Over-straining is a form of burnout, which develops amongst runners whose training exceed their body's adaptive capacity. Unlike over-training it includes physiological fatigue that causes nervous and hormonal disturbances (Kent, 1994).
- Over-training occurs when a runner trains beyond his/her body's physiological and psychological capacity, which is unable to recover during the rest periods. Over-training is a result of mental and physical fatigue that produces poor performance (Kent, 1994).
- Over-use injury is caused by over-exerting the body with excessive loads at normal frequency of movement or with normal load at an increased frequency, or with low loads at an excessive rapid frequency of movement. Over-use injuries often occur at microscopic level, caused by repeated microtrauma (Kent, 1994).
- Over-use syndrome comprises the pathological signs and symptoms produced by repeated use of the body in physically stressful conditions (Kent, 1994).
- Over-training syndrome comprises the signs and symptoms of over-training that produce deterioration of running performance (Kent, 1994). The following symptoms indicate over-training syndrome:

- Persistent poor performance and high fatigue ratings,
- Prolonged recovery from typical training sessions or competitive events,
- Disturbed mood states characterised by general fatigue, apathy, depression, irritability and loss of competitive drive,
- Persistent feelings of muscle soreness and joint stiffness,
- Elevated pulse rate and increased susceptibility to upper respiratory infections and gastrointestinal disturbances,
- Insomnia,
- Loss of appetite, body mass and inability to maintain proper body mass for competition, and
- Overuse injuries (Raglin and Wilson, 1999).

According to Maughan and Miller (1983); Wen, et al. (1997); Noakes (2001) and Steinacker, et al. (2001) the order of the most prevalent musculoskeletal overuse injuries amongst marathoners is: patellofemoral joint pain syndrome, iliotibial band friction syndrome, Achilles tendinosis, delayed onset of muscle soreness, muscle cramps and bone strains. Discussions of these overuse injuries will follow.

2.4.4.1 Patellofemoral pain syndrome (PFPS)

Initially this condition was described as damage to the tissue behind the patella in the cartilaginous lining of the femur and tibia. Thus PFPS was

considered to be chondromalacia. This suggests that running produced degeneration of the cartilage and would lead to arthritis. Fortunately Pretorius, et al. (1986) and Devereaux, et al. (1986) recognised that PFPS is not chondromalacia and degeneration of the cartilage of the knee joint, but rather severe pain in either the medial, and/or lateral and/or inferior borders of the patella at the attachment sites of the medial and lateral retinacula and patella tendon. Dye, et al. (1998) theorises that patellofemoral problems are due to excessive physiological and mechanical loading and to chemical irritation of the nerve endings, which cause peripatellar synovitis.

Factors influencing the onset of PFPS amongst marathoners are the wearing of inappropriate soft shoes (that fail to control and limit the excessive amount of ankle pronation), abnormal musculoskeletal structural conditions (pes planus, pes cavus, femoral neck anteversion, increased Q-angle, and poor ankle flexibility) and poor application of training methods (frequent long slow distance running, inadequate rest, sudden increase in speed and mileage and excessive running on cambered roads) (Noakes, 2001).

Treatment of PFPS includes rest and a prescription of anti-pronation shoes that limit ankle pronation. Natri, et al. (1998); Ghousoub, et al. (2003); Crossley, et al. (2005) and Hazneci, et al. (2005) report that non-operative stabilisation techniques facilitate the recovery of PFPS. These stabilisation techniques include strengthening and stretching of the quadriceps, hamstrings, abductors and adductors muscles. Cowan, et al. (2002) report that symmetrical strengthening of vastus medialis oblique and vastus lateralis

allows for improved patella tracking over the trochlea groove of the knee joint and thereby prevents PFPS. Runners possessing stronger asymmetrical lateral structures pull the patella laterally into the trochlea groove, thereby producing pain. Heintjies, et al. (2003) and Hazneci, et al. (2005) report that isokinetic strengthening of the knee joint is most effective in stabilizing the knee joint and hence, subduing pain. Thereafter the runner should continue strengthening the knee joint with resistance (isotonic) strengthening exercises in order to maintain muscle strength, which will prevent future recurrent injury.

2.4.4.2 Iliotibial band friction syndrome (ITBFS)

Iliotibial band friction syndrome is an overuse injury characterised by severe pain localized over the lateral femoral epicondyle. The onset of pain starts from the middle towards the end of the run. Runners often complain of pain on downhill running. During running the runner's knee is flexed at approximately 30°, at which point the iliotibial band (ITB) slips over the femoral epicondyle and produces pain. High run mileage, or sudden increases in running speed and mileage, or excessive racing contributes to this condition.

Treatment of the above condition includes rest, symmetrical strengthening and stretching of lower limb muscles, and a prescription of anti-inflammatory medication. Fredericson and Wolf (2005) and Fredericson and Weir (2006) propose that the rehabilitation of runners who have contracted ITBFS should

include stabilisation of the hip and knee joints. The muscles that comprise the ITB originate from the hip and insert along the femur onto the lateral aspect of knee. The stabilisation of these joints must include stretching and strengthening exercises. The objective of the stretching exercises is to increase the length and flexibility of the ITB, thereby preventing the repetitive friction of the ITB over the lateral femoral epicondyles during running. The strengthening exercises will increase the muscle strength of the weak gluteal muscles in the hip joint, thereby creating proper muscle symmetry. The proper muscle symmetry will prevent the movement of the iliotibial band's distal attachment towards its proximal attachment, thus alleviating the friction of the ITB over the lateral femoral epicondyles.

2.4.4.3 Achilles tendinosis

Achilles tendinosis is a localised pain in the Achilles tendon. The two types of Achilles tendinosis present as either partial tears or complete tears. Partial Achilles tendinosis is common amongst marathoners and ultra-marathoners. Achilles tendinosis affects the functioning of the ankle. Galloway, et al. (1992); Gibbon, et al. (1999) and Langberg, et al. (2006) propose that the Achilles tendon and calf muscle undergo rapid repetitive eccentric muscle contraction at heel-strike, followed by rapid concentric muscle contraction at toe-off, which produces micro tearing and degeneration of Achilles tendon. Endurance running degenerates the Achilles tendon, which reduces its ability to store and release conserved elastic energy into a strong muscle

contraction. The weak muscle contraction produces a weak force during the push-off stage of the swing phase. Degeneration of the Achilles tendon is primarily due to accumulative overload, which extends beyond the Achilles tendon's tensile strength, thus producing micro tearing of fibres (McCroory, et al., 1999 & Noakes, 2001). McCroory, et al. (1999) hypothesise that the following factors predispose marathoners to Achilles tendinosis:

- A sudden increase in run mileage (increase in the number of LSD runs and/or distance of LSD) and/or speed (the introduction of or the increase in the number of interval run or hill running sessions) contributes to micro tearing.
- The advance of age decreases the elasticity of tissue, which increases the risk of micro tearing of the Achilles tendon.
- Worn-out shoes do not reduce a high degree of pronation, which increases the susceptibility of micro tearing of the Achilles tendon.
- Biomechanical factors predisposing endurance runners to Achilles tendinosis include inflexible calf muscles, hypermobile feet, pes planus, pes cavus and clunk foot.

Treatment includes rest, symmetrically stretching and strengthening of the lower limb musculature, change of shoes (select the appropriate anti-pronation shoes with rigid heel counters and a firmer mid sole to better control the excessive pronation) and physiotherapy (Noakes, 2001). Resistance training strengthens these weak muscle fibres both eccentrically and concentrically, thereby increasing the tensile strength of the Achilles tendon. The increased strength of the Achilles tendon allows it to withstand the

repetitive eccentric loading during running, without producing micro tearing. An alternative to conservative resistance strengthening is surgery. The short-term prognosis of surgery is promising, but the long-term prognosis has reported recurrent muscle fibre tearing. Alfredson and Lorentzon (2000) attribute the pessimistic long-term prognosis to muscle fibre and calcaneus weakening.

2.4.5 Upper respiratory tract infections

Common upper respiratory tract infections of endurance runners are influenza and colds. These upper respiratory tract infections require rest, which reduces the time available for the marathoner to train and to adequately prepare for the Comrades Marathon.

2.4.5.1 Influenza

Influenza is an infection of the lungs and airways by one of the influenza viruses, causing fever, running nose, sore throat, cough, headache and a general feeling of illness. The most common complication of influenza is pneumonia. This can be either viral pneumonia (in which the influenza virus spreads to the lungs) or bacterial pneumonia (in which unrelated bacteria attack the person's weakened immune system). In both cases, the person may have a worsened cough, difficulty breathing, and persistent fever. The

influenza vaccination is the best way to avoid contracting influenza. The main treatment for influenza is rest (5-7 days), drinking plenty of fluids and avoiding exertion (Beers, et al., 2003).

2.4.5.2 Chronic obstructive lung disorder (cold)

The common cold is a viral infection of the lining of the nose, sinuses, throat and large airways. Many different viruses cause the common cold, but the rhinoviruses are identified more often than the others. An effective vaccine has not yet been developed, because of the many different viruses that cause colds. Colds mainly spread through contact between an infected and a healthy person. The best preventive measure is to practise good hygiene. The infected person should drink plenty of fluids, continue with prescribed pharmacological medication, rest, and avoid exertion (Beers, et al., 2003).

2.4.6 Environmental factors

Environmental factors include high temperatures, low temperatures, wind, rain and high levels of humidity. The cohort of this study resided in the KwaZulu-Natal province and therefore experienced the same weather patterns. The different weather patterns equally affected both the control and experimental groups' Comrades Marathon training preparation. The control and experimental groups were part of a close-knit group of homogenous

recreational marathoners who adhered to the same traditional Comrades Marathon training programmes. The KwaZulu-Natal province experienced the similar traditional weather patterns during the five-year period previous to the specific period from 01/10/04 to 16/06/05 (the Comrades Marathon training preparation phase). In addition to this, the cohorts of the study were accustomed to these traditional weather patterns, which did not affect their Comrades Marathon training preparations.

2.5 Factors affecting the performance of Comrades Marathoners on race day

The Comrades Marathon presents many challenges, but nothing so overwhelming as the obstacles that a runner has to overcome on race day. For a Comrades Marathon runner to excel on race day, he/she has to be in a well-conditioned psychosomatic state. The runners would have had to complete the necessary training, but importantly, would also have had to be able to adapt and overcome all challenges that may have presented themselves on race day. Such challenges may include: musculoskeletal injury, environmental conditions and nutritional factors.

2.5.1 Musculoskeletal injuries

Whilst running the Comrades Marathon the runner's body is placed under great stress, which sometimes manifests itself via musculoskeletal injuries. These injuries include acute/sudden muscle strains, muscle cramping, dislocations of joints, and anterior knee pain.

2.5.1.1 Acute (sudden) muscle strains

Runners are at risk for developing acute muscle strains at all times while they run. Grades one and two muscle strains adversely affect the performance of the Comrades Marathoner, but may allow the runner to complete the race at a slower pace. Grade three muscle strains will prohibit further running of the Comrades Marathon and induce premature retirement from the race.

2.5.1.2 Muscle cramps

Muscle cramps are described as spasmodic, painful, involuntary muscle contractions (Schwellnus, 1999). The two types of muscle cramping are nocturnal cramping and exertional cramping. Nocturnal cramping is differentiated from exertional muscle cramping by its unique characteristic of cramping at night. Exertional cramping usually occurs during unaccustomed prolonged exercise. Marathoners who experience exertional muscle

cramping are runners who tend to run longer and faster than they are accustomed to. Schweltnus (1999) identified the following risk factors influencing muscle cramping: progression of age, a long history of running, high body mass index, irregular and infrequent stretching sessions and a family history of cramping. Prevention of exertional cramping includes a gradual increase in training intensity, mileage and regular long slow distance runs for runners intending to complete marathons and ultra-marathons. Attention should also be given to proper nutrition before, during and after completion of marathons and ultra-marathons, as well as run pacing (not running faster and beyond the runner's capability). Schweltnus (1999) postulates that marathoners and ultra-marathoners should regularly stretch before and during long runs to prevent muscle cramping. Santos, et al. (2004) document that electrolyte supplementation prior to marathons and ultra-marathons reduce muscle cell damage and inflammation, which are common symptoms of muscle cramping. Walsh (2001) reports that muscle cramping does hinder Comrades Marathon performance, whilst severe muscle cramping may force a runner to prematurely retire from the Comrades Marathon.

2.5.1.3 Dislocations of joints

A dislocation is a complete separation of the articulating bones as a result of the joint being forced beyond its maximal passive range of motion (Kent, 1994). The person experiences pain, swelling around the joint, joint

instability, and lack of joint function. Such a condition will force the runner to prematurely retire from the Comrades Marathon. Subluxation of a joint involves the joint surface distortion, when the joint is moved beyond its maximum passive range of motion. Unlike a complete dislocation, partial contact exists between the articulating bones (Kent, 1994). Subluxation of joints could also force the marathoner to retire from the Comrades Marathon. If the marathoner continues the race his completion time will be longer.

2.5.1.4 Anterior knee pain

Anterior knee pain is the most common symptom that is produced during the Comrades Marathon. Anterior knee pain is a result of patellofemoral joint pain syndrome and/or patellar tendinopathy, and/or fat pad impingement and/or patellofemoral instability (Brukner and Khan, 2000). The common aetiology of the above conditions is related to abnormal biomechanics of the patella. The patella tracks laterally in the trochlea groove during knee extension, producing pain. Many Comrades Marathoners experiencing mild anterior knee pain insist on continuing the race. These runners' knees are usually taped to externally correct the abnormal patellar biomechanics. Anterior knee pain reduces the running speed of the marathoner, thereby compromising his/her completion time. Severe anterior knee pain can render the hardest runner immobile, forcing him/her to retire from the race prematurely. Immediate treatment is rest and premature retirement from the Comrades Marathon. After adequate rest, the marathoner is advised to follow a rehabilitative

programme that emphasises stabilisation of the patellofemoral joint. Stabilisation of the patellofemoral joint includes stretching and strengthening of all musculature surrounding the patellofemoral joint as well as improvement of proprioception (Brukner and Khan, 2000).

2.5.2 Environmental conditions

The weather comprises of a variety of climatic conditions that have in the past affected the performance of Comrades Marathon runners. These climatic conditions include extreme temperature, high humidity levels, wind and rain. Extreme environmental conditions could increase the physiological strain on the Comrades Marathon runner during the race.

2.5.2.1 Extreme high environmental temperature and humidity levels

Extreme high temperatures and humidity levels on race day could expose the runner to life and health threatening risks. Participation in the Comrades Marathon produces high heat levels in the runner's body. This heat needs to be dissipated by the runner's body. If this does not occur efficiently, then the core body temperature could rise to dangerously high levels. Sweating is the body's thermoregulatory attempt to reduce its high core temperature. Ultra-marathon running in high environmental temperature could also produce

various health threatening conditions, such as dehydration, hyponatraemia, heat collapse, heat exhaustion, heat stroke and heat cramps. These conditions are discussed hereunder.

2.5.2.1.1 Dehydration

Dehydration is defined as the depletion of body fluids – a condition that can hinder thermoregulation and cause an increase in core temperature. The symptoms of dehydration include diarrhea, excessive sweating, vomiting, increased core temperature and increased skin temperature. If the runner's sweat rate continually exceeds his fluid replacement rate during the Comrades Marathon, then the runner could suffer from dehydration. Noakes (2001) documents the fact that dehydrated Comrades Marathoners run the risk of developing health-threatening conditions that vary from mild heat stroke to cardiac arrest. The reduction in the body's fluid volume may result in a reduction in blood pressure and cardiac output. Dehydration definitely impedes Comrades Marathon performance. Earlier investigation (Wyndham and Strydom, 1971) reported that the cause of dehydration was sweating, fluid loss and lack of rehydration. This information encouraged marathoners to ingest water whilst running. However, recent studies report that the main cause of dehydration that is presently found is inadequate rehydration (McConnel, et al., 1983 & Daries, et al., 2000). Inadequate rehydration varies from insufficient fluid intake to inadequate electrolyte replacement. Sweating causes body loss of water and electrolytes, therefore Comrades Marathoners

need to regularly ingest water, electrolytes and carbohydrates in order to ensure adequate hydration throughout the race. As a result of this nutritional crisis created during marathons and ultra-marathons, sport fluid rehydration drinks have been produced in recent times. The purpose of the rehydration drink is to adequately replenish loss of water, electrolytes and carbohydrates. The appropriate amount of fluid that needs to be ingested can be calculated by the following equation:

$$\text{Amount of rehydration per hour (l/h)} = \text{sweat rate per hour (l/h)}$$

Sweat rate (l/h) = (Pre-race weight – Post-race weight) + ingested fluid during race

Running time (hours)

Noakes (2001) suggests that a Comrades Marathoner's fluid rehydration would be adequate if the runner lost 2-3kg and did not dehydrate more than 3% of his/her pre-race weight.

$$\text{Dehydration (\%)} = (\text{Pre-race weight} - \text{post-race weight}) \times 100$$

Pre-race weight

Electrolyte loss (sodium, potassium, chloride and magnesium) from sweat during marathons and ultra-marathons needs to be adequately replaced in

order to ensure normal cellular functioning. Electrolytes are chemical substances that dissociate into electrically charged particles to facilitate continued muscular contractions. Continued loss of electrolytes during marathon and ultra-marathon running could facilitate muscle cramping (Santos, et al., 2004). Comrades Marathoners also suffer carbohydrate loss because carbohydrates are used as the primary energy fuel of any activity. Adequate replacement of carbohydrates is essential to marathoners and ultra-marathoners during running. However much controversy remains in regard to the exact carbohydrate concentration level that is desirable, in a rehydration solution, available to the runner. The amount of electrolyte replacement in a rehydration drink at present is 20mmol/l of sodium (Noakes, 2001). Gisolfi, et al. (1995) report that high sodium concentration (50mmol/l) and high carbohydrate content (10% of the solution) results in a poor rate of absorption of water and carbohydrates. McArdle, et al. (1996) suggest that the ideal oral rehydration solution should contain a carbohydrate concentration between 5 to 8%. An oral rehydration solution in this range allows adequate carbohydrate replenishment without inhibiting water absorption, fluid homeostasis and temperature regulation compared to ingestion of plain water during marathon and ultra-marathon running in hot weather.

Another method of cooling the body (in addition to adequate hydration) is sponging the body while running. It is imperative to sponge the body while running in hot weather and high humidity. Prolonged running in heat causes the blood to pool in the veins of the arms and legs of the marathoner. As skin temperature rises, the veins dilate more and more, and the amount of blood in

these veins increase correspondingly. This produces a decrease in venous return to the heart, thereby decreasing blood circulation. The body's objective in transporting the warm blood to the skin is to effectively dissipate the heat of blood from the body to the environment by conduction. Therefore, if the skin's temperature were lowered, the rate of conduction would be higher, thereby allowing more heat to be dissipated from the blood. This would increase the venous return of blood to the heart, which increases blood flow.

2.5.2.1.2 Hyponatraemia

The development of hyponatraemia involves extreme sodium loss ($< 135\text{mEq./L}$) through prolonged sweating coupled with dilution of extracellular sodium from consuming excessive plain, hypotonic water (Goudie, et al., 2006). The symptoms of hyponatraemia include, headaches, confusion, malaise, nausea, cramping, seizures, coma, pulmonary edema and even death (McArdle, et al., 2001). Inadequate fluid rehydration during marathon running produces a state of dehydration. Marathoners, in an attempt to prevent dehydration ingest excessive amounts of plain hypotonic water leading to a state of hyponatraemia. Hyponatraemia has emerged as an important cause of life-threatening illnesses, but also of deaths, amongst marathoners. In the 2002 Boston Marathon, 13.6% of the Almond, et al., (2005) cohort experienced hyponatraemic symptoms. Almond, et al., (2005) attributed the causes of exercise hyponatraemia to excessive ingestion of plain water and inadequate ingestion of electrolyte rehydration solution. Goudie, et al., (2006) reports that

marathoners experience hyponatraemic symptoms a considerable time after running a marathon. In the case of the 2003 London Marathon, 14 marathoners reported symptoms of hyponatraemia a day after the run (Goudie, et al., 2006). The following recommendations are aimed at preventing the onset of hyponatraemia:

- Refrain from over-hydration by not consuming more than 1000mL of plain water each hour either before, during or after exercise, and
- Add a relatively small amount of sodium (approximately 25mEq/L) to the ingested fluid. It is also advisable to include glucose in the electrolyte rehydration fluid to facilitate intestinal water uptake (Surgenor and Uphold, 1994).

2.5.2.1.3 Heat collapse

Heat collapse is the loss of consciousness associated with hot and humid environmental conditions or exercising in clothing that restricts heat loss and causes overheating. Symptoms include elevated core temperature and sweaty skin. Excessive sweating and shunting of blood to the skin and muscles reduces blood flow to the brain, thereby causing fainting. It is a potentially dangerous condition that leads to heat exhaustion or heat stroke (Kent 1994).

2.5.2.1.4 Heat exhaustion

Heat exhaustion is a condition of fatigue caused by prolonged exposure to environmental heat. Symptoms of heat exhaustion include an elevated heart rate, cold and sweaty skin, drowsiness and vomiting. Kent (1994) proposes that heat exhaustion can be prevented by regular proper rehydration.

2.5.2.1.5 Heat stroke

Heat stroke is a potentially fatal condition caused by over-exposure to heat. The condition is characterised by high body core temperature, hot and dry skin (which is usually flushed), mental confusion, loss of motor co-ordination and unconsciousness. There is an urgent need to reduce the core temperature rapidly by loosening clothing, fanning and sponging with tepid water. However iced fluids and ice baths should not be administered because they cause vasoconstriction and reduce the elimination of heat. Medical attention is necessary and hospitalization may be required as there is a danger of renal failure (Kent, 1994). Heat stroke is increasing in frequency amongst marathoners and ultra-marathoners. Medical evaluations of heat stroke amongst runners reveal the causes to be acute renal failure, rhabdomyolysis, dehydration and muscle cramping. Most runners experiencing heat stroke fail to rehydrate properly when running (inadequate electrolyte and fluid replacement), thereby increasing the risk of dehydration, renal failure and rhabdomyolysis (Harte, et al., 1980; Lee, et al., 1990 &

Miralles, et al., 1993). Robert (2006) reports that exertional heat stroke can occur amongst trained marathoners who run in cool temperatures, but with high humidity levels. Dennis and Noakes (1999) hypothesized that marathoners who possessed a smaller body mass are at a reduced risk of developing humidity and heat related illnesses (such as heat stroke and heat exhaustion) because of their relatively lower metabolic heat production. Heat production during marathon running is dependant on the runner's body mass and running speed. Heat loss depends on the marathoner's surface area. Marathoners who possess a smaller body mass have a greater surface area relative to their body mass, which facilitates greater heat loss. Lighter marathoners tend to expend less energy to run a given distance at a given speed, and therefore their heat production is reduced. For this reason, trained marathoners possessing smaller body masses have a marginally greater tolerance to humidity and heat related illnesses that can affect their running performance adversely.

2.5.2.1.6 Heat cramps

Heat cramps are characterised by painful muscular contractions caused by prolonged exposure to environmental heat and by excessive fluid and electrolyte loss. Kent (1994) postulates that adequate hydration and intake of electrolytes in one's diet should prevent this condition. Santos, et al. (2004) documents that marathoners and ultra-marathoners who supplemented their

diets with electrolytes a week prior the race reduced muscle cell damage and inflammation, which are common symptoms of muscle cramping.

2.5.2.1.7 Heat syncope

Heat syncope is fainting or sudden loss of strength due to overheating (Kent, 1994). Resting in a cool environment will reduce the body temperature. Once the patient regains consciousness, he/she must rehydrate.

2.5.2.2 Extreme low environmental temperature

Extreme cold temperatures could also produce negative consequences. Due to the fact that runners will take a longer time to warm up before running at optimal running pace, the time taken to complete the Comrades Marathon will be longer than anticipated. Such conditions may also cause runners to run at a faster pace early in the marathon in order to minimize the time they would lose in a lengthier period for warming up the muscles on a cold day. This would induce early onset of muscle fatigue, thus causing a longer completion time. Inadequate warm-up on a cold day would increase the incidence of muscle cramping (Noakes, 2001). Endurance runners are also at increased risk of contracting various upper respiratory tract infections on cold days. Normally inhaled air is warmed and humidified before reaching the bronchi. The warming of the incoming air greatly increases its capacity to hold

moisture. Nasal secretions are increased while running in cold weather, in the body's attempt to humidify cold inhaled air. Thus humidification of inhaled air in cold weather causes significant water and heat loss from the respiratory tract during prolonged running. Nasal moisture loss when running in cold weather contributes to mouth dryness, a burning sensation in the throat, irritation in the respiratory passages, and general dehydration. Apart from increased risk of developing upper respiratory tract infections when running especially during the early hours of a cold race day, Comrades Marathoners are at an additional risk, namely to contract another respiratory condition known as Athlete's nose (exercise induced rhinorrhoea). Wearing of a scarf or balaclava that covers the mouth and nose will trap the water in the exhaled air. It will also warm and moisten the next breath of inhaled cold air, thereby helping to minimize uncomfortable respiratory symptoms (McArdle, et al., 2001 & Noakes, 2001).

2.5.2.3 Wind

Wind can positively or negatively affect running performance. All runners intuitively know that running against the wind requires more energy to maintain a given pace. The energy expenditure of running against the direction of the wind is dependent on the following factors: air density, runner's projected surface area and the runner's velocity (McArdle, et al., 1996). Running into a headwind could create an additional energy expenditure of 3 to 9% (Hill, 1927 & Pugh, 1970). This loss of time coupled

with observing other runners pass them, further heightens their fears and anxieties. The amplification of their urges to run faster would adversely affect their performance. High wind velocities alter the running biomechanics of marathoners, thereby increasing the energy cost of running (Davies, 1980). The altered biomechanics become more expensive, because the wind velocities increase the drag resistance. The increased drag resistance reduces the marathoner's speed. High wind velocities cause marathoners to shorten their strides and to lean more forward with rounded shoulders. Such altered running biomechanics increase the marathoner's running economy. The increased energy cost adversely affects the marathoner's performance (Davies, 1980).

2.5.3 Nutritional factors

Proper nutrition forms the foundation for excellent endurance running. Nutrition provides the fuel for biological work and the chemicals for extracting and using the potential energy contained within this fuel. Additional nutrients provide the essential elements for synthesizing new tissue and repairing existing cells. One needs to appreciate the importance of adequate nutrition and special dietary modifications to enhance running performance.

An optimal diet for any endurance runner is one in which the supply of required nutrients is adequate for energy use, tissue maintenance, repair and growth, without excess energy intake (McArdle, et al., 2001). The Comrades

Marathon runners' energy intake must match their energy expenditure in order to ensure continued prolonged running. Due to the large measure of aerobic exercise that an endurance runner performs, his diet should be high in carbohydrates. The recommended daily dietary allowance for an endurance runner's carbohydrate intake is 10 grams per kilogram of the individual's body mass (McArdle, et al., 2001). A common condition that surfaces amongst Comrades runners is a state of chronic fatigue, in which successive days of strenuous training become progressively more difficult to deal with. Persistent strenuous running without adequate carbohydrate supplementation gradually depletes the body's carbohydrate reserves and renders the body to a hypoglycemic state.

Another rich energy source that the body actively utilises is lipids. Endurance runners' lipid intake should not exceed 30% of daily energy intake. Of this, 70% should be in the form of unsaturated fatty acids (McArdle, et al., 2001). An attempt to eliminate all lipids from one's diet is unwise and would be detrimental to the person's running performance. Lipids are essential in the following vital body functions: insulation of visceral organs, protection of organs, shock absorption, transportation of vitamins A, D, E and K, and essential fatty acids. Diets high in fat and low in carbohydrates and proteins are unable to cope with the demands of endurance running (McArdle, et al., 2001). Carbohydrates, fat and protein serve other functions in addition to providing energy to the body. For example, proteins serve as important building blocks of the body. Reduced dietary protein intake consequently reduces tissue growth, repair and maintenance. A diet high in fat and low in

carbohydrates and proteins could have adverse effects on an endurance runner. A diet high in fat content could lead to hypertriglyceride (elevated triglyceride concentration) and hyperlipidemia (elevated blood triglyceride and cholesterol) (Durstine and Moore, 2003).

The daily dietary protein content should not exceed 0.83 grams per kilogram of the runner's body mass (McArdle, et al., 1996). Proteins provide the building blocks for synthesis of cellular material during exercise, for repair of damaged tissue and for growth of new tissue. However, excessive protein intake could lead to kidney damage.

Regular fluid supplementation during Comrades Marathon participation is vital to prevent dehydration (McArdle, et al., 1996 & Walsh, 2001). Due to the excessive amounts of heat that the body produces and dissipates, a great volume of body fluids are lost in the body's attempt to cool itself (McArdle, et al., 1996). This fluid loss is accompanied by electrolyte and mineral loss. Fluid supplementation with adequate electrolytes and minerals is necessary to prevent dehydration from occurring during the run. The strenuous running drains the body of chromium, copper, manganese and zinc (Noakes, 1988; Brukner & Khan, 2000 & Walsh, 2001), all of which are important trace elements. During the Comrades Marathon trace elements need to be replenished to ensure that the runner will be able to function optimally to complete the race. Therefore careful nutritional planning and adherence to such a plan is necessary for the successful completion of the Comrades Marathon. It is common practice amongst marathoners to employ the

nutritional technique mentioned below to enhance their endurance running performance.

2.5.3.1 Glycogen super compensation

Glycogen super compensation is commonly known as carbohydrate loading, which is a popular practice amongst Comrades Marathon runners. Carbohydrate loading is a process of nutritional modification that results in an additional storage of glycogen in the muscle fibers that can be approximately three to four times the normal levels (Goss and Karam, 1987 & Plowman and Smith, 1996).

There are two carbohydrate loading techniques that are commonly used by Comrades Marathon runners. The first is regarded as the classic technique, which is based on research conducted by Swedish investigators (Bergstorm, et al., 1967). This technique involves two phases, the muscle glycogen depletion phase and the muscle glycogen storage phase. During the muscle glycogen depletion phase the runner is expected to perform three days of strenuous running and consume no carbohydrates. This serves to decrease muscle glycogen stores. The runner then rests during the next three days and eats a carbohydrate diet exclusively (muscle glycogen storage phase). This serves to increase the muscle glycogen stores considerably (Plowman and Smith, 1996).

This classic technique is effective, but is subjected to a few criticisms, namely:

1. A high fat and protein diet during the depletion phase is problematic. High fat ingestion is unhealthy because it elevates blood lipid levels. Additionally, the ingested lipids are incompletely metabolized, thereby producing abnormally high ketone levels (Newsholme and Leech, 1983 & Costill, 1988).
2. A diet with little carbohydrate intake during the depletion phase could cause hypoglycaemia (abnormally low blood glucose levels) resulting in fatigue, restlessness, weakness, psychological disturbances and irritability - thus making it difficult to maintain the strenuous aerobic training prescription during this phase.
3. Following a high protein diet during the depletion phase can cause excessive strain on the kidneys, resulting in possible kidney problems.
4. Following a diet that is high in carbohydrates (80 to 90%) during the loading phase (three days prior to the race) can leave the runner feeling stiff and heavy owing to high water retention resulting from the high carbohydrate intake – thus creating psychological and physiological problems for the runner to contend with.

Subsequent research has shown that the classic technique of carbohydrate loading does not maximize muscle glycogen storage (Plowman and Smith, 1996). A modified carbohydrate loading technique was therefore developed. This technique emphasises a slow tapering off in duration and intensity of exercise. The training taper is accompanied by a progressive increase in carbohydrate intake. This carbohydrate loading technique does not adversely

affect the health of the runner but achieves the objective of maximally increasing muscle glycogen storage (Plowman and Smith, 1996). The nutritional goals for an optimal competition diet are:

- To ensure adequate fuel supply in the pre-event span.
- To ensure adequate fuel supply during the event (no matter the duration of the event).
- To facilitate temperature regulation by preventing dehydration.
- To avoid gastrointestinal discomfort during competition/race (Plowman and Smith, 1996).

CHAPTER THREE: RESEARCH METHODOLOGY AND PROCEDURES

- 3.1 Sample selection**
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CHAPTER THREE

RESEARCH METHODOLOGY AND PROCEDURES

In this chapter, the method by which subjects were selected and the subsequent data that was gathered will be described. The chapter will furthermore deal with the administration of the test battery, the intervention programme, test protocols and a description of the statistical treatment of the data.

3.1 Sample selection

The author issued telephonic invitations to representatives of all the athletic clubs surrounding the Durban area and governed by the KwaZulu-Natal Athletic Association to attend the research proposal presentation. At this presentation the nature of the study, hypotheses, rationale of the study, limitations and delimitations of the study were discussed. At the research proposal the following criteria for eligibility of subjects to participate in the presented and discussed:

- Subjects were restricted to endurance runners who had previously successfully completed the Comrades Marathon in less than eleven hours.
- Endurance runners from athletic clubs in the surrounding areas of Durban were recruited to participate in the study.

- Only male subjects were eligible to participate in the study, which were between the ages of 25 to 50 years.
- The sample group was restricted to Comrades Marathon finishers who had officially completed a minimum of three up runs (from Durban to Pietermaritzburg) and two down runs (from Pietermaritzburg to Durban).
- The subjects had to continue with their regular Comrades Marathon running training as in previous years.

The author also requested the representatives of the athletic clubs to issue invitations to all their runners to participate in the study. The Chatsworth athletic club and the Umhlatuze athletic club responded to the invitation. Thereafter the author made contact with the respective athletic club representatives to schedule briefing sessions. The geographical location of the athletic clubs made the briefing sessions and data collection of the study more accessible. At a briefing session the rationale, objectives and nature of the study were clarified to all subjects. Each subject completed a Physical Activity Readiness Questionnaire (appendix A) and an informed consent form (appendix B).

A sample population of 115 subjects initially volunteered and the athletes were randomly distributed into two groups, the control (CT) group and experimental (RST) group. Initially the CT group constituted 57 subjects, whilst the RST group constituted 58 subjects. However, four subjects from the CT and one subject from the RST group failed to complete the pre-intervention test battery, thereby eliminating themselves from the study. The

sample size was therefore reduced to 110 subjects, namely 53 subjects in the CT group and 57 in the RST group. The RST group was subjected to the high intensity muscle endurance resistance training intervention programme as a supplement to their normal endurance run training. The CT continued with traditional endurance run training in preparation for the 2005 Comrades Marathon.

3.2 Data collection

Data was collected from both the CT and RST groups during pre- and post-intervention test batteries. The RST group completed the intervention programme in addition to their normal Comrades Marathon run training, whilst the CT group only completed their normal Comrades Marathon run training. The duration of the intervention exercise programme was one entire Comrades Marathon athletic training season (one season equals 34 weeks). Once the pre-intervention test battery had been completed, subjects of the RST group began the intervention exercise programme. At the end of 34 weeks of regular completion of the intervention programme, subjects underwent a post-intervention test. Table 3.1 below comprises the actual test battery. These tests were used to determine the physical fitness status of the subjects. The experimental phase of the study lasted from 01/10/04 to 16/06/05.

Table 3.1: Test battery for determining subjects' physical performance parameters

Parameters	Tests	Objectives
Comrades Marathon 2005 performance	<ul style="list-style-type: none"> ◆ The actual time taken to complete the Comrades Marathon 2005 run. 	<ul style="list-style-type: none"> ◆ To determine whether the intervention exercise programme was successful in assisting the experimental group to improve their 2005 Comrades Marathon performance.
Participation profile of sample group	<ul style="list-style-type: none"> ◆ Compilation of the sample group's performances in specific races during the 2005 Comrades Marathon athletic training season. These races consist of: the Crescent 21.1km run, Athletics North 42.2 km run, Buffalo 42.2 km run, Two Oceans Marathon and Comrades Marathon 2005. 	<ul style="list-style-type: none"> ◆ Firstly to construct an athletic profile for the sample group for these specific races; then to compare the sample group's (both experimental group and the control group) performance in these races after the completion of the intervention programme to the previous years' results, when they did not engage in a high intensity endurance resistance strength programme. The criteria for confirming improved performance were: faster 2005 Comrades Marathon completion time, and the other specified races.
Injury Profile (appendix C)	<ul style="list-style-type: none"> ◆ A sport injury questionnaire, which determined the injury and persistence of this injury during the last five 	<ul style="list-style-type: none"> ◆ Subjects completed this questionnaire, which enabled the author to identify the various sport injuries that they contracted during

	years. This was compared to the incidence of injury experienced by the control and experimental groups during the 2005 Comrades Marathon training season.	the Comrades Marathon preparation.
Physical characteristics	<ul style="list-style-type: none"> ◆ Body mass ◆ Height ◆ 3 skinfold site measurements. 	<ul style="list-style-type: none"> ◆ Determine each subject's body mass. ◆ Determine subject's height. ◆ Determine subject's percentage of body fat.
Aerobic energy system	<ul style="list-style-type: none"> ◆ 10km Time trial 	<ul style="list-style-type: none"> ◆ Determine subject's 10 km completion time.
Short-term energy system	<ul style="list-style-type: none"> ◆ 400m-Sprint test 	<ul style="list-style-type: none"> ◆ Determine subject's 400m-sprint completion time and thereby indicating the short-term energy system performance.
Immediate energy system	<ul style="list-style-type: none"> ◆ Wingate anaerobic cycle test 	<ul style="list-style-type: none"> ◆ Determine subject's peak power output and thereby estimate immediate energy system capacity.
Abdominal muscular endurance	<ul style="list-style-type: none"> ◆ One-minute sit-ups test 	<ul style="list-style-type: none"> ◆ Determine subject's abdominal muscular strength and endurance.
Upper body muscular endurance	<ul style="list-style-type: none"> ◆ One-minute press-up test 	<ul style="list-style-type: none"> ◆ Determine subject's upper body muscular strength and endurance.
Lower limb dynamic muscle strength	<ul style="list-style-type: none"> ◆ Dynamic back-leg lift strength test 	<ul style="list-style-type: none"> ◆ Determine subject's dynamic lower back and leg strength.

3.3 Administration of test battery

A graduate research assistant, who had been thoroughly trained in the proper execution of the tests, assisted the author in administering the test batteries. Caution and patience were practiced throughout the study. In the interests of obtaining accurate records and due to the length of the test battery, only twenty subjects were tested per day.

3.4 Description of the intervention exercise programme

The author identified easily accessible venues, where subjects from the different clubs could converge and supervised training of the intervention exercise programme could take place. The author supervised the intervention exercise programme to the RST group during the initial seven training sessions. This was done to ensure proper execution of technique during training and safety from injury. Thereafter the author regularly visited the RST group to observe their respective resistance training sessions. The RST group exercised two days per week with their intervention exercise programme, in addition to their primary endurance run training. After each resistance strength training session the subjects were required to rest for 24 hours before attempting the next resistance training session (but this does not necessarily mean rest from their running training). A description of the high intensity muscle endurance resistance training programme appears in table 3.2.

Table 3.2: High intensity endurance resistance intervention exercise programme

Muscle	Exercise	Sets	Reps	Resistance
Back	Wide grip Latissimus dorsi Pull downs	2	20	70% x body mass
	Bent over flyes	2	20	10% x body mass
Legs	Squats	2	20	70% x body mass
	Leg extensions	2	20	60% x body mass
	Hamstring curls	2	20	40% x body mass
	Adductors/abductors	2	20	40% x body mass
	Calves	2	20	40% x body mass
Pectorals	Flat bench press	2	20	40% x body mass
Deltoids	Press behind the neck	2	20	30% x body mass
	Lateral raises	2	20	10% x body mass
Biceps	Barbell curls	2	20	25% x body mass
Triceps	Dips	2	20	Body mass
	Push downs	2	20	30% x body mass
Core	Crunches	2	15	
	Transverse crunches	2	15	
	Knee raises	2	15	
	Lateral hip curls	2	15	
	Pelvic lifts	2	15	
	Superman	2	15	

NB:

- ◆ Warm-up: +/- 5km run
- ◆ Statically stretch all major muscle groups before and after training.

The above intervention programme was a supplement to the endurance runners' normal run training (which progressively increased in intensity). After consultation with endurance runners' prior to the study, the author feared that

if the intervention programme possessed any progression (in terms of duration and/or intensity) this would jeopardize the subjects' adherence to the intervention programme and therefore no progression was included.

3.5 Control of the extraneous factors influencing the cohorts of the study

The following control measures negated the effects of the extraneous factors influencing the cohorts of the study:

- The experimental and control groups belonged to a close-knit group of homogenous recreational marathoners who adhered to the same traditional Comrades Marathon training programme. Therefore the running injuries common to marathoners could equally affect both groups.
- The sample group was restricted to Comrades Marathon finishers who officially completed a minimum of three up runs (from Durban to Pietermaritzburg) and two down runs (from Pietermaritzburg to Durban). This eliminated the possible effects of the learning curve that runners undergo during the initial few years of running the Comrades Marathon.
- The experimental and control groups of this study invited the author to attend a lecture that discussed sport nutrition. The lecture discussed the benefits of sport nutrition before, during and after the Comrades Marathon, as well as the potential disaster of poor sport nutrition

before, during and after the Comrades Marathon. The cohorts of the study were exposed to the same sport nutritional advice.

- All the participants of the experimental and control groups lived in the province of KwaZulu-Natal, thereby experiencing the same weather patterns that affected both groups' Comrades Marathon training preparations.
- Finally, the only difference between the groups was that the experimental group supplemented their traditional Comrades Marathon training with the intervention programme, whilst the control group only adhered to their traditional Comrades Marathon training programme.

3.6 Test protocols

3.6.1 Comrades Marathon 2005

Objective: To record the subject's actual completion time, thereby determining whether the intervention exercise programme was useful in improving the subject's performance.

Scoring: The completion time was recorded in minutes. The subject's completion time was compared to their previous attempts. A faster 2005 Comrades Marathon completion time indicated that the intervention exercise programme was successful in assisting the experimental group.

3.6.2 Participation profile of the sample group

Objective: To record the sample groups' (both control and experimental groups) performance in selected races for the 2005 Comrades Marathon athletic season, thereby ascertaining whether the intervention exercise programme was beneficial to the experimental group.

Method: The following races were selected;
21.1km Crescent Challenge, Athletic North 42.2 km Marathon, Buffalo 42.2 km Marathon, the Two Oceans 56 km Ultramarathon, and the 2005 Comrades Marathon.

The completion times for each race for the 2005 Comrades Marathon athletic season was compared to previous races' completion times, which were used to determine whether the intervention programme was successful in improving the experimental group's running performance over a variety of different distances. This analysis also served to determine at which distance the intervention exercise programme was of greatest benefit to the runners.

Scoring: The completion times were recorded in minutes. Faster post-intervention race completion times indicated an improvement in

race performance, thereby indicating that the intervention programme was successful in assisting the experimental group.

3.6.3 Physical characteristics

3.6.3.1 Body mass (Coopoo, 1995)

Equipment: A Detecto scale (manufactured in Webb City, USA).

Last calibration was performed on 01/09/04.

Method: The body mass was recorded with subjects only wearing their shorts. All subjects were weighed without their shoes.

Scoring: The body mass was recorded in kilograms (to one decimal point).

3.6.3.2 Height (Coopoo, 1995)

Equipment: A Detecto stadiometer scale (manufactured in Webb City, USA).

Last calibration was performed on 01/09/04.

Method: The subject stood on the stadiometer in an upright, erect position with the head in the Frankfurt position. The stadiometer arm was lowered to the person's vertex to measure their height.

Scoring: The height was recorded in centimetres (to one decimal point).

3.6.3.3 Skinfolds (Scales, 1998)

Equipment: Lange skinfold calliper.

Method: The skinfold calliper reading was a measurement of the compressed thickness of a double layer of skin and the underlying subcutaneous tissue, which was assumed to be adipose tissue. The skinfold thickness was measured by grasping a fold of skin and the underlying subcutaneous tissue between the thumb and forefinger, 1-2cm above the site that was to be measured. The skinfold was pulled away from the underlying muscle and the jaws of the calliper were placed on either side of the site, at a depth of 1cm. The skinfold was held firmly throughout the application of the calliper and the reading was taken when the needle became steady after the full pressure of the calliper jaw had been applied. The calliper was applied at right angles to the fold at all times.

All measurements are recorded on the right hand side, except the abdominal site, which was measured on the left. All measurements are recorded in millimetres. Tolerance limit for skinfold measurements was 1,5 mm.

Chest: The technician made a mark at half the distance from the anterior axillary fold (the front of the armpit) and nipple. The technician then grasped the chest skinfold 1cm diagonally above the mark, that is with long axis of the skinfold towards the nipple. The technician applied the calliper's jaw point across the skinfold, 1cm inferior to the grasp.

Abdominal: Measured in a vertical plane five centimetres to the left of the subject's umbilicus.

Mid thigh: Measured at the mid point on the anterior surface of the thigh with fold parallel to the long axis of the thigh. The subject's body mass was concentrated on the leg that was not being measured, so that the knee joint of the ipsilateral leg formed an angle of 120°.

Scoring: The sum of the above mentioned three site skinfolds were equated to the age predicted body fat values found on the percent body fat chart (Morrow, et al., 1995 cited in Scales, 1998).

3.6.3.4 10km Time trial

Objective: To determine the subject's 10 km completion times.

Equipment: Athletic track/field, stopwatch and whistle.

Procedure: The test commenced on the blow of the first whistle. Subjects were required to run 10 kilometres at a fast, steady pace. Once the subject had completed the distance, the whistle was blown. This signalled the termination of the test. Immediately on completion of the run, the subject's completion time was recorded.

Scoring: The completion time was recorded in minutes (to one decimal point).

3.6.3.5 400m-Sprint test

Objectives: To determine the subject's fastest 400m-sprint completion time and thereby indirectly determine subject's short-term energy system efficiency.

Equipment: Athletic track/field, stopwatch and a whistle.

Method: The 400m-sprint commenced on the blow of the first whistle. The subject ran as fast as possible to complete the distance. Once the subject completed the distance, the whistle was blown for a second time. This signalled the end of the test. Immediately on completion of the test the subject's 400m-completion time was recorded.

Scoring: The quickest time to complete the 400m was recorded in seconds (to one decimal point). The faster the 400m-sprint time, the more efficient the short-term energy system. Subjects had two trials.

3.6.3.6 Wingate anaerobic cycle test (McArdle, et al., 1996)

Equipment: Monark ergometer.

Objectives: To determine subject's peak power output and thereby indirectly estimate their immediate energy system's capacity.

Method: Athlete warmed up by cycling for 10 minutes. The actual test lasted for 30 seconds. Within three seconds a fixed resistance was applied to the flywheel and the athlete continued to pedal "all out" for 30 seconds. An electrical counter continuously

recorded the flywheel's revolutions in five-second intervals. The flywheel resistance equated 0.075 kg per kg body mass.

Scoring: The scoring was obtained by computing the subject's revolution per minute score into the equation below. Peak Power Output was the highest power output observed in any of the five-second intervals. Peak Power Output (PP) indicated the energy generating capacity of the immediate energy system. Peak Power Output was calculated as follows:

$$\begin{aligned} \text{PP} &= \text{Force} \times \text{distance} \div \text{time} \\ &= (\text{rpm} \times \text{distance}/\text{rev.}) / 0.0833 \text{ minutes} \\ &= \text{kg m}/\text{min}. \end{aligned}$$

3.6.3.7 One minute sit-up test (Coopoo, 1995)

Objective: To indirectly determine subject's abdominal muscular strength and endurance.

Equipment: One gym mat and a stopwatch.

Method: The subject assumed a supine position on the mat, with fingers interlocked behind the neck, knees bent and feet held flat on the mat by the examiner (starting position). The examiner knelt,

straddled across the subject's feet, placing his hands on the calves of the subject's leg just below the back of the knee to prevent the subject from sliding and to maintain the starting position throughout the test. The subject was not required to perform the sit-up continually.

Scoring: The movement "sit-up and return" was counted as one execution. The score was the total number of completed executions performed in 60 seconds.

3.6.3.8 One minute press-up test (Coopoo, 1995)

Objective: To indirectly determine the subject's upper body muscular strength and endurance.

Equipment: One gym mat and a stopwatch.

Method: Subject was asked to lay down in a prone position with legs together. Hands were pointed forward and positioned under the subject's shoulders. Subject pushed up from the floor by straightening elbows and keeping the body straight. Subject lowered body to an inch above the ground. This completed one press-up execution.

Scoring: After one complete execution the subject was credited with one press-up. Bending of the back, sagging of the abdomen and elbows not fully extended resulted in the subject being credited with half a press-up.

3.6.3.9 Lower back-leg lift dynamic strength test

Objective: To determine the subject's lower back and leg dynamic strength.

Equipment: One lower back-leg lift dynamometer.

Method: Subject partially squatted on the end plate of the dynamometer. Subject then gripped a bar, which was chained to the dynamometer. The starting position was in a partial squat position. On the "go" signal the subject attempted to straighten his legs and stand erect. The force exerted by the subject to straighten his body was recorded as the subject's lower back and leg dynamic strength.

Scoring: Tester read and recorded the score of the dynamometer. The subject had two trials. The score was recorded in kilograms (to one decimal point).

3.7 Data analysis

Inferential and differential statistical methods were employed in order to analyse data such as t-tests, ANOVA, correlation, tables and graphs.

Windows Excel was used to analyse the data.

CHAPTER FOUR: DISCUSSION OF RESULTS

4.1 Control of factors that may affect validity of results

4.1.1 Introduction

4.1.2 Comparison of pre-intervention physical characteristics of the control and experimental groups

4.1.3 Comparison of pre-intervention physical performance parameters of the control and experimental groups

4.1.4 Comparison of run training profiles of the control and experimental groups from 01/10/04 to 16/06/05

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4.1.6 Conclusion

4.2 The effects of a high intensity muscle endurance resistance programme on Comrades Marathon completion times

4.2.1 Conclusion

4.3 The effects of the intervention programme on the experimental group's 21.1km and 42.2km race performances

4.4 Comparison of the post-intervention physical characteristics of the control and experimental groups

4.4.1 The effects of the intervention programme on the control and experimental groups' physical characteristics

4.4.2 Conclusion

4.5 The effects of the intervention programme on the control and experimental groups' physical performance parameters

4.5.1 The effects of the intervention programme on the control and experimental groups' 10km time trial performances

4.5.2 The effects of the intervention programme on the control and experimental groups' 400m sprint times

4.5.3 The effects of the intervention programme on the control and experimental groups' immediate energy system's capacity

4.5.4 The effects of the intervention programme on the control and experimental groups' abdominal muscle strength and endurance

4.5.5 The effects of the intervention programme on the control and experimental groups' upper body muscle strength and endurance

4.5.6 The effects of the intervention programme on the control and experimental groups' lower body dynamic strength

4.5.7 Conclusion

4.6 Comparison of sport injuries experienced by the control and experimental groups

CHAPTER FOUR

DISCUSSION OF RESULTS

4.1 Control of factors that may affect validity of results

4.1.1 Introduction

The primary aim of this study was to determine if a high intensity muscle endurance resistance programme, in addition to the normal run training, would result in faster completion times for Comrades Marathon runners. Proving the above could be controversial as a whole host of other factors might also contribute to faster completion times for the Comrades Marathon runners. These factors must be either eliminated or satisfactorily controlled in order for the results to be deemed reliable. Therefore, this study must demonstrate clearly that improvements in the Comrades Marathon completion times, if found, could only have resulted from the high intensity muscle endurance resistance programme. The above potential problem was addressed in the following ways: the use of a comparable control group, the maintenance of comparable lifestyles and the control of other external and internal influences during the periods for which the results were compared.

The subjects for this study were randomly allocated into a control and experimental group, which were treated identically except that the

experimental group was subjected to a high intensity muscle endurance resistance programme. A major concern of the author was to adequately demonstrate that the two groups were comparable. This concern was addressed in the following way: comparison between the groups' pre-intervention physical characteristics, pre-intervention physical performance parameters, run training profiles and previous Comrades Marathon profiles.

4.1.2 Comparison of pre-intervention physical characteristics of the control and experimental groups

Table 4.1. The mean scores (standard deviation) of the control and experimental groups' pre-intervention physical characteristics

Variables	Control (n= 53)	Experimental (n= 57)	Percent difference	Significance (p-value)
Age (yrs)	41.9(9.3)	41.9(9.3)	0	p>0.05
Body mass (kg)	68.2(11.3)	68.2(12)	0	p>0.05
Height (cm)	176.0(14)	176.0(14)	0	p>0.05
% Body Fat	16.8(6.4)	17.7(7.1)	+4.7%	p>0.05
Fat-free mass (%)	83.06(6.3)	81.86(7.7)	-1.4%	p>0.05

It is interesting to note that the mean body fat percentage values of the subjects of this study is slightly above the 50th percentile indicated by McArdle, et al. (1996) as 15% body fat. A lower percentage of body fat would have been expected for endurance runners. Barrett and Ellapen (2005) found

similar (17.3% body fat) values in a group of recreational endurance runners. This differs widely from the 8% body fat (McArdle, et al., 1996) found in elite endurance runners. It is postulate that the higher than normal fat percentage amongst this cohort was due to them being recreational endurance runners' and not elite endurance runners.

4.1.3 Comparison of pre-intervention physical performance parameters of the control and experimental groups

Table 4.2. The mean scores (standard deviation) of the control and experimental groups' pre-intervention physical performance parameters

Variables	Control (n= 53)	Experimental (n= 57)	Percent Difference	Significance (p-value)
10km (min.)	51.1(8.5)	51.1(8.6)	0	p>0.05
400m (sec.)	85.0(6.0)	85.1(6.2)	+0.1	p>0.05
Wingate (kg m/min)	5850.0(203.0)	5850.0(203.0)	0	p>0.05
Sit-ups (reps./min)	27.7(6.9)	27.7(6.9)	0	p>0.05
Press-ups (reps./min)	18.5(9.9)	18.5(9.9)	0	p>0.05
Lower body strength (kg)	105.1(5.6)	105.0(5.6)	-0.09	p>0.05

The primary objective of the pre-intervention tests was to determine whether any significant differences existed in the physical performance parameters between the groups which would have made the control group unsuitable for comparison to the experimental group in the post-intervention test. Table 4.2

demonstrates that the pre-intervention mean scores (standard deviations) of the control and experimental groups' physical performance parameters are almost identical and non-significantly ($p > 0.05$) different, thus making them comparable. This closeness of mean scores is due to the random selection from a homogenous group of recreational runners who shared similar training schedules, participated in the same races and followed similar diets.

4.1.4 Comparison of run training profiles of the control and experimental groups from 01/10/04 to 16/06/05

Table 4.3. The mean (standard deviation) run training mileage log for both the control and the experimental groups from 01/10/04 to 16/06/05

Groups	Oct. 2004	Nov. 2004	Dec. 2004	Jan. 2005	Feb. 2005	Mar. 2005	Apr. 2005	May 2005	June 2005
Control (n=53)	160km (3.7)	199.9km (5.7)	160km (5.1)	200km (3.8)	240km (4.1)	300km (3.6)	360km (5.3)	400km (3.6)	79.9km (1.5)
Experimental (n=57)	160km (5.8)	199.9km (5.7)	159.9km (5.4)	200km (4.7)	239.9km (4.5)	300km (3.9)	360km (4.9)	400km (3.5)	79.9km (1.7)
Significance (p-value)	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$	$p > 0.05$

Table 4.3 indicates the comparable run training mileage completed by the control and experimental groups from 01/10/04 to 16/06/05, which did not significantly ($p > 0.05$), differ. The almost identical mean values for the control and experimental groups is due to the fact that they all form part of a closely

knit group of running clubs sharing the same training programmes and participating in the same races. A critical delimitation that allowed subjects eligibility to participate in the study was the fact that they were seasoned Comrades Marathoners who would continue with their previous run training schedules. This delimitation eliminated the influence of different training programmes on the outcome of the study. The control and experimental groups' average run training mileage from 01/10/04 to 31/01/05 was 179.9 km/month (first 17 weeks of the study). The average run training mileage of both groups from 01/02/05 to 16/06/05 was 275.9km/month (second 17 weeks of the study). This data illustrates that the runners, during their second 17 weeks of the study, trained more intensely. Normally from February to 16 June endurance runners run more road races, because of the following reasons:

- The KwaZulu-Natal Athletics Association co-ordinated more road races
- Endurance runners participated in more races during this time in order to adapt themselves to environmental race day conditions.

4.1.5 Comparison of previous Comrades Marathon performances of the control and experimental groups

The purpose of this section is to illustrate the close range of completion times of both groups in their previous Comrades Marathons when neither group was subjected to an additional muscle endurance resistance programme.

Table 4.4 The mean (standard deviation) Comrades Marathon completion times of the control and experimental groups from 2000 to 2004

Years	2000 (Up)	2001 (Down)	2002 (Up)	2003 (Down)	2004 (Up)
Control Group (n=53)	627.1(87.1)	643.4 (72)	647.4 (88.9)	639.1 (80.2)	650.0(80.9)
Experimental Group (n=57)	627.1(87.1)	640.1(93.8)	632.0(88.8)	630.5(91)	625.0(85.8)
Percent difference (%)	0	-0.5	-2.3	-1.3	-3.8
Significance (p-value)	p>0.05	p>0.05	p>0.05	p>0.05	p>0.05

Table 4.4 displays the comparative but statistically non-significant ($p > 0.05$) Comrades Marathon completion times of the control and experimental groups from 2000 to 2004. The random division of the homogenous population group (who prescribed to similar traditional run training programmes) into control and experimental groups was responsible for producing the close range of Comrades Marathon completion times. The control group's Comrades Marathon mean completion time for the races from 2000-2004 ranged from 627.1 – 650.0 minutes. The experimental group's Comrades Marathon mean completion time from 2000-2004 ranged from 625.0 – 640.1 minutes. The control group's mean Comrades Marathon completion time for the specified four year period (2000-2004) was 641.43 minutes. The experimental group's mean Comrades Marathon completion time for the same specified four year period (2000-2004) was 630.9 minutes.

4.1.6 Conclusion

The author finally concluded that the control and experimental groups had comparable pre-intervention physical characteristics, pre-intervention physical performance parameters and run training profiles for the entire duration of the study as well as previous Comrades Marathon completion times. Thereafter, all differences between the control and experimental groups' Comrades Marathon completion times, physical characteristics and physical performance parameters was attributed to the high intensity muscle endurance resistance training programme, which only the experimental group was subjected to.

4.2 The effects of a high intensity muscle endurance resistance programme on Comrades Marathon completion times

Data collected during the study will be presented and examined to determine whether the high intensity muscle endurance resistance programme had improved the experimental group's 2005 Comrades Marathon times. This will be accomplished by comparing the experimental group's post-intervention Comrades Marathon times with that of the control group, and with their own previous years' performances.

The experimental group's post-intervention Comrades Marathon mean completion times (585.8 minutes) differed significantly ($p < 0.05$) from that of the control group (645.4 minutes) by 9.2%. The experimental group, on

average, completed the 2005 Comrades Marathon 59.6 minutes faster than the control group (with an average running speed of 40.8 seconds faster per kilometer than the control group). To further substantiate the findings, namely that the intervention programme resulted in faster Comrades Marathon completion times for the experimental group, the post-intervention results were compared with those of previous Comrades Marathon down runs (2001 and 2003). Data collected indicated that the post-intervention Comrades Marathon was completed in the fastest time (585.8 minutes) followed by the 2003 performance (630.5 minutes) and then the 2001 performance (640.1 minutes). A comparative analysis of variance (ANOVA) of the above data proved to be significant ($p < 0.05$). The ANOVA reported no significant difference ($p > 0.05$) between 2001 and 2003 completion times. However considerable differences ($p < 0.05$) occurred between 2005 and 2001 and 2005 and 2003 completion times. Data indicated that the Comrades Marathon 2005 completion times proved to be the most significant ($p < 0.05$) amongst the three years.

The selection of the comparison of fastest previous individual down run Comrades Marathon completion times with that of the post-intervention Comrades Marathon completion times ultimately distinguished the success that the intervention programme had achieved with regard to the experimental group. The fastest previous individual down run times were significantly ($p < 0.05$) slower than 2005 completion times by 5.9% (the experimental group ran an average speed of 24.6 seconds faster per kilometer in 2005). This achievement is outstanding, when consideration is given to the effect of

ageing on runners' performance (as runners age, they begin to run slower). Seventy-four percent of the experimental group improved from their fastest individual down run Comrades Marathon times, whilst 3.5% ran identical times and 22.5% did not improve. It is hypothesized that the following adaptations in combination might have produced the faster post-intervention Comrades Marathon performance:

- During the 2005 Comrades Marathon training season the experimental group was subjected to the high intensity muscle endurance resistance training programme, whereas in other years they were not. The intervention programme increased subjects' total body muscle strength and endurance, which helped them to maintain an efficient running posture and co-ordination (improved running biomechanics). It is proposed that the improved running biomechanics economized their running energy expenditure, which improved their running performance. Fordyce (1996); Brukner and Khan (2000) & Noakes (2001) advocate that resistance strength training helps runners to maintain an efficient running posture. These structural strengthening exercises assist runners to acquire better muscle symmetry. The symmetrical muscle balance induces a more effective agonist/antagonist muscle relationship, which leads to better running biomechanics (Brukner and Khan, 2000). Johnson, et al. (1995) have reported that core and upper body strength training delay the onset of fatigue in the upper limb, upper body and postural musculature during endurance running, thereby maintaining efficient running

biomechanics, which facilitate faster running performances. Resistance strengthening of surrounding musculature (agonistic, antagonist and stabilizer muscles) of joints enhances their co-activation and contraction, which improves running biomechanics and eventually produces faster running (Kyrolainen, et al., 2001). Poor running biomechanics (e.g. dropped head, rounded shoulders, externally rotated feet and a shuffling gait) increase the runner's energy expenditure, which produces slower running speeds (Hogbrog, 1952; Heinert, 1988 & Hauswirth, 1999). Slower running speeds produce slow race completion times. Efficient running biomechanics allows the runners to expend less energy per stride, thereby producing an energy-sparing effect. This conserved energy is used to help the runner to run faster (Nelson and Gregor, 1976; Heinert, 1988; Minetti, 1994; & Hauswirth, 1999). The key component to improved running economy is the ability to store and recover elastic energy from muscle contractions, which increase the force generated by the muscles. The greater force generated per stride produces an optimal stride length, which allows the runner to complete a given distance quicker at the same stride frequency, subsequently reducing his energy expenditure, thus leading to running biomechanical efficiency (Dolezal and Potteiger, 1998; Johnson, et al., 1995 & Jung 2003). It is postulated that the ability to generate greater force per stride is derived from the intervention programme, which increases the capability of the lower limb musculature to contract stronger (producing more energy) and thereby storing more elastic energy, which subsequently allows for

greater recovery of this stored elastic energy. Concurrent, high intensity muscle endurance resistance training with running has documented no effect on runners' VO_{2max} and lactate thresholds, but significant improvements in running biomechanics and total body muscle strength and endurance. The improved running biomechanics and total body muscle strength and endurance has been identified as the influencing factors that are responsible for the runners' subsequent improved running performance (Allen, et al., 1976; Wilmore, et al., 1978; Gettman, et al., 1979, Hurley, et al., 1984; Marcinik, et al., 1985; Dolezal and Potteiger, 1998; Tanaka and Swensen, 1998 & Jung, 2003).

- The intervention programme reduced the experimental group's percent body fat by 22.6% (refer to table 4.5, page 135). The control and experimental groups' pre-intervention percent body fat has been documented as high (16.8% and 17.7% respectively) in comparison to sedentary males (15%) and elite endurance runners (8%) (McArdle, et al., 1996). This study's sample population was a homogenous group of recreational endurance runners whose endurance running goals differed from elite runners. Their main goals in endurance running were to have fun and better their previous completion race times. Recreational endurance runners do not pay close attention to their daily nutrition as compared to elite runners, and as a result their energy intake exceeds their energy output. These runners tend to consume food rich in fat, protein and cholesterol and drink excessive amounts of alcohol. It is hypothesized that the subjection of the experimental

group to the intervention programme increased their energy output over and beyond their regular energy expenditure. The experimental group consisted of seasoned recreational endurance runners who had the ability to liberate energy from their body fat stores for the regular completion of the intervention programme. The ability to liberate energy during running from body fat stores is a training adaptation of seasoned endurance runners (McArdle, et al., 1996). This regular additional liberation of energy from fat consequently helped the experimental group to reduce their high percentage of body fat by 22.6%. Mahadeva (1953) and Clément and Hall (1988) state that a reduction in runners' percentage of body fat improves their running biomechanics, thereby enabling them to expend lesser energy per stride, thus conserving energy, which is used later to increase running speed. The reasoning that the experimental group became lighter in body mass (due to a reduction in percentage of body fat) which could have allowed them to expend less energy while running, and thereby allowing them to run faster, is invalid (refer to table 4.5, page 135). The experimental group's body mass remained relatively the same (refer to table 4.5, page 135). The experimental group's post-intervention increased percentage of fat-free mass (+4.8%) allowed them to increase the force generated per stride. The greater force generated per stride produced an optimal stride length, which allowed the runners to complete a given distance quicker using the same stride frequency, subsequently reducing their energy expenditure, thus leading to an improved running biomechanical efficiency (Dolezal and

Potteiger, 1998; Johnson, et al., 1995 & Jung 2003). The enhanced running biomechanics helped runners to run faster. It is postulated that the ability to generate greater force per stride was derived from the intervention programme, which increased the capability of the lower limb musculature to contract more strongly (producing more energy) and thereby storing more elastic energy, which subsequently allowed for greater recovery of this stored elastic energy.

- The intervention programme improved the experimental group's abdominal muscle strength and endurance (27.8%), upper body muscle strength and endurance (32.4%), and lower body dynamic strength (28.9%), which improved their running biomechanics, thereby enhancing their running (refer to table 4.6, page 139). Marcinik, et al. (1991) showed that high intensity muscle endurance resistance training increased lower limb strength by 41%. These researchers have suggested that the increased lower limb muscle strength was an influencing factor responsible for improved endurance running performance (Marcinik, et al., 1991). It is proposed that the increased upper body muscle strength and endurance and abdominal muscle strength and endurance helped the experimental group to maintain an efficient running posture, which facilitated an improved economy of motion. This improved economy of motion helped the runners to run faster. Johnson, et al. (1995) have documented that core and upper body strength training help delay the onset of fatigue in the upper limb, upper body and postural musculature during endurance running,

thereby maintaining efficient running biomechanics, which facilitates faster running performances.

- The intervention programme was designed to increase the structural/musculoskeletal joint integrity and stability. The author recorded all injuries that the control and experimental groups experienced from 01/10/04 to 16/06/05 (refer to tale 4.7, page 150). It is hypothesized that the increased structural/musculoskeletal joint integrity of the experimental group helped to stabilize their joints, which reduced the incidence of injury, thereby improving running performance. The experimental group experienced a significant ($p < 0.05$) 43.3% reduction in the incidence of total number of injuries as compared to the control group. Kyrolainen, et al. (2001) have documented that musculoskeletal joint strengthening increases musculoskeletal joint integrity and stability, which facilitates faster running.

4.2.1 Conclusion

The data presented and discussed justifies the claim that the high intensity muscle endurance resistance training programme was responsible for the experimental group's 2005 Comrades Marathon success. Evidence provided earlier (in section 4.1) eliminates all suspicion that any other internal or external influencing factors may have contributed to the success of the experimental group's 2005 Comrades Marathon. The experimental group's

2005 Comrades Marathon performance was faster than the control group's 2005 Comrades Marathon performance, as well as the experimental group's previous attempts.

4.3 The effects of the intervention programme on the experimental group's 21.1km and 42.2km race performances

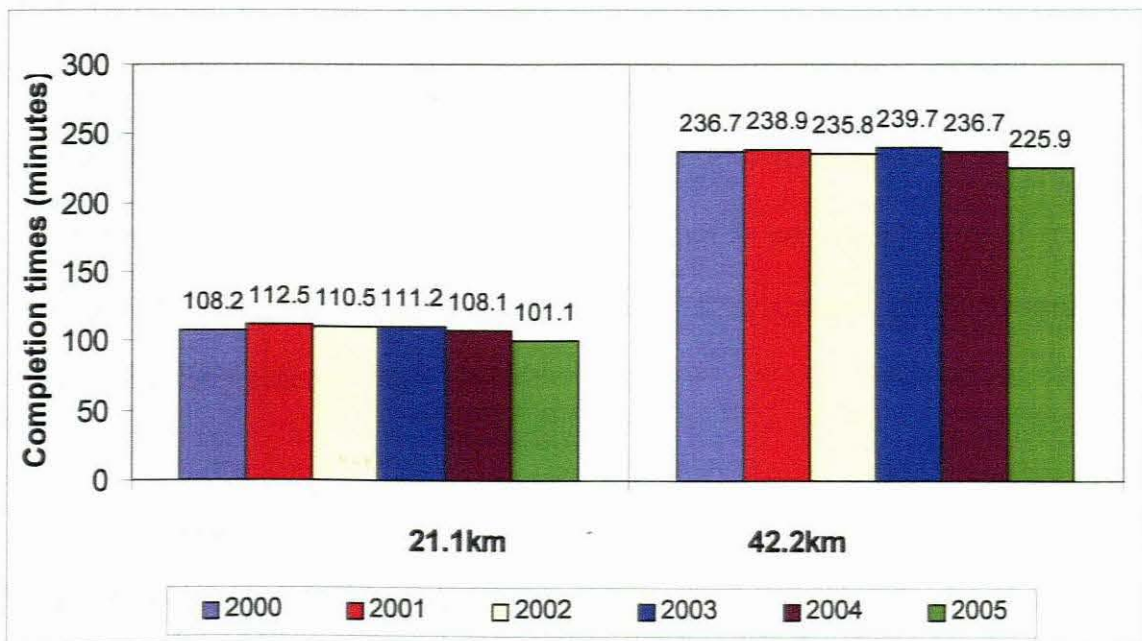


Figure 4.1. The effects of the intervention programme on the experimental group's 21.1km and 42.2km races

The intervention programme had a positive impact on the runners' performances in the shorter distances. ANOVA demonstrated that the experimental group ran significantly ($p < 0.05$) faster in 2005 than other years in both the 21.1km and 42.2km races. A comparative t-test between the 2004 (second fastest 21.1km) and the post-intervention 21.1km (fastest 21.1km)

race times proved to be significant ($p < 0.05$). The experimental group was able to run an average of 19.9 seconds faster per kilometer for the post-intervention 21.1km (which is a 6.5% improvement). The experimental group's post-intervention 21.1km completion times were 3.4% quicker than their fastest previous individual 21.1km completion times. Similarly, the experimental group also enjoyed a 3.4% improvement in their post-intervention 42.2km race times in comparison to their fastest previous individual 42.2km completion times. A strong correlative relationship existed between the experimental group's 21.1km and 42.2km post-intervention performances ($r = 0.78$). It is postulated that the intervention programme was successful in improving the experimental group's running performance by enhancing their running economy. This evidence serves to strengthen the success of the experimental group's post intervention 2005 Comrades Marathon performance.

4.4 Comparison of the post-intervention physical characteristics of the control and experimental groups

A secondary aim of the study was to determine the effects of the high intensity muscle endurance resistance programme on the physical characteristics of seasoned Comrades Marathoners. This knowledge will help the reader to gain a more comprehensive understanding of the benefits of the intervention programme. The objective of the review of the post-intervention physical

characteristics is to determine whether any significant statistical deviations (as well as the magnitude of deviation) occurred from the pre-intervention test.

4.4.1 The effects of the intervention programme on the control and experimental groups' physical characteristics

Table 4.5 The comparative display of the control and experimental groups' physical characteristics (mean (standard deviation))

Variables	CONTROL GROUP (n=53)				EXPERIMENTAL GROUP (n=57)			
	Pre-test	Post-test	Percent difference	t-test significance p-value	Pre test	Post-test	Percent difference	t-test significance p-value
Age (yrs)	41.9(9.3)	42.1(9.7)	+0.5	p> 0.05	41.9(9.3)	42.1(9.7)	+0.5	p>0.05
BM (kg)	68.2(11.3)	67.6(10.4)	-0.9	p>0.05	68.2(12)	67.5(9.4)	-1.0	p>0.05
Height (cm)	176.0(14)	176.0(14)	0	p>0.05	176.0(14)	176.0(14)	0	p>0.05
%BF	16.8(6.4)	16.8(6.3)	0	p>0.05	17.7(7.1)	13.7(4.3)	-22.6	p< 0.05
% Fat free mass	83.0(6.3)	83.0(6.3)	0	p>0.05	82.3(7.7)	86.3(4.4)	+4.8	p<0.05

The post-intervention test results revealed negligible, non-significant ($p > 0.05$) changes to the control group's body mass, percentage of body and percentage of fat-free mass (refer to table 4.5). The experimental group's post-intervention body mass indicated a statistically non-significant ($p > 0.05$) change. The experimental group's post-intervention percent body fat displayed a significant ($p < 0.05$), 22.6% reduction and a reciprocal 4.8% increase in percent fat-free mass. Table 4.5 illustrates a negligible 0.1 kg

difference between the control and experimental groups' post-intervention test body mass measurements. Analysis of table 4.5 indicates that the experimental group's post-intervention percentage of body fat decreased and percentage fat-free mass increased in comparison to the control group's (which remained the same as their pre-intervention results). It is proposed that the subjection of the experimental group to the intervention programme increased their energy output over and beyond their regular energy expenditure. The experimental group consisted of seasoned recreational endurance runners who had the ability to liberate energy from their body fat stores for the regular completion of the intervention programme. The ability to liberate energy from body fat stores during running is a training adaptation of seasoned endurance runners (McArdle, et al., 1996). A prerequisite for eligibility to participate in the study was that the control and experimental groups had to be a part of a homogenous group of runners, who were seasoned, trained endurance runners. This regular additional liberation of energy from fat subsequently helped the experimental group to reduce their high percentage of body fat by 22.6% (refer to table 4.5, page 135). The reduced percentage of body fat assisted the experimental group by enhancing their running biomechanics, which improved their running performance. Mahadeva (1953) and Clément and Hall (1988) state that reduction in runners' percentage of body fat (which decreased their body mass) improved their economy of motion, thereby enabling the runners to decrease their energy expenditure per stride, thus conserving energy, which was used later to increase running speed. Runners who have a higher percentage of body fat expend more energy when running at a given speed over a given distance

as compared to runners with a lower percentage of body fat (McArdle, et al., 1996). Runners who possess a higher percentage of body fat and body mass have poorer economy of motion and therefore, generally, run slower when compared to runners who possess a lower percentage of body fat and body mass (McArdle, et al., 1996). The intervention programme helped the experimental group to significantly ($p < 0.05$) reduce their percentage of body fat (22.6%) and simultaneously increase their percentage of fat-free mass (4.8%), thereby maintaining the same relative body mass (refer to table 4.5, page 135). The experimental group's post-intervention percentage of fat-free mass increased by 4.8%, allowing them to increase the force generated per stride. The greater force generated per stride produced an optimal stride length, which allowed the runners to complete a given distance quicker using the same stride frequency, subsequently reducing their energy expenditure, thus leading to an improved running biomechanical efficiency (Dolezal and Potteiger, 1998; Johnson, et al., 1995 & Jung 2003). The enhanced running biomechanics helped runners' to run faster. The intervention programme helped the experimental group to decrease their percentage of body fat and increase their percentage of fat-free mass that, in combination, improved their running biomechanics. It is postulated that the ability to generate greater force per stride was derived from the intervention programme, which increased the musculature of the lower limb's capability to contract stronger (producing more energy) and thereby storing more elastic energy, which subsequently allowed for greater recovery of this stored elastic energy.

4.4.2 Conclusion

The intervention programme was responsible for the significant ($p < 0.05$) 22.6% body fat loss and reciprocal 4.8% percent fat-free mass increase, which improved the experimental group's running biomechanics, thereby facilitating a faster running performance.

4.5 The effects of the intervention programme on the control and experimental groups' physical performance parameters

An additional aim of the study was to determine the effects of the high intensity muscle endurance resistance programme on the physical performance parameters of seasoned Comrades Marathoners. This evidence will assist the reader to better comprehend the benefits of the intervention programme, thereby allowing the reader to determine whether these training benefits' helped to facilitate the experimental group's faster completion time of the Comrades Marathon. This will be accomplished by reviewing the post-intervention physical performance parameters in order to determine whether any significant statistical deviations from the pre-intervention test (and the magnitude of change) occurred. These selected physical performance parameters consisted of: aerobic system (10km run), short-term energy system (400m-sprint test), immediate energy system (Wingate anaerobic cycle test), abdominal muscle strength and endurance (one-minute sit-up test), upper body muscle strength and endurance (one-minute press-up test)

and dynamic lower body strength (dynamic back-leg lift strength test). Table 4.6 represents the pre- and post-intervention results of the physical performance parameters of the control and experimental groups.

Table 4.6 The comparative display of the control and experimental groups' physical performance parameters (mean (standard deviation))

CONTROL GROUP (n=53)					EXPERIMENTAL GROUP (n=57)			
Variables	Pre-test	Post-test	Percent difference	t-test significance p-value	Pre test	Post-test	Percent difference	t-test significance p-value
10 km (min.)	51.1(8.5)	50.0(7.3)	-2.1	p> 0.05	51.1(8.6)	44.9(6.6)	-12.1	p< 0.05
400m-sprint (sec)	85.0(6.0)	84.9(5.9)	-0.1	p> 0.05	85.1(6)	60.8(2.7)	-28.5	p< 0.05
Wingate (kg m/min)	5850(203)	5846.3(203)	0	p> 0.05	5850(203)	6804.4(166)	+16.3	p< 0.05
Sit-ups (rep/min.)	27.7(6.9)	27.7(6.1)	0	p> 0.05	27.7(6.9)	35.4(5.5)	+27.8	p< 0.05
Press-ups (reps/min)	18.5(9.9)	18.4(9.3)	-0.5	p> 0.05	18.5(9.9)	24.5(9.7)	+32.4	p< 0.05
Lower body strength (kg)	105.1(5.6)	103.0(5.5)	-1.9	p> 0.05	105.0(5.6)	135.3(8.8)	+28.9	p< 0.05

4.5.1 The effects of the intervention programme on the control and experimental groups' 10km time trial performances

The 10km time trial run was employed to indicate any running improvement (being a sport specific and functional test). Yeager (2004); Walsh (2001) & Noakes (2001) have reported that improvement in a runner's 10 km race

times indicated a trend of improvement in their Comrades Marathon completion time. Noakes (2001) has extrapolated runners' Comrades Marathon completion times from their endurance 10km race time, thereby indicating the importance of this physical performance parameter. At the pre-intervention test, the control as well as the experimental group ran the 10km time trial in 51.1 minutes (refer to table 4.6, page 139). At the post-intervention test the control group experienced a statistical, non-significant ($p > 0.05$) 2.1% improvement, whilst the experimental group experienced a significant ($p < 0.05$) 12.1% improvement (refer to table 4.6, page 139). It is assumed that the same adaptations that were responsible for the experimental group's significant ($p < 0.05$) post-intervention Comrades Marathon performance produced a significant ($p < 0.05$) 10km time trial improvement (refer to 4.2, page 121). The intervention programme improved the experimental group's running biomechanics via the following mechanisms:

- The intervention programme increased the experimental group's total body strength and endurance, which allowed them to generate greater force per stride. This greater force per stride produced an optimal stride length, which allowed runners' to complete the given distance quicker by using the same stride frequency. The generation of the greater force per stride length was derived from the intervention programme, which increased the experimental group's lower limb musculature capability to contract more strongly, thereby producing more energy, which helped to create an optimal stride length.

- The intervention programme helped the experimental group to significantly ($p < 0.05$) decrease their percentage of body fat (22.6%) and increase their percentage of fat-free mass (4.8%), which, in combination, improved their running biomechanics by producing a more efficient stride length. It is proposed that the subjection of the experimental group to the intervention programme increased their energy output over and beyond their regular run training energy expenditure, reduced their body fat percentage and increased their percentage of fat-free mass. It is postulated that the ability to generate greater force per stride was derived from the intervention programme, which increased the lower limb's musculature capability to contract more strongly (producing more energy) and thereby storing more elastic energy, which subsequently allowed for greater recovery of this stored elastic energy.
- The intervention programme increased the experimental group's abdominal and upper body muscle strength and endurance as well as lower body dynamic strength, which together facilitated a more efficient running posture, thereby enhancing their running biomechanics. Johnson, et al. (1995) have documented the fact that core and upper body strength training helped delay the onset of fatigue in the upper limbs, upper body and postural musculature during endurance running, thereby maintaining efficient running biomechanics, which facilitates faster running performances. Marcinik, et al. (1991) showed that high intensity muscle endurance resistance training increased lower limb strength, which was the influencing factor responsible for improved

endurance running performance in their subjects (Marcinik, et al., 1991).

4.5.2 The effects of the intervention programme on the control and experimental groups' 400m sprint times

The 400m-sprint test was administered to measure the subjects' short-term energy system efficiency. The control and experimental groups ran almost identical pre-intervention 400m-sprint test completion times (refer to table 4.6, page 139). The control group's post-intervention 400m-sprint time non-significantly ($p > 0.05$) improved by 0.1% but, interestingly, the experimental group's post-intervention 400m-sprint performance significantly ($p < 0.05$) improved by 28.5%. It is postulated that the following adaptations in combination might have produced the experimental group's significant 400m-sprint time improvement:

- The intervention programme increased the experimental group's total body muscle strength and endurance, which improved their running biomechanics. The improved running biomechanics conserved energy expended during running, which was used to increase running speed.
- The intervention programme enhanced the individuals' short-term energy systems' efficiency. The duration of each exercise set was approximately 60 seconds; repetitions per exercise set were 20, and the subsequent rest interval between each exercise set was a

maximum of 15 seconds. Although one set of exercises would not improve the runners' short-term energy systems, the repetitive sets of exercises would have had an accumulative fatigue effect. This accumulative fatigue effect on the short-term energy system (termed lactate stacking) might have produced the enhanced energy capacity. It has been well documented that high intensity muscle endurance resistance training and high intensity resistance circuit training does improve endurance runners' short-term energy systems' efficiency (Allen, et al., 1976; Wilmore, et al., 1978; Gettman, et al., 1979; Hurley, et al., 1984; Marcinik, et al., 1985; McArdle, et al., 1996; Dolezal and Potteiger, 1998; Tanaka and Swensen, 1998; Beachle and Earle, 2000 & Jung, 2003). These cross-training programmes are able to enhance an individual's short-term energy system efficiency by the duration of each exercise set (0-45 seconds), the rest intervals between each exercise set (0-30 seconds), and the frequent repetition per exercise set (minimum of 20 repetitions per set) (Dolezal and Potteiger, 1998; Tanaka and Swensen, 1998; Beachle and Earle, 2000 & Jung, 2003). The accumulative fatigue produced by the repetitive exercise sets mimics the concept of lactate stacking, which eventually produces an enhanced short-term energy system (Hermansen, 1971 & McArdle, et al., 1996).

4.5.3 The effects of the intervention programme on the control and experimental groups' immediate energy system's capacity

The Wingate anaerobic cycle test results provided an indication of the subjects' immediate energy system capabilities. The control and experimental groups had identical pre-intervention test performances (5850 kg m/min). The control group maintained this similar immediate energy system capacity after the 34-week period. The intervention programme was performed at high intensity and maximal effort, which significantly ($p < 0.05$) improved the experimental group's Wingate anaerobic cycle test performance by 16.3% (refer to table 4.6, page 139). The intervention programme increased the lower limb musculature strength, because of the number of lower limb exercises it contained (refer to table 3.2, page 104). It is postulated that the increased lower limb strength improved the lower limb's immediate energy systems capacity. Marcinik, et al. (1991) showed that high intensity muscle endurance resistance training increased lower limb strength by 41%. These researchers have suggested that the increased lower limb muscle strength was an influencing factor responsible for improved endurance running performance (Marcinik, et al., 1991).

4.5.4 The effects of the intervention programme on the control and experimental groups' abdominal muscle strength and endurance

It is interesting to note that the mean pre-intervention one-minute sit-up test score of the subjects (27.7 repetitions per minute) of this study is slightly below the 50th percentile indicated by McArdle, et al. (1996) as 32 repetitions per minute. A higher one-minute sit-up test score would have been expected for endurance runners. The one-minute sit-up test is a field test, from which the runners' abdominal muscle strength and endurance was indirectly inferred. Good abdominal strength and endurance facilitates better respiration, which enhances running economy, thereby increasing running performance (McArdle, et al., 1996). The control group was able to maintain identical, non-significant ($p > 0.05$) abdominal strength and endurance status at post-intervention test, while the experimental group was able to significantly ($p < 0.05$) increase their abdominal muscle strength and endurance by 27.8% (refer to table 4.6, page 139). The intervention programme improved the experimental group's abdominal muscle strength and endurance, because it contained specialized abdominal strengthening exercises e.g. crunches and full sit-ups (refer to table 3.2, page 104). It is hypothesized that the experimental group's improved abdominal muscle strength and endurance helped them to attain an efficient running posture, which improved their running biomechanics. Johnson, et al. (1995) have documented that abdominal muscle strengthening helps delay the onset of fatigue in the postural musculature during endurance running, thereby maintaining efficient running biomechanics, which facilitate faster running performances.

4.5.5 The effects of the intervention programme on the control and experimental groups' upper body muscle strength and endurance

The control group's mean pre-intervention test score (18.5 repetitions per minute) was below the expected 50th percentile (22 repetitions per minute) for the one-minute press-up test score for endurance runners (McArdle, et al., 1996). The one-minute press-up test is a field test employed to indirectly infer the runner's upper body muscular strength and endurance. The control group was able to sustain a relatively consistent upper body muscular strength and endurance status (producing a negligible upper body muscle strength and endurance change). In contrast, the experimental group's post-intervention upper body muscle strength and endurance status significantly ($p < 0.05$) improved by 32.4%, because the intervention programme contained specialized upper body exercises (e.g. bench press, latissimus dorsi pull downs, shoulder press, frontal raises – refer to table 3.2, page 104). It is proposed that the increased upper body strength and endurance helped the experimental group to maintain a more efficient running posture, which economized their energy expenditure per stride, thereby improving their running. Johnson, et al. (1995) have reported that upper body strength training helps delay the onset of fatigue in the upper limbs, upper body and postural musculature during endurance running, thereby maintaining efficient running biomechanics, which facilitate faster running performances.

4.5.6 The effects of the intervention programme on the control and experimental groups' lower body dynamic strength

The control and experimental group shared relatively similar mean pre-intervention lower body dynamic strength values (refer to table 4.6, page 139). The control group's lower-body dynamic strength results remained relatively constant after the 34-week period of the study thus indicating no improvement (refer to table 4.6, page 139). The intervention programme helped the experimental group to increase their lower body dynamic strength by 28.9% because it contained many specialized abdominal, lower back and lower limb exercises (e.g. crunches, full sit-ups, superman, squats, leg extensions, hamstring curls, abductor and adductors resistance exercises – refer to table 3.2, page 104). The increased lower body strength helped runners to generate greater force per stride, thereby creating an optimal stride length, which allowed the runners to complete a given distance quicker by using the same stride frequency, subsequently reducing energy expenditure, and thus leading to running biomechanical efficiency and improved running performance. It is postulated that the ability to generate greater force per stride was derived from the intervention programme, which increased the capability of the lower limb musculature to contract stronger and store more elastic energy, which subsequently allowed for greater recovery of this stored elastic energy. Dolezal and Potteiger (1998), and Tanaka and Swensen (1998) documented significant lower limb strength improvement after endurance runners had been strength and endurance run trained concurrently – an intervention which they advocate was responsible for the improved

running economy in that it facilitated faster running. Marcinik, et al. (1991) reported that high intensity muscle endurance resistance training increased lower limb strength (41%) which was an influencing factor responsible for improved running economy, which facilitates faster running amongst their subjects (Marcinik, et al., 1991).

4.5.7 Conclusion

Data gathered and analyzed revealed the following evidence:

- The high intensity muscle endurance, resistance training programme that supplemented endurance run training succeeded in significantly ($p < 0.05$) reducing the experimental group's 10km time trial by 12.1%.
- The high intensity muscle endurance, resistance training programme that supplemented endurance run training succeeded in significantly ($p < 0.05$) improving the experimental group's 400m-sprint-time trial by 28.5%.
- The high intensity muscle endurance, resistance training programme that supplemented endurance run training succeeded in significantly ($p < 0.05$) improving the experimental group's Wingate anaerobic cycle test scores by 16.3%.
- The high intensity muscle endurance, resistance training programme used as a supplement to endurance run training did significantly ($p < 0.05$) improve the experimental group's one minute sit-up test scores by 27.8%.

- The high intensity muscle endurance, resistance training programme used in supplementing endurance run training did significantly ($p < 0.05$) improve the experimental group's one minute press-up test scores by 32.4%.
- The high intensity muscle endurance, resistance training programme that supplemented endurance run training did significantly ($p < 0.05$) improve the experimental group's lower body dynamic strength by 28.9%.

4.6 Comparison of sport injuries experienced by the control and experimental groups

Although all runners intend to improve their physiological conditioning through running, it is during this time that they are placed under great risk of developing sport injuries. In this study the researcher considered a sport injury to be damage to tissue, which prevented the subject from running for longer than 72 hours.

Table 4.7: Comparative statistics of sport injuries experienced by the control and experimental groups from 01/10/04 to 16/06/05 (the experimental period of the study)

Injury site	Control (n=53)	Experimental (n=57)	Percent Difference (%)
Knee	20	10	-50
Achilles tendon & calf	18	4	-77.8
Metatarsal	15	9	-40
Toenails/blisters	9	9	0
Hip/groin	9	5	-44.4
Heel	8	8	0
Ankle	7	4	-42.8
Shin	5	3	-40
Nerve injuries (lower limb)	5	4	-20
Quadriceps	4	1	-75
Hamstrings	3	1	-66.7
Back	1	1	0
Sum	104	59	-43.3

The experimental group experienced a significant ($p < 0.05$) 43.3% lower incidence of total number of injuries than the control group. There were three common injuries that both groups experienced equally, namely: toenails/blisters, heel and back injuries. The toenails/blisters and heel injuries are categorized as overuse injuries caused by the run training mileage. An over-use injury is caused by over-exerting the body by excessive work loads/running (Kent, 1994). Since both groups completed almost identical run mileage, the incidence of toenails/blister and heel injuries should have been equal in number (refer to tables 4.3, page 122 and 4.7, page 150). Close

inspection of table 4.7 reveals that the experimental group suffered fewer structural/musculoskeletal injuries than the control group. The experimental group experienced a significantly ($p < 0.05$) 52.3% lower incidence of musculoskeletal injuries than the control group, i.e. lower incidence of musculoskeletal injuries to the knee, Achilles tendon and calf, metatarsal, hip/groin, ankle, shin, nerves, quadriceps and hamstrings. The identical running mileage (refer to table 4.3, page 122) completed by the control and experimental groups should have produced equal incidence of these musculoskeletal injuries, yet the experimental group did not contract the same number of injuries. The intervention programme increased structural/musculoskeletal joint integrity and stability. It is proposed that the increased structural joint integrity and stability reduced the incidence of injury amongst the members of the experimental group. The intervention programme was a structural, cross-training, strengthening programme, designed on the principle of specificity of conditioning (in that it was intended to increase the muscular strength and endurance of the muscles involved in endurance running, thereby reducing the incidence of injuries) and the principle of progressive overload (thereby increasing the muscular strength and endurance so as to increase muscle resistance to injury). Brukner and Khan (2000) & Prentice (2004) indicated that regular completion of resistance strength training strengthens muscles, ligaments, tendons and joints, which subsequently reduces the risk and incidence of structural/musculoskeletal injuries. Kyrolainen, et al. (2001) has documented that structural/musculoskeletal joint strengthening increases joint integrity and stability, which reduces the incidence of injury and facilitates faster running.

CHAPTER FIVE: SUMMARY AND RECOMMENDATIONS

5.1 Introduction

5.2 Data collection

5.3 Analysis and discussion of results

5.3.1 Comparison of the control and experimental groups' 2005 Comrades Marathon completion times

5.3.2 The effects of the intervention programme on the physical characteristics of the control and experimental groups

5.3.3 The effects of the intervention programme on the physical performance parameters of the control and experimental groups

5.4 **The effects of the intervention programme on the incidence of sport injuries on the control and experimental groups**

5.5 Recommendations

CHAPTER FIVE

SUMMARY AND RECOMMENDATIONS

This chapter entails a summary of the study and recommendations for future research.

5.1 Introduction

The effects of combined resistance strength training and endurance running on running performance had become a popular research topic. Researchers have concluded that cross-training does not increase nor decrease VO_{2max} (Evans, 1995 & Balabaninis, et al., 2003). However, researchers have also documented that resistance strength training does improve running performance (Kyrolainen, et al., 1991; Fordyce, 1996; Paavolainen, et al., 1999; Walsh, 2001 & Yeager, 2004). The above-mentioned controversial literature has left the endurance runners and sport scientists confused. The primary aim of this study was to determine whether a high intensity muscle endurance resistance programme, in addition to the normal run training, would result in faster completion times for Comrades Marathon runners. Proving the above could have been controversial, as a whole host of other factors could have also contributed to faster completion times for the Comrades Marathon runners. These factors were eliminated or satisfactorily controlled in order to render the results reliable. This study therefore demonstrated clearly that improvements in Comrades Marathon completion

times have only resulted from the high intensity muscle endurance resistance programme. This potential problem was addressed in the following ways: the use of a comparable control group, the maintenance of comparable lifestyles, and the control of other external and internal influences during the periods for which the results were compared.

5.2 Data collection

A sample population of 115 subjects initially volunteered and were then randomly allocated into two groups, namely the control (CT) group and the experimental (RST) group. Initially the CT group constituted 57 subjects, whilst the RST group constituted 58 subjects. However, four subjects from the CT and one subject from the RST failed to complete the pre-intervention test battery, thereby eliminating themselves from the study. The sample size was therefore reduced to 110 subjects, resulting in 53 subjects in the CT group and 57 in the RST group. The following delimitations were imposed onto the study:

- The sample group was restricted to endurance runners who previously completed the Comrades Marathon successfully in less than eleven hours.
- Endurance runners to participate in the study were recruited from athletic clubs in the surrounding areas of Durban.
- The sample group was comprised of male subjects.
- The sample group was limited to individuals between the ages of 25 to 50 years.

- The sample group was restricted to Comrades Marathon finishers who officially completed a minimum of three up runs (from Durban to Pietermaritzburg) and two down runs (from Pietermaritzburg to Durban). This eliminated the learning curve that runners undergo during the initial few years of completing the Comrades Marathon.
- The subjects had to continue with normal running training patterns of previous years.

The researcher's major concern was to adequately demonstrate that the two groups were comparable. This concern was addressed in the following way: comparison between the groups' pre-intervention physical characteristics, pre-intervention physical performance parameters, run training profiles and previous Comrades Marathon profiles. The random allocation of the homogenous population produced two comparable groups.

All subjects underwent a pre-intervention test battery, which was divided into physical characteristics (age, body mass, height, percentage of body fat and percentage of fat-free mass) and physical performance parameters (10km time trial, 400m-sprint test, Wingate anaerobic cycle test, one minute sit-up test, one minute press-up test and dynamic back-leg lift strength test). The primary objective of the pre-intervention test was to determine if any significant differences existed between the groups, which would have made the control group unsuitable for comparison to the experimental group in the post-intervention test. The statistical data analysis of both the groups' pre-intervention test results indicated that the physical characteristics and

performance parameters were almost identical and non-significantly ($p > 0.05$) different and thereby comparable (refer to tables 4.1, page 120 and 4.2, page 121).

To further demonstrate the comparability of the control and experimental groups, the author analysed their run training profiles from 01/10/04 to 16/06/05. Both groups completed equal mean run training mileage for the entire duration of the study (01/10/04 to 16/06/05) that was statistically non-significant ($p > 0.05$) – thereby justifying the claim that both groups had comparable run training mileages for the entire duration of the study (refer to table 4.3, page 122). The almost identical mean values for the control and experimental groups are due to the fact that they all form part of a closely knit group of running clubs sharing the same training programmes and participating in the same races.

The researcher analysed the control and experimental groups' previous Comrades Marathon performances in an attempt to determine if any significant differences existed between the groups, which would have made the control group unsuitable for comparison. The statistical analysis of both the groups' previous Comrades Marathon (2000-2004) completion times proved to be non-significantly ($p > 0.05$) different and thereby comparable (refer to table 4.4, page 124). The random division of the homogenous population group (who prescribed to similar traditional run training programmes) into the control and experimental groups was responsible for producing the close range of Comrades Marathon completion times.

Finally the author concluded that the control and experimental groups had comparable pre-intervention physical characteristics, pre-intervention physical performance parameters, run training profiles for the entire duration of the study and previous Comrades Marathon completion times. Henceforth all differences between the control and experimental groups' Comrades Marathon completion times, physical characteristics and physical performance parameters would be attributed to the high intensity muscle endurance resistance training programme. The RST was subjected to the high intensity muscle endurance resistance training intervention programme as a supplement to their normal endurance run training. The CT continued with traditional endurance run training in preparation for the 2005 Comrades Marathon.

5.3 Analysis and discussion of results

Data collected during the study was examined to determine whether the high intensity muscle endurance resistance programme improved the experimental group's 2005 Comrades Marathon times. This was accomplished by comparing the experimental group's post-intervention Comrades Marathon times with that of the control group, and with their own previous years' performances.

5.3.1 Comparison of the control and experimental groups' 2005

Comrades Marathon completion times

The control group completed the 2005 Comrades Marathon in an average time of 645.4 minutes, whilst the experimental group finished in 585.8 minutes. The experimental group's post-intervention Comrades Marathon performance was significantly ($p < 0.05$) faster than the control group by 59.6 minutes (with an average running speed of 40.8 seconds faster per kilometre than the control group). To further substantiate the findings that the intervention programme resulted in faster Comrades Marathon completion times of the experimental group, the post-intervention results were compared with those of previous Comrades Marathon down runs (2001 and 2003). Data collected indicated that the post-intervention Comrades Marathon was completed the fastest (585.8 minutes) followed by the 2003 performance (630.5 minutes) and 2001 performance (640.1 minutes). A comparative analysis of variance (ANOVA) of the above data proved that the year 2005 was the most significant ($p < 0.05$) of the three years. The comparison of fastest previous individual down run Comrades Marathon completion times with that of the post-intervention Comrades Marathon completion times ultimately validates the successful outcome that the intervention programme provided with regard to the performance of the experimental group. The fastest previous individual down run times were significantly ($p < 0.05$) slower (by 5.9%) than 2005 completion times (the experimental group ran an average speed of 24.6 seconds faster per kilometre). This achievement is outstanding, when consideration is given to the effect of ageing on runners'

performance (as runners' age, they begin to run slower). Seventy-four percent of the experimental group improved from their fastest individual down run Comrades Marathon times, whilst 3.5% ran identical times and 22.5% did not improve. The experimental group's success was attributed to the intervention programme. It was hypothesized that the following adaptations in combination might have produced the faster post-intervention Comrades Marathon performance:

- The intervention programme increased the experimental group's total body muscle strength and endurance which enabled runners to improve their running biomechanics by helping them to maintain an efficient running posture and better co-ordination. The intervention programme's structural strengthening exercises assisted runners to acquire better muscle symmetry. The improved symmetrical muscle balance induced a more effective agonist/antagonist muscle relationship, which led to improved running biomechanics. The key component to improved running economy is the ability to store and recover elastic energy from muscle contractions, which increases the force generated by the muscles. The greater force generated per stride produces an optimal stride length, which allows the runner to complete a given distance quicker at the same stride frequency, subsequently reducing his energy expenditure, and thus leading to running biomechanical efficiency. It is postulated that the ability to generate greater force per stride was derived from the intervention programme, which increased the capability of the lower limb musculature to contract stronger (producing more energy) and thereby

storing more elastic energy, which subsequently allowed for greater recovery of this stored elastic energy.

- The intervention programme significantly ($p < 0.05$) reduced the experimental group's percentage of body fat (-22.6%) and reciprocally increased their percentage of fat-free mass (+4.8%). The reduction in percentage of body fat did not produce a statistically corresponding reduction in body mass (refer to table 4.5, page 135). The increased muscle strength generated greater force per stride which produced an optimal stride length, which allowed the runners to complete a given distance quicker at the same stride frequency, subsequently reducing energy expenditure, and thus leading to running biomechanical efficiency. The enhanced running biomechanics helped runners to run faster.
- The intervention programme increased the experimental group's abdominal muscle strength and endurance, upper body muscle strength and endurance and lower body dynamic strength. It is postulated that the improvements in the above-mentioned physical performance parameters helped to produce running biomechanical efficiency, which enhanced running speed. The increased abdominal and upper body strength and endurance helped the runners to maintain a more efficient running biomechanical posture by delaying the onset of fatigue in their abdominal, upper limb, upper body and postural muscles while running. The increased lower body dynamic strength increased the force generated per stride, which improved their running

biomechanics. These strength adaptations in combination helped them to run faster.

- The intervention programme increased the structural/musculoskeletal joint integrity and stability. It is postulated that the increased structural/musculoskeletal joint integrity and stability reduced the total incidence of overuse injury experienced by the experimental group by 43.3% as compared to the control group. Close inspection of table 4.7 (page 150) reveals that the experimental group suffered fewer structural/musculoskeletal injuries than the control group. The experimental group experienced a significantly ($p < 0.05$) 52.3% lower incidence of musculoskeletal injuries than the control group, i.e. lower incidence of musculoskeletal injuries to the knee, Achilles tendon and calf, metatarsal, hip/groin, ankle, shin, nerves, quadriceps and hamstrings.

5.3.2 The effects of the intervention programme on the physical characteristics of the control and experimental groups

The intervention programme was able to significantly ($p < 0.05$) reduce the experimental group's percentage of body fat (-22.6%) and reciprocally increase their percentage of fat-free mass (+4.8%). The reduction in percentage of body fat did not produce a statistically corresponding reduction in body mass (refer to table 4.5, page 135).

5.3.3 The effects of the intervention programme on the physical performance parameters of the control and experimental groups

After 34 weeks of traditional aerobic-based run training, the control group was able to negligibly ($p > 0.05$) improve their 10km completion times by -2.1% (refer to table 4.6, page 139). The control group was unable to improve their 400m-sprint time, Wingate anaerobic test performance, one-minute sit-up performance, one-minute press-up performance and lower body dynamic strength performance (refer to table 4.6, page 139).

The experimental group's post-intervention test results indicated statistically significant ($p < 0.05$) improvements in their 10km completion times (-12.1%), 400m-sprint test (+28.5%), Wingate anaerobic test performance (+16.3%), one-minute sit-up test score (+27.8%), one-minute press-up test score (+32.4%), and lower body dynamic strength (+28.9%) (refer to table 4.6, page 139). It is proposed that the above-mentioned physical performance parameter improvements assisted the experimental group to run faster. The increased abdominal and upper body strength and endurance helped the runners to maintain a more efficient biomechanical running posture by delaying the onset of fatigue in their abdominal, upper limb, upper body and postural muscles while running. The increased lower body dynamic strength increased the force generated per stride, which improved their running biomechanics. These strength adaptations in combination helped them to run faster.

5.4 The effects of the intervention programme on the incidence of sport injuries on the control and experimental groups

The intervention programme increased the structural/musculoskeletal joint integrity and stability of the members of the experimental group. It is proposed that the increased structural/musculoskeletal joint integrity and stability reduced the total incidence of overuse injury experienced by the experimental group by 43.3% as compared to the control group. Close inspection of table 4.7 (page 150) reveals that the experimental group suffered fewer structural/musculoskeletal injuries than the control group. The experimental group experienced a significantly ($p < 0.05$) 52.3% lower incidence of musculoskeletal injuries than the control group, i.e. lower incidence of musculoskeletal injuries to the knee, Achilles tendon and calf, hip/groin, metatarsal, ankle, shin, nerves, quadriceps and hamstrings.

5.5 Recommendations

The following recommendations are suggested for future research:

- A follow-up investigative study to determine the physiological and biochemical adaptations brought about by the above intervention programme, which improved the endurance runners' comrades marathon performance.

- The effects of a high intensity muscle resistance training programme as a supplement to normal endurance run training of female Comrades Marathoners.
- A comparative study on the effects of a high intensity muscle resistance training programme as a supplement to normal endurance run training of male and female Comrades Marathoners.
- The effects of an aqua-training programme as a supplement to normal endurance run training of Comrades Marathoners.
- A comparative study on the effects of a high intensity muscle resistance training programme versus an aqua-training programme as a supplement to normal endurance run training of Comrades Marathoners.

The dissemination of the findings of this study will be through publications in South African Journal of Research in Sport, Physical Education and Recreation, African Journal of Physical, Health Education, Recreation and Dance, Runner's World, local newspaper and lectures, conferences and symposia.

REFERENCE LIST

ABE, D., YANAGAWA, K., YAMANOBE, K. and TAMURA, K. (1998). Assessment of middle-distance running performance in sub-elite young runners using energy cost running. European Journal of Applied Physiology, 77: 320-325

ALFREDSON, H. and LORENTZON, R. (2000). Chronic Achilles tendinosis: recommendations for treatment and prevention. Sports Medicine, 29(2): 138-148

ALLEN, T.E., BYRD, R.J. and SMITH, D.P. (1976). Hemodynamic consequences of circuit weight training. Research Quarterly, 47: 299-306

ALMOND, C.S., SHIN, A.Y., FORTESCUE, E.B., MANNIX, R.C., WYPIJ, D., INSTADT, B.A., DUNCAN, C.N., SALERNO, A.E., NEWBURGER, J.W. and GREENES, D.S. (2005). Hyponatraemia amongst runners in the Boston Marathon. New England Journal of Medicine, 325 (15): 155- 1556

BAHR, R. and MAEHLUM, S. (2004). Clinical guide to sport injuries. Champaign, IL: Human Kinetics

BALABANINIS, C.P., PSARAKIS, C.H., MOUKAS, M., VASSILIOU, M.P. and BEHRAKIS, P.K. (2003). Early phase changes by concurrent endurance and strength training. Journal of Strength and Conditioning Research, 71(2): 393-401

BALADY, G.J.; BERRA, K.A.; GOLDING, L.A., GORDON, N.F., MAHLER, D.A., MYERS, J.N. and SHELDAHL, L.M. (2001). ACSM's guidelines for exercise testing and prescription (6th Edition). Philadelphia: Lippincott Williams & Wilkins

BAQUET, G. GUINHOUYA, C., DUPONT, G., NOURRY, C. and BERTHOIN, S. (2004). Effects of short-term interval training programme on physical fitness in prepubertal children. Journal of Strength and Conditioning Research, 18(4): 708- 713

BARRETT, L.P. and ELLAPEN, T.J. (2005). The effects of a high intensity muscle endurance resistance training programme on road runners' 10km performance. Unpublished manuscript. University of Zululand

BASSETT, D.R. and HOWLEY, E.T. (2000). Limiting factors for maximum oxygen uptake and determinants of endurance performance. Journal of Sport Medicine and Physical Fitness, 32(1): 70-84

BEACHLE, T.R. and EARLE, R.W. (2000). Essentials of Strength Training and Conditioning. Champaign, IL: Human Kinetics

BECKHAM, S.G. and EARNEST, C.P. (2000). Metabolic cost of free weight circuit weight training. Journal of Sport Medicine and Physical Fitness, 40(2): 118-125

BEERS, M.H., FLETCHER, A.J., JONES, T.V. and PORTER, R. (2003). The Merck manual of Medical Information (2nd Home Edition). New York: Pocket Books

BERG, K., OLSEN, R., MCKINNEY, M., HOFSCHIRE, P., LATIN, R. and BELL, W. (1989). Effect of reduced training volume on cardiac function, VO₂max, and running performance. Journal of Sport Medicine and Physical Fitness, 29(3): 245-252

BERGSTORM, J.L., HERMANSEN, L., HULTMAN, E. and SALTIN, B. (1967). Diet, muscle glycogen and physical performance. Acta Physiologica Scandinavica, 7: 140 – 150

BISHOP, D., JENKINS, D.G. and MACKINNON, L.T. (1999). The effects of strength training on endurance performance and muscle characteristics. Medical and Science in Sports and Exercise, 31(6): 886-891

BRUKNER, P. and KHAN, K. (2000). Clinical Sports Medicine. New York: The McGraw Hill Companies

BURCH, G.E. (1979). Of Jogging. American Heart Journal, 97: 407

BUSHMAN, B.A., FLYNN, M.G., ANDRES, F.F., LAMBERT, C.P., TAYLOR, M.S. and BRAUN, W.A. (1997). Effects of 4 weeks of deep water run training on running performance. Medicine and Science in Sports and Exercise, 29(5): 694-699

CARAFFA, A., CERULLI, G., PROJETTI, M., ASIA, G. and RIZZO, A. (1996). Prevention of anterior cruciate ligament injuries in soccer: A prospective controlled study of proprioception training. Knee Surgery Sports Traumatology Arthroscopy, 4: 19-21

CASABURI, R. (1987). Effects of endurance training on possible determinants of VO_2 during heavy exercise. Journal of Applied Physiology, 62: 199

CHILLAG, S.A. (1986). Endurance athletes: Physiologic changes and nonorthopedic problems. South African Medical Journal, 79(100): 1264-1272

CHTARA, M., CHAMARI, K., CHAOUACHI, M., CHAOUACHI, A., KOUBAA, D., FEKI, Y., MILLET, G.P. and AMRI, M. (2005). Effects of intra-session concurrent endurance a training sequence on aerobic performance and capacity. British Journal of Sports Medicine, 39(8): 555-560

CLAREMENT, A.P. and HALL, S.J. (1988). Effects of extremity loading on energy expenditure and running mechanics. Medicine and Science in Sports and Exercise, 20: 161

COETZER, P., NOAKES, T.D., SANDERS, B., LAMBERT, M.I., BOSCH, A.N. and WIGGINS, T. (1993). Superior fatigue resistance of elite black South African distance runners. Journal of Applied Physiology, 75(4): 1822-1827

COOPOO, Y. (1995). The effects of exercise and diet on selected physiological and biochemical parameters in a sedentary Indian male cohort. Doctor of Philosophy. Durban: University of Durban Westville

COSTILL, D.L. (1988). Carbohydrates for exercise: Dietary demands for optimal performance. International Journal of Sports Medicine, 9(1): 1-18

COWAN, S.M., BENNELL, K.L., CROSSLEY, K.M. HODGES, P.W. and McCONNELL, J. (2002). Physical therapy alters recruitment of the vasti in patellofemoral pain syndrome. Medicine and Science in Sports and Exercise, 34(12): 1879-1885

CROSSLEY, K.M, COWAN, S.M., McCONNELL, J. and BENNELL, K.L. (2005). Physical therapy improves knee flexion during stair ambulation in patellofemoral pain. Medicine and Science in Sports and Exercise, 37(2): 176-183

DARIES, H.N, NOAKES, T.D. and DENNIS, G.I. (2000). Effects of fluid intake volume on 2-hour running performance in a 25°C environment. Medicine and Science in Sports and Exercise, 32: 1783-1789

DAVIES, C.T. (1980). Effects of wind assistance and resistance on forward motion of a runner. Journal of Applied Physiology, 48(4): 702-709

DAVIMES, L. and LEVINRAD, I. (1990). An evaluation of hamstring/quadriceps strength ratios in elite long distance runners and sprinters. South African Journal Sports Medicine, 5(1): 16-20

DeLORNE, T.L. and WATKINS, A.L. (1951). Progressive resistance exercise. New York: Appleton-Century-Crofts

DEMAERE, J.M. and RUBY, B.C. (1997). Effects of deep water and treadmill running on oxygen uptake and energy expenditure in seasonally trained cross-country runners. Journal of Sport Medicine and Physical Fitness, 37(3): 175-181

DENNIS, S.C. and NOAKES, T.D. (1999). Advantages of a smaller body mass in humans when distance running in warm, humid weather. Journal of Applied Physiology, 79(3): 280-284

DEVEREAUX, M.D., PARR, G.R., LACMANN, S.M., PAGE THOMAS, D.P. and HAZELMAN, B.L. (1986). Thermographic diagnosis in athletes with patellofemoral arthralgia. Journal of Bone and Joint Surgery, 68(B) 42-44

DOLEGNER, F.A., KOLKHORST, F.W. and WHITSETT, D.A. (1994). Long slow distance training in novice marathoners. Research Quarterly Exercise and Sport, 65(4): 339-346

DOLEZAL, B.A. and POTTEIGER, J.A. (1998). Concurrent resistance and endurance training influence basal metabolic rate in non dieting individuals. Journal of Applied Physiology, 85(2): 695 – 700

DURSTINE, J.L. and MOORE, G.E. (2003). ACSM's Exercise management for persons with chronic diseases and disabilities (2nd Edition). Champaign, IL: Human kinetics

DUTTO, D.J. and BRAUN, W.A. (2004). DOMS-associated changes in ankle and knee joint dynamics during running. Medicine and Science in Sports and Exercise, 36(4): 560-566

DYE, S.F., VAUPEL, G.L. and DYE, C.C. (1998). Conscious neurosensory mapping of the internal structures of the human knee without intra-articular anaesthesia. American Journal of Sports Medicine, 26: 773-777

EKBLOM, B. (1969). Effects of training on circulatory response to exercise. Journal of Applied Physiology, 24: 518

ESFARJANI, F. and LAURSEN, P.B. (2006). Manipulating high intensity interval training: Effects on VO₂max, the lactate threshold and 3000m running performance in moderately trained males. Journal of Sport Medicine and Physical Fitness, 2: 22-28

EVANS, W.J. (1995). The ageless athlete. Muscle and Fitness, 1: 142-144

EYESTONE, E.D., FELLINGHAM, G., GEROGE, J. and FISHER, A.C. (1993). Effects of water running and cycling on maximum oxygen consumption and 2-mile run performance. American Journal of Sports Medicine, 21(1): 41-44

FARRELL, P.A., WILMORE, J.H., COYLE, E.F., BILLING, J.E. and COSTILL, D.L. (1979). Plasma lactate accumulation and distance running performance. Medicine and Science in Sports and Exercise, 11(4): 338-344

FORDYCE, B. (1996). Run the Comrades. Johannesburg: Delta Books

FRANCH, J., MADSEN, K., DJURHUUS, M.S, and PEDERSEN, P.K. (1998). Improved running economy following intensified training correlates with reduced ventilatory demands. Medicine and Science in Sports and Exercise, 30(8): 1250-1256

FREDERICSON, M and WEIR, A. (2006). Practical management of iliotibial band friction syndrome in runners. Clinical Journal of Sport and Medicine, 16(3): 261-268

FREDERICSON, M. and WOLF, C. (2005). Iliotibial band syndrome in runners: Innovations in treatment. Medicine and Science in Sports and Exercise, 35(5): 451-459

GALLOWAY, M.T., JOKI, P. and DAYTON, O.W. (1992). Achilles tendon overuse injuries. Clinical Sports Medicine, 11(4): 771-782

GARRETT, W.E. (1990). Muscle strain injuries. Clinical and basic aspects. Medicine and Science in Sports and Exercise, 22(4): 436-443

GETTMAN, L.R., ARYES, J.J., POLLOCK, L., DURSTINE, L. and GRANTHAM, W. (1979). Physiological effects on adult men of circuit strength training and jogging. Physician Sports medicine, 9: 44-60.

GHOUSSOUB, K., GHANEM, I., SABBAGH, S., HASSANS, A., KARRAT, K. and DAGHER, F. (2003). Results of long-term rehabilitation in the treatment of patellofemoral syndrome: Retrospective study about 63 patients. Le Journal Medicine Libanalis, 51(4): 198-205

GIBBON, W.W., COPPER, J.R. and RADCLIFFE, G.S. (1999). Sonographic incidence of tendon micro tears in athletes with chronic Achilles tendinosis. British Journal of Sports Medicine, 33: 129-130

GISOLFI, C.V. SUMMERS, R.D., SCHEDL, H.P. and LEILER, T.L. (1995). Effects of sodium concentration to a carbohydrate-electrolyte solution on intestinal absorption. Medicine and Science in Sports and Exercise, 27: 1414-1420

GOSS, F.L. and KARAM, C. (1987). The effects of glycogen supercompensation on the electrocardiographic response during exercise. Research Quarterly for Exercise and Sport, 58(1): 68-71

GOUDIE, A.M.; TUNSTALL-PEDOE, D.S; KERINS, M. and TERRIS, J. (2006). Exercise associated hyponatraemia after a marathon: case series. Journal of Royal Society of Medicine, 99 (7): 363-367

HAENNEL, R., TEO, K., QUINNEY, A. and KAPPAGODA, T. (1989). Effects of hydraulic circuit training on cardiovascular function. Medicine and Science in Sports and Exercise, 21 (5): 605-612

HAGBERG, J.M. (1998). Expanded blood volumes contribute to increased cardiovascular performance of endurance-trained older men. Journal of Applied Physiology, 85: 484

HARBER, M.P., GALLAGHER, P.M., CREER, A.R., MINCHEV, K.M and TRAPPE, S.W. (2004). Single muscle fibre contractile properties during a competitive season in male runners. American Journal of Physiology, 287(5): R1124-131

HARRIS, K and HOLLY, R.G. (1987). Physiological response to circuit weight training in borderline hypertensive subjects. Medicine and Science in Sports and Exercise, 19: 246-252

HARTE, L.E., EGIER, B.P., SHIMIZU, A.G., TANDAN, P.G. and SUTTON, J.R. (1980). Exertional heat stroke: the runner's nemesis. Canadian Medical Association, 122(10): 1144-1150

HAUSSWIRTH, C. (1999). Effects of cycling alone or in a sheltered position on subsequent running performance during a triathlon. Medicine and Science in Sports and Exercise, 31: 599

HAZNECI, B., YILDIZ, Y., SEKIR, U., AYDI, T. and KALYON, T.A. (2005). Efficacy of isokinetic exercise on joint position sense and muscle strength in patellofemoral pain syndrome. American Journal of Physiology, Medicine and Rehabilitation, 84(7): 521-527

HEINERT, L.D. (1988). Effects of stride length variation on oxygen uptake during level and positive grade treadmill running. Research Quarterly Exercise and Sport, 59: 127

HEINTJIES, E., BERGER, M.Y., BIERMA-ZEINSTRAS, S.M., BERNSEN, R.M., VERHAAR, J.A. and KOSS, B.W. (2003). Exercise therapy for patellofemoral pain syndrome. Cochrane Database System Review, 4: CD003472

HENNING, C.E. and GRIFFIS, N.D. (1990). Injury prevention of anterior cruciate ligament (videotape). Mid-American Centre for Sports Medicine

HERMANSEN, L. (1971). Lactate production during exercises. In B Pernow and B Saltin, (Edition) Muscle metabolism during exercise. New York: Plenum

HEWETT, T.E. (2000). Neuromuscular and hormonal factors associated with knee injuries in female athletes: Strategies for intervention. Sports Medicine, 29(5): 313-327

HEWETT, T.E, STROUPE, A.L., NANCE, T.A. and NOYES, F.R. (1996). Plyometric training in female athletes: Decreased impact forces and increased hamstring torques. American Journal of Sports Medicine, 24(6): 765-773

HICKSON, R. (1980). Interference of strength development to simultaneous training for strength and endurance. European Journal of Applied Physiology, 45: 225

HICKSON, R.C (1981). Skeletal muscle cytochrome-c and myoglobin, endurance, and frequency of training. Journal of Applied Physiology, 51: 746

HICKSON, R.C. (1985). Reduced training intensities and loss of aerobic power, endurance and cardiac growth. Journal of Applied Physiology, 58: 492

HIGDON, H. (2006). Marathon the ultimate training and racing guide.
London: Rodale International

HILL, A.V. (1927). The air resistance to a runner. Proceedings of the
Royal Society of London (Biology), 102: 380

HILL, A.V. and LUPTON, H. (1923). Muscular exercise, lactic acid and
the supply and utilization of oxygen. Quarterly Medical Journal, 135-
171

HOFF, J., HELGERUD, J. and WISLOFF, U. (1999). Maximal strength
training improves work economy in trained female cross-country skiers.
Medicine and Science in Sports and Exercise, 31(6): 870-876

HOGBOG, P. (1952). Length of stride, stride frequency, flight period
and maximum distance between the feet during running with different
speeds. Internationale Zeitschrift fuer Angewandte Physiologic
Einschliesslich Arbeitsphysiologie, 14: 431

HOLLOSZY, J.O. and COYLE, E.F. (1984). Adaptations of skeletal
muscle to endurance training and their metabolic consequences.
Journal of Applied Physiology, 56: 831

HURLEY, B.F., SEALS, D.R., EHANSI, A.L., CARTIER, C.J., DALSKY, G.P., HAGBERG, J.M. and HOLLOSZY, J.O. (1984). Effects of intensity strength training on cardiovascular function. Medicine and Science in Sports and Exercise, 16: 483-489

IRRGANG, J., SAFRAN, M. and CROOK, S. (1995). The knee: ligamentous and meniscal injuries, in Athletic Injuries and Rehabilitation, edited by J. Zachazewski, D. Magee and W. Quillen. Philadelphia: W.B. Saunders

JACOBS, I. (1987). Sprint training effects of muscle myoglobin, enzymes, fibers and blood lactate. Medicine and Science in Sports and Exercise, 19: 368

JANSEN, E. (1978). Changes in muscle fibre distribution in man. Medicine and Science in Sports and Exercise, 10: 235

JANSEN, E. and KAIJSER, I. (1977). Muscle adaptation to extreme endurance training in man. Acta Physiologica Scandinavica, 100: 315

JENKINS, D. (1985). Ligament injuries and their treatment. Rockville: MD Aspen

JOHNSON, B.D. (1996). Respiratory muscle fatigue during exercise: Implications for performance. Medicine and Science in Sports and Exercise, 28: 1129

JOHNSON, R.E., QUINN, T.J. and KERTZER, R. (1995). Improving running economy through strength training. Strength Conditioning, 17(4): 7-13

JOHNSTON, R.E., QUINN, T.J. and KERTZER, R. (1997). Strength training in female distance runners: impact on running economy. Journal of Strength and Condition Research, 11(4): 224-229

JUNG, A.P. (2003). The impact of resistance training on distance running performance. Journal of Sports Medicine, 33(7): 539 – 552

KENT, M. (1994). The oxford dictionary of sports science and medicine (1st Edition). New York: Oxford University Press

KRIEDER, R.B. (1998). Overtraining in sport. Champaign, IL: Human Kinetics

KRIP, B. (1997). Effects of alteration in blood volume on cardiac function during maximal exercise. Medicine and Science in Sports and Exercise, 29: 1469

KUIPER, M. (1996). How much is too much? Performance aspects of over-training. Research Quarterly for Exercise and Sport, 67: S65

KYROLAINEN, H. KOMI, P.V. and KIM, D.H. (1991). Effects of power training neuromuscular performance and mechanical efficiency. Scandinavian Journal of Medicine and Science in Sports, 1: 78-87

KYROLAINEN, H., BELLI, A., and KOMI, P.V. (2001). Biomechanical factors affecting running economy. Medicine and Science in Sports and Exercise, 33 (8): 1330-7

LANGBERG, H., ELLINGSGAARD, H., MADSEN, T., JANSSON, J., MAGNUSSON, P., AAGAARD, P. and KJAER, M. (2006). Eccentric rehabilitation exercises increases peritendinous type 1 collagen synthesis in humans with Achilles tendinosis. Scandinavian Journal of Medicine and Science in Sports, 2: 55-61

LEE, R.P., BISHOP, G.F. and ASHTON, C.M. (1990). Severe heat stroke in an experienced athlete. Medical Journal Australia, 153(2): 100-104

LEGAZ, A.A., MUNGUIA, I.D. and SERVETO, G. (2006). Physiological measures associated with marathon running performance in high-level male and female homogenous groups. International Journal of Sport Medicine, 27(4): 289-295

MacDOUGALL, J.D. (1998). Muscle performance and enzymatic adaptation to sprint interval training. Journal of Applied Physiology, 84: 21-38

MAHADEVA, K. (1953). Individual variations in metabolic cost of standardized exercises: The effects of food, age, sex and race. Journal of Physiology, 121: 225-228

MARCINIK, E.J., HODGON, J.A., MITTLEMAN, K. and O'BRIEN, J.J. (1985). Aerobic/calisthenic and aerobic/circuit weight training programme for Navy men: A comparative study. Medicine and Science in Sports, 17: 482-487

MARCINIK, E.J., POTTS, J., SCHLABACH, G., WILL, S., DAWSON, P. and HURLEY, B.F. (1991). Effects of strength training on lactate threshold and endurance performance. Medicine and Science in Sports, 23: 739-743

MARIEB, E.N. (2004). Human Anatomy and Physiology (6th Edition). New York: Pearson, Benjamin & Cummings

MARTIN, W.H. III (1997). Effects of endurance training on fatty acid metabolism during whole body exercise. Medicine and Science in Sports, 29: 635

MAUGHAN, R.J. and MILLER, J.D. (1983). Incidence of training-related injuries among marathon runners. British Journal of Sports Medicine, 17(3): 162-165

McARDLE, W.D., KATCH, F.I and KATCH, V.L. (1996). Exercise Physiology (4th Edition). New York: Lippincott, Williams & Wilkins

McARDLE, W.D., KATCH, F.I. and KATCH, V.L. (2001). Exercise Physiology (5th Edition). New York: Lippincott, Williams & Wilkins

McCONNELL, G.K., COSTILL, D.L., WIDRICK, J.J., HICKEY, M.S., TANAKA, H. and GASTIN, P.B. (1983). Reduced training volume and intensity maintain aerobic capacity but not performance in distance runners. International Journal of Sports Medicine, 14: 33-37

McCONNELL, A.K. and SEMPLE, E.S.G. (1996). Ventilatory sensitivity to carbon dioxide: the influence of exercise and athleticism. Medicine and Science in Sports and Exercise, 28: 685

McCRORY, J.L., MARTIN, D.F. and LOWERY, R.F. (1999). Etiologic factors associated with Achilles tendonitis in runners. Medicine and Science in Sports and Exercise, 31: 1374-1381

MILLET, G.P., JAOUEN, B., BORRANI, F. and CANDAU, R. (2002). Effects of concurrent endurance and strength training on running economy and VO₂ kinetics. Medicine and Science in Sports and Exercise, 34(8): 1351-1359

MINETTI, A.C. (1994). Mechanical determinants of the minimum energy cost of gradient running in humans. Journal of Experimental Biology, 195-211

MIRALLES, R., GRACES, J.M., MOLINA, L., ACENA, R. and GARCIA PALLEIRO, P. (1993). Exhaustion syndromes in a popular marathon. Medical Clinic (Barcelona), 100(9): 343-345

MORRIS, A., LUSSIER, L., BELL, G. and DOOLEY, J. (1983). Hamstring/quadriceps strength ratios in collegiate middle-distance and distance runners. Physician and Sportsmedicine, 11(10): 71-77

NATRI, A., KANNUS, P. and JARVIVEN, M. (1998). Which factors predict long-term outcome in chronic patellofemoral pain syndrome? A 7-year-old prospective follow-up study. Medicine and Science in Sports and Exercise, 30: 1572-1577

NELSON, R.C. and GREGOR, R.J. (1976). Biomechanics of distance running: longitudinal study. Research Quarterly, 47: 471-474

NEWSHOLME, E.A. and LEECH, E.A. (1983). Biochemistry for Medical Science. New York: John Wiley & Sons

NIKOLAOU, P.K., MacDonald, B.L., GLISSON, R.R., SEABER, A.V. and GARRETT, W.E. (1987). Biomechanical and histological evaluation of muscle after controlled strain injury. American Journal of Sports Medicine, 15: 9-14

NOAKES, T.D. (1988). Why marathon runners collapse. South African Medical Journal, 73: 569-571

NOAKES, T.D. (2001). Lore of Running (4th Edition). Cape Town: Oxford University Press

PAAVOLAINEN, L., HAKKINEN, K., HAMALAINEN, I., NUMMELA, A. and RUSKO, H. (1999). Explosive strength training improves 5km running time by improving running economy and muscle power. Journal of Applied Physiology, 86: 1527-1533

PASSMORE, R. and DURNIN, J.V.G.A. (1955). Human energy expenditure. Physiological Reviews, 35: 801-835

PLOWMAN, S.A. and SMITH, D.L. (1996). Exercise Physiology. Boston: Allayan and Bacon

PRENTICE, W.E. (2004). Rehabilitation techniques for Sports Medicine and Athletic Training. New York: McGraw-Hill

PRETORIUS, D., NOAKES, T.D., IRVING, G.A. and ALLERTON, K.E. (1986). Runner's knee: What is it and how effective is conservative treatment. Physician Sportsmedicine, 14, 71-81

PUGH, L.G.C.E. (1970). Oxygen uptake in track and treadmill running with observation on the effects of air resistance. Journal of Physiology (London), 207: 823

RAGLIN, J.S. and WILSON, G.S. (1999). Overtraining in athletes. In Hanin YL, (Edited) Emotion in Sport. Champaign, IL: Human Kinetics

RIETJENS, G.J., KUIPERS, H., HARTGENS, F. and KEIZER, H.A. (2002). Red blood cell profile of elite Olympic distance triathletes. A three-year follow-up. International Journal of Sports Medicine, 23(6): 391-396

ROBERT, W.O. (2006). Exertional heat stroke during a cool weather marathon: a case study. Medicine and Science in Sports and Exercise, 38(7): 197-1203

ROBERTS, T.J., MARSH, R.L., WEYAND, P.G. and TAYLOR, C.R. (1997). Muscular force in running turkeys: The economy of minimizing work. Science, 2756

SANTOS, R.V., BASSIT, R.A., CAPERUTO, E.C. and COSTA ROAS, L.F. (2004). The effect of creatine supplementation upon inflammatory and muscle soreness markers after a 30km race. Life Science, 75 (16): 1917-1924

SAUNDERS, P.U., PYNE, D.B., TELFORD, R.D. and HAWLEY, J.A. (2004). Factors affecting running economy in trained distance runners. Medicine and Science in Sports and Exercise, 34(7): 465-485

SCALES, N. (1998). SISA Protocols- Track Sprinting. Unpublished manuscript. South Africa

SCHAEFER, M.E. (1992). Adrenergic responsiveness and intrinsic sinoatrial automaticity of exercise-trained rats. Medicine and Science in Sports and Exercise, 24: 887

SCHWELLNUS, M.P. (1999). Skeletal muscle cramps during exercise. Physician and Sportsmedicine, 27 (November): 109-115

SJOSTROM, M., FRIDEN, J. and EKBLUM, B. (1987). Endurance, what is it? Muscle morphology after an extremely long distance run. Acta Physiologica Scandinavica, 130(3): 513-520

SONSTEGARD, D.A, MATTHEWS, L.S. and KAUFER, H. (1978). The surgical replacement of the knee joint. Scientific American, 238 (January): 44-51

SPURRS, R.W., MURPHY, A.J. and WATSFORD, M.L. (2003). The effects of plyometric training on distance running performance. European Journal of Applied Physiology, 89(1): 1-7

STEINACKER, J.M., STEUER, M. and HOLTKE, V. (2001). Orthopaedic problems in older marathon runners. Sportverletz Sportschaden, 15(1): 12-15

SURGENOR, S. and UPHOLD, R.E. (1994). Acute hyponatraemia in ultra-endurance athletes. American Journal of Emergency Medicine, 13 (1): 116-117

SVEDENHAG, J. and SEGER, J. (1992). Running on land and in water: comparative exercise physiology. Journal of Sport Medicine and Physical Fitness, 24(10): 1155-1160

SWAIN, D.P. (1994). Target heart rates for the development of cardio-respiratory fitness. Medicine and Science in Sports and Exercise, 26: 112-113

TAKAHASHI, J., ISHIHARA, K. and AOKI, J. (2006). Effect of aqua exercise on recovery of lower limb muscles after downhill running. Medicine and Science in Sports and Exercise, 24(8): 835-842

TANAKA, H. and SWENSEN, T. (1998). Impact of resistance training on endurance performance. A new form of cross training? Journal of Sports Medicine, 25(3): 191 – 200

TAYLOR, H.L., BUSKRIK, E., and HENSCHER, A. (1955). Maximal oxygen intake as an objective measure of cardio-respiratory performance. Journal of Applied Physiology, 8: 73-80

TRAPPE, S., WILLIAMSON, D., GODARD, M., PORTER, D., ROWDEN, G. and COSTILL, D. (2000). Effect of resistance training on single muscle fibre contractile function in older men. Journal of Sports Medicine, 89(1): 143-152

TURNER, A.M., OWINGS, M. and SCHWANE, J.A. (2003). Improvement in running economy after 6 weeks of plyometric training. Journal of Strength and Conditioning Research, 17(1): 60-67

VAN HEERDEN, H.J. (1996). Preparticipation evaluation and identification of aetiological risk factors in the epidemiology of sports injuries among youths. Doctor of Philosophy. Pretoria: University of Pretoria

VOYATZIS, D. (2005). Water training: More than swimming "Upstream" for Fitness. Hyperlink : {[http//healthgate.com](http://healthgate.com)] Retrieved on 21/07/2005

WALSH, G. (2001). The Ultra Marathon. The Ultra, 10

WEN, D.Y., PUFFER, J.C. and SCHMALZRIED, T.P. (1997). Lower extremity alignment and risk of overuse injuries in runners. Medicine and Science in Sports and Exercise, 29: 1291-1298

WILBER, R.L., MOFFATT, R.J., SCOTT, B.E., LEE, D.T. and CUCUZZO, N.A. (1996). Influence of water run training on the maintenance of aerobic performance. Medicine and Science in Sports and Exercise, 28(8): 1056-1062

WILLIAMSON, N (2006). Everyone's guide to Distance Running. Cape Town: Oxford University Press South Africa

WILMORE, J.H., PARR, R.B. and GIRANDOLA, N. (1978).
Physiological alterations consequence to circuit weight training.
Medicine and Science in Sports and Exercise, 10: 79-84

WYNDHAM, C.H. and STRYDOM, N.B. (1971). The danger of
inadequate water intake during marathon running. South African
Medical Journal, 43: 893-896

YEAGER, S. (2004). Train like a Champ. Fit, (February): 51 – 5

APPENDICES

APPENDIX A	Physical Activity Readiness Questionnaire (PARQ)
APPENDIX B	Informed Consent
APPENDIX C	Comrades Marathon Injury Profile Questionnaire

APPENDIX A

Physical Activity Readiness Questionnaire (PAR-Q)

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 1994)

PAR - Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
<input type="checkbox"/>	<input type="checkbox"/>	1. Has your doctor ever told that you have a heart condition and that you should only do physical activity recommended by a doctor?
<input type="checkbox"/>	<input type="checkbox"/>	2. Do you feel pain in your chest when you do physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	3. In the past month, have you had chest pain when you were not doing physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
<input type="checkbox"/>	<input type="checkbox"/>	5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
<input type="checkbox"/>	<input type="checkbox"/>	7. Do you know of any other reason why you should not do physical activity?

FIG. 2-1. PAR-Q form. Reprinted with permission from Reference 7.

Continued on Next Page

If
you
answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want—as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active—begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal—this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever—wait until you feel better; or
- if you are or may be pregnant—talk to your doctor before you start becoming more active.

Please note: If your health changes so that you then answer YES to any of the above questions, tell your doctor or health professional. Ask whether you should change your physical activity plan.

FOR THE USE OF THE PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity and/or health appraisals without first consulting their doctor and/or physical activity professional.

You are encouraged to copy the PAR-Q but only if you use the entire form.

FIG. 2-1. Continued

Continued on Next Page

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

NAME _____

SIGNATURE _____ DATE _____

SIGNATURE OF PARENT _____ WITNESS _____
or GUARDIAN (for participants under the age of majority)

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FIG. 2-1. Continued

(Balady, et al., 2001)

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APPENDIX B
UNIVERSITY OF ZULULAND
DEPARTMENT OF HUMAN MOVEMENT SCIENCE
INFORMED CONSENT

Explanation of tests

You will perform a series of fitness tests, such as a 10km run, 400m-sprint, Wingate anaerobic cycle test, one-minute sit-up test, one-minute press-up test and a lower back-leg dynamic strength test. Other tests that will be conducted are, body mass, stature and skinfold measurement. You may stop the tests at any time if you feel signs of fatigue or extreme discomfort.

Risks and Discomforts

The possibility of certain changes during the test may occur. These include abnormal blood pressure, fainting, irregular heart rhythm and heart attack or stroke in rare instances. There is also a slight possibility of straining a muscle or spraining a ligament during the muscle fitness testing. In addition, you may experience soreness 2 hours after testing that may last for 48 hours post-test. Every effort will be taken to minimize these risks.

Responsibility of the subject

Information you possess about your fitness and health status must be disclosed. Your prompt reporting of extreme discomfort is of great importance.

Benefits to be expected

The results obtained from the tests will assist in this study, aimed at improving further Comrades Marathoners' performance.

Enquiries

Any questions regarding the procedures used in tests and the study is encouraged. If you have any concerns or questions, please ask for further explanation.

Freedom of consent

Your permission to perform these tests is voluntary. You are free to stop the testing any time, if you desire.

I have read this form and understand the testing procedures that I will be performing, as well as the related risks and possible discomforts. With full knowledge of this, and having an opportunity to ask questions that have been answered to my satisfaction, I consent to participate in this study.

Subject

Signature

Tester

Signature

APPENDIX C

UNIVERSITY OF ZULULAND

DEPARTMENT OF HUMAN MOVEMENT SCIENCE

COMRADES MARATHON INJURY PROFILE QUESTIONNAIRE

Name: _____ Tel.: (w) _____

Age: _____ (h) _____

Club: _____ (cell) _____

e-mail address: _____

Residential address: _____

1. Have you used resistance training (gym work) in your Comrades Marathon preparation previously?

Yes	No
-----	----

2. List 5 of your official Comrades Marathon completion times (at least 3 up-runs and 2 down-runs)

Year of Comrades Marathon	Up or Down Run	Please record official completion times
2004	Up	
2003	Down	
2002	Up	
2001	Down	
2000	Up	

3. Please record your official completion times for the following races?

Race	2004	2003	2002	2001	2000
Crescent 21.1km					
Athletic North 42.2km					
Buffalo 42.2km					
Two Ocean 52km					

4. Please indicate with a cross "x" the sport injuries you experienced in your previous Comrades Marathon seasons.

Injury site	2004	2003	2002	2001	2000
Knee					
Achilles tendon & calf					
Toenails/blisters					
Hip/groin					
Heel					
Ankle sprain					
Shin splint					
Nerve injuries					
Quadriceps					
Hamstrings					
Back					
ITB Syndrome					
Metatarsal					

5. Physical characteristics and performance parameters

Physical characteristic or Performance parameter	Pre-test	Post-test
Body mass (kg)		
Height (cm)		
Sum of skinfolds (mm)		
10km time trial (min.)		
400m sprint (sec.)		
Wingate cycle test (kgm/min.)		
Sit-up test (rep./min.)		
Press-up test (rep./min.)		
Lower body strength (kg)		