Effects of offloaded running versus active recovery on performance after an ultra-marathon

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DECLARATION

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LIST OF ABBREVIATIONS

ADL	Activities of Daily Living
ARS	Average Running Speed
ATP	Adenosine Triphosphate
BMI	Body Mass Index
BWS	Body Weight Support
CK	Creatine Kinase
DOMS	Delayed-Onset Muscle Soreness
DWR	Deep Water Running
EIMD	Exercise-Induced Muscle Damage
EMG	Electromyogram
HR_{max}	Maximum Heart Rate
HR_{ave}	Average Heart Rate
HRR	Heart Rate Recovery
HREC	Human Research and Ethics Committee
LBPP	Lower Body Positive Pressure
$m.s^{-1}$	Minutes per Second
MVC	Maximal Voluntary Contraction
NSAID	Non-Steroidal Anti-Inflammatory Drug
PTRS	Peak Treadmill Running Speed
ParQ	Physical Activity Readiness Questionnaire
RPE	Rate of Perceived Exertion
PB	Personal Best Time
POMS	Profile of Mood States
RHR	Resting Heart Rate
SD	Standard Deviation
TT	Time Trial
UCT	University of Cape Town
VAS	Visual Analogue Scale
VO_{2max}	Maximal Oxygen Consumption
WBC	White Blood Cell

GLOSSARY OF TERMS

Ultra-Marathon	In running it is typically considered to involve any distance longer than a standard marathon, which is 42.2km [1].
Comrades Marathon	The Comrades Marathon is an approximately 90 km ultra-marathon run between Durban and Pietermaritzburg annually, the direction of which changes every year [2]. In 2017, runners took part in the "*up*" run, which was 87 km [3] and started in Durban and finished in Pietermaritzburg.
Exercise-Induced Muscle Damage (EIMD)	Muscle damage that usually results from exercise associated with a combination of eccentric loading, an unaccustomed high intensity, and a repetitive nature [4]; the effects of which have been measured at various physiological levels. Subsequent changes in cardio-respiratory function, metabolic impairments, alterations in myology such as a decrease in force production of muscles, variations in neuromuscular control [5] and central fatigue adaptations [6], have been measured as a result of EIMD.
Delayed-Onset Muscle Soreness (DOMS)	Delayed-onset muscle soreness is a collective group of symptoms that athletes usually report as a consequence of EIMD: pain or soreness, muscle stiffness and swelling [7].
Rate of Perceived Exertion	A subjective measure used as an index of effort during exercise. Conventionally measured on rate of perceived exertion (RPE) scale from 0 - 20, described by Borg (1982) [8], to measure the degree of heaviness, fatigue and strain experienced during exercise. A modified Borg scale used previously [9–11] during time trial performance testing was used in this study.

Anti-Gravity Treadmill	Also referred to as an Alter-G, G-trainer or LBPP treadmill. A rehabilitation tool for weight-supported running or walking. The device uses a regular motorized treadmill enclosed in an airtight chamber attached at waist of the runner wearing special shorts that zip into the chamber. After weighing and calibrated pressurization, positive pressure can be applied into to the lower body, effectively lifting the runner incrementally and reducing their body weight. This makes it possible to provide different amounts of lift to essentially offset body weight up to 80% (80% offloaded) or at various other percentages of total body weight based on the requirements of the run [12].
Body Weight Support (BWS)	Pressure in the chamber around the anti-gravity treadmill incrementally lifts the runner and allows them to run at up to 20% of their body weight, or 80 % offloaded i.e. with up to 80% body weight support (BWS) [13,14].
Deep Water Running (DWR)	Deep water running is a useful form of light recovery or offloaded exercise [15,16]. The exercise is implemented in the deep end of an ordinary swimming pool in which an athlete runs while their body is kept upright by means of a buoyancy belt resulting in a form of weight supported ambulation. During DWR, impact with the ground is avoided, thus resulting in reduced load on musculoskeletal structures [17]. Body weight support of up to 35% is thought to be achieved during DWR. [18]
Visual Analogue Scale (VAS)	The VAS is a subjective rating scale used to quantify the intensity of a painful stimulus. The VAS consists of a horizontal 100 mm line that has polar descriptors at each end. The participants rate their pain by drawing a vertical line on a pain rating scale, where 0 mm represents “no pain”, and 100-mm represents “maximal pain”. The distance in millimetres (mm) along the pain rating scale to the vertical line drawn is measured, and the pain score is calculated 19.

ABSTRACT

Background

The endurance running training process, which includes competition and recovery, requires managing a complex interaction of positive training adaptations and negative effects such as exercise-induced muscle damage (EIMD). Various active recovery interventions have been explored to speed up recovery from events such as ultra-marathon runs. This includes offloaded recovery strategies such as deep water running (DWR). More recently, the use of an anti-gravity treadmill for offloaded recovery after a cardio-vascular event such as an ultra-marathon race has been proposed. There is however, limited research to support this, as well as how to appropriately test this as a recovery strategy.

Aim

To investigate the effects of an offloaded running recovery intervention compared to a standard active recovery strategy on running performance and markers of recovery after an ultra-marathon race.

Specific Objectives

The specific objectives were to 1) compare differences in a 5 km time trial performance between an experimental group (who received an offloaded recovery intervention on an anti-gravity treadmill) and a control group (who received a standard active recovery protocol) 14 days before and ten days after an ultra-marathon race; 2) To compare secondary outcome measures of heart rate and rate of perceived exertion during these 5 km time trial, 3) To compare differences in self-reported muscle and, 4) daily activity levels, between the two groups before the race; and over a seven-day period after the ultra-marathon race, 5) To compare heart rate, rating of perceived exertion, muscle pain and running speed of the experimental group runners during 30-minute offloaded recovery runs on an anti-gravity treadmill.

Methods

Eighteen participants ran the Comrades ultra-marathon race to induced muscle damage. The experimental group consisted of nine male runners who performed an offloaded recovey protocol of three to four recovery runs, using an anti-gravity treadmill, in the week following the ultra-marathon. The control group consisted of nine male runners who perfromed a standard active recovery protocol in the week following the ultra-marathon. A 5 km time trial run was performed 14 days before, and ten days after the ultra-marathon. The participant's rating of perceived exertion and heart rate and split speeds were measured during the time trial runs. Daily measurements of muscle pain (using a visual analogue scale that assessed muscle pain in the hamstrings, quadriceps and calf muscles) and daily activity levels (using pedometers) were recorded one day before and for seven days after the ultra-marathon.

Results

Groups were similar in demographics, racing experience and ultra-marathon performances. There were no significant differences in running speed during the 5-km time trial performance between groups, or pre-post the ultra-marathon race; however, there was a significant difference in the measurement over time ($p < 0.00001$). The study showed a significant interaction between groups over time pre-post the ultra-marathon race for heart rate ($p = 0.008$) and rating of perceived exertion ($p = 0.008$) during the 5-km time trial. There was a significant increase in all measures of pain, for all three muscle groups over-time ($p < 0.00001$) for both groups. Certain pain ratings were significantly lower in the experimental group on days three, four and five after the ultra-marathon. There was an observation of almost no pain during the 30-minute recovery runs on the anti-gravity treadmill performed by the experimental group.

Discussion and Conclusion

The findings of this study suggest that there may be benefits in using the anti-gravity treadmill as a recovery tool that a) provided temporary relief in muscle pain during a recovery run and; b) may alleviate muscle pain once implemented in the days following an ultra-marathon race. Some improvements in heart rate and RPE during a 5-km time trial, were observed, supporting the potential effectiveness of an offloaded recovery in limiting some of the deleterious effects of EIMD after an ultra-marathon race. However, the benefits of using the anti-gravity treadmill, according to this study, are very limited. It is hoped that this study could provide bases for further investigation into anti-gravity treadmill running, as well as how to more accurately manipulate different percentages of body weight support, for recovery and training purposes.

CHAPTER 1: INTRODUCTION AND SCOPE OF THE THESIS

1.1 INTRODUCTION

The endurance running training process, which includes competition and recovery, is associated with managing a complex interaction of positive training adaptations and negative effects of fatigue such as stress responses and negative health outcomes [11,20]. Slow recovery from competitions such as an ultra-marathon race can be detrimental to performance [9], may predispose an athlete to injury and can result in fatigue effects from exercise-induced muscle damage (EIMD) [21]. For endurance runners, these undesirable consequences can last for several weeks after a ultra-marathon race [22]. Symptoms are most frequently reported as stiffness, delayed-onset muscle soreness (DOMS) [5] and swelling [7]. Exercise-induced muscle damage has been shown to have a negative effect on many other recovery markers [2,5,22–26].

Although recovery occurs as a passive physiological process, many athletes make use of a range of active recovery strategies and interventions in an attempt to accelerate and enhance the recovery process [27–29,30] and promote a positive training adaptation [21]. It has previously been suggested that active exercise may be one of the most beneficial recovery strategies [5] and that performing the same exercise that induced muscle damage, but at a low intensity [23] as a recovery strategy, may facilitate repair at the site of muscle damage [31–33]. However, since fatigue is task dependant such that an ultra-marathon has very specific effects on neuromuscular structures [34], many questions arise as to how to accurately implement active recovery after such an event. Intensity, duration and mode of recovery runs after races of various lengths require further investigation [20,29,31,35,36].

One form of active recovery is offloaded running which, in theory, allows for a reduction in load on musculoskeletal structures whilst still challenging the cardiovascular system to an intensity that is sufficient to maintain fitness and performance during recovery periods [37]. Weight-supported exercise such as deep water running (DWR) has been shown an effective form of offloaded recovery from exercise-induced muscle damage [18,38] and to maintain performance during recovery periods in endurance runners [39,40]. A more recent method of offloaded running has been achieved using an anti-gravity treadmill; a rehabilitation tool for weight-supported exercise [12]. The device allows for an incremental offloading of bodyweight, thus attenuating the ground reaction forces [14,41] and load on the body during running [42].

The use of an offloaded device such as an anti-gravity treadmill may assist in the maintenance of cardiovascular fitness during recovery from a myocardial event; and research into the use of offloaded running specifically for recovery has been suggested [43].

In response to these claims and recommendations, this study was conducted within the field of endurance running recovery, specifically with regards to the use of an offloading treadmill device as an active recovery strategy. The overall aim of this study was to investigate the effects of an active offloaded recovery intervention utilising an anti-gravity treadmill compared to a standard active recovery intervention, on running performance and markers of recovery after an ultra-marathon run.

1.2 AIMS AND OBJECTIVES

1.2.1 Aim of the Study

To investigate the effects of an offloaded running recovery intervention compared to a standard active recovery protocol on running performance and markers of recovery after an ultra-marathon race.

1.2.2 Specific Objectives

- To determine the effects of an offloaded recovery intervention using an anti-gravity treadmill in an experimental group of ultra-marathon runners, compared to a standard active recovery protocol in a control group of ultra-marathon runners during the recovery period after an ultra-marathon race by:
    - Comparing differences in a 5 km time trial performance between the experimental and control groups at baseline, 14 days before an ultra-marathon; and post-race, ten days after an ultra-marathon race.
    - Comparing differences in secondary outcome measures of 5 km time trial heart rate and rate of perceived exertion between the experimental and control groups at baseline and post-race.
    - Comparing differences in self-reported muscle pain using a visual analogue scale (VAS) between the experimental and control groups before the race; and over a seven-day period after the ultra-marathon race.
- To describe heart rate, rating of perceived exertion, muscle pain and running speed of the experimental group runners during 30-minute offloaded recovery runs on an anti-gravity treadmill.
- To determine differences in daily activity levels (using a pedometer) between the experimental and control groups before the race; and over a seven-day period after the ultra-marathon race.

1.2.3 Significance of this Study

The purpose of this study was to gain insight into methods of running recovery after an ultra-marathon run, specifically offloaded recovery. This study will provide further understanding of the effects of offloaded recovery running on various markers of recovery and performance. It is hoped that the study will encourage future research into the use of offloaded running within the field of ultra-marathon recovery.

1.3 PLAN OF DEVELOPMENT

In preparation for this dissertation, a broad review of the literature on effects of endurance running, running recovery, active recovery strategies and more specifically offloaded forms of recovery will be presented (Chapter 2). This will be followed by an experimental study with a pre-test–post-test design, that was formulated to investigate the effects of an offloaded running recovery intervention compared to a standard active recovery protocol on running performance and markers of recovery after an ultra-marathon race. The results of this study are presented, interpreted and discussed. Limitations of the study and recommendations for future research are given in Chapter 3. A summary and conclusion section is included in Chapter 4.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

The endurance running training process is complex. It includes competition and recovery and is associated with managing an interaction of positive training adaptations and negative effects of fatigue such as distress responses, overtraining and undesirable health outcomes [11,20]. After endurance running competition or an unaccustomed running effort, these negative fatigue effects can result in a reduction in running performance which may be attributed to symptoms associated with exercise-induced muscle damage (EIMD) [44], thus hindering the runners' training progress. Recovery is a process involving the restoration of psychological and physiological processes to homeostasis; it is pro-active, individualized and an integral part of the endurance training process [1]
.

Endurance runners are continuously pushing boundaries to speed recovery so that they can endure high volumes of training, prepare for competitions and improve performance [45]. Subsequently, various recovery interventions have been explored and integrated into training strategies to achieve this training balance and attenuate negative effects from endurance running training and events. These strategies are broadly classified into passive and active forms of recovery [21]. Various forms of offloaded active recovery strategies have been developed to decrease loading on the body while still getting the cardiovascular effects of training. This has most commonly been implemented through deep water running; however, more recently the use of an anti-gravity treadmill has been suggested as a potential recovery tool after an ultra-marathon event [43].

This review explores endurance running recovery and the research process is outlined in Figure 1. This review will explore the literature on exercise-induced muscle damage resulting from endurance running. Modalities and methods that have been developed to speed up running recovery and attenuate symptoms of exercise-induced muscle damage are discussed. Active forms of recovery are explored with specific attention paid to offloaded forms of active recovery. Finally, a more recent form of offloaded running on an anti-gravity treadmill is introduced and it is hypothesized that this could be an effective modality for running recovery.

The scientific and medical literature was searched using databases and online search engines including EBSCO, PubMed, CINAHL, and Google Scholar. The following keywords were used:

"Endurance running", "ultra-marathon running", "Comrades marathon", "recovery", "exercise-induced muscle damage (EIMD)", "delayed-onset muscle soreness (DOMS)", "muscle soreness", "muscle fatigue", "performance", "heart rate", "passive recovery", "active recovery", "reduced loading", "offloaded recovery", "deep water running, "aqua running", "lower-body positive pressure", "anti-gravity running", "anti-gravity", and *"anti-gravity treadmill"*.

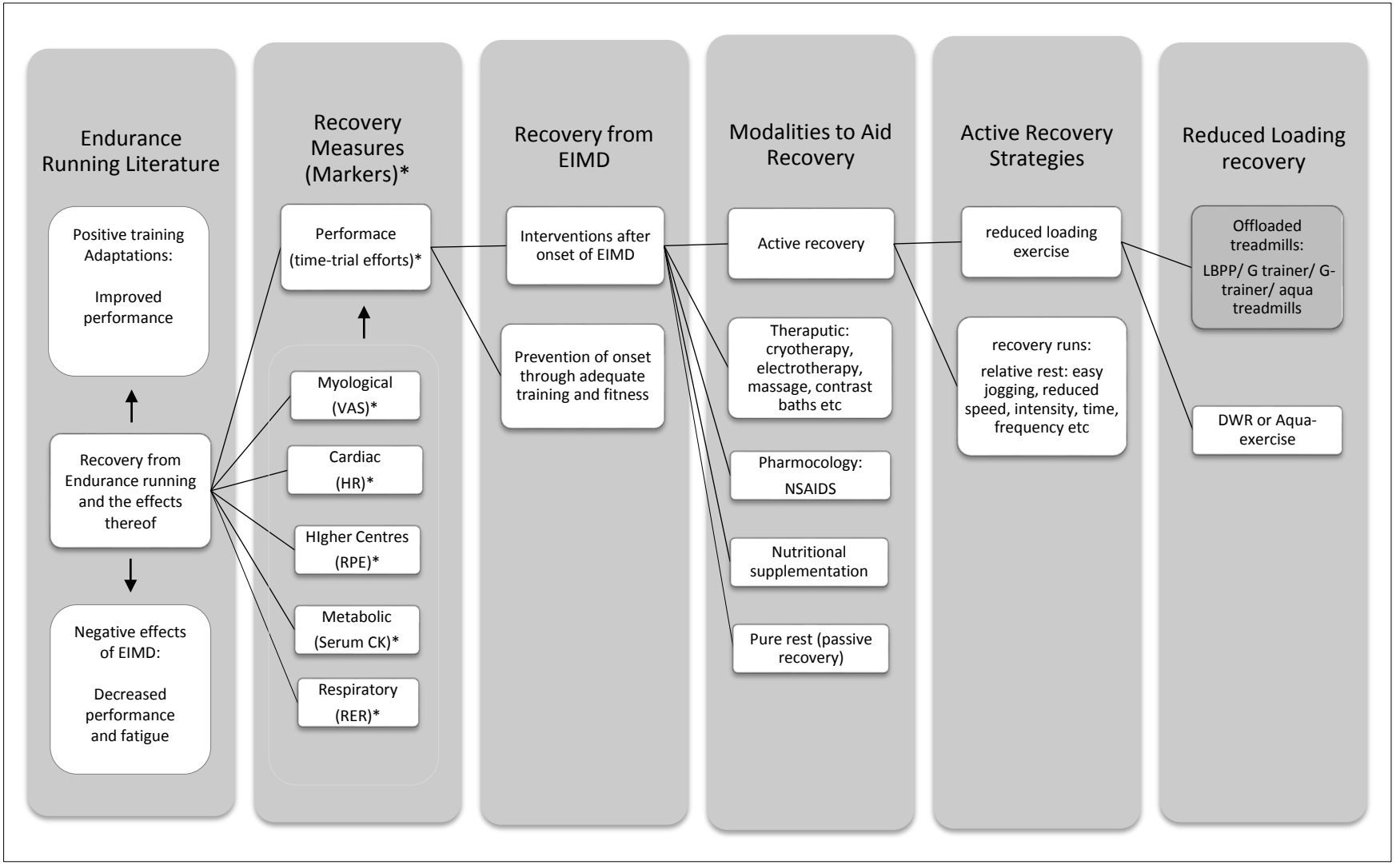

Figure 1: Schematic diagram of components of the literature review.

2.2 EFFECTS OF ENDURANCE RUNNING

Completion of an ultra-marathon run requires physical and mental strength [46]. During endurance running, athletes have to manage feedback from their muscles, tendons, joints, lungs and even digestive organs, all of which may increase the athlete's perceptions of exertion during the race [47]. These events impose severe physiological stressors on athletes [11,22], especially as many athletes tend to push their bodies beyond ordinary limits [48]. Runners have a unique ability to keep running even when their physical capacities are exceeded, and subsequently ultra-marathon races induce intense fatigue [47]. Despite this fatigue, it seems that endurance runners also have an excellent capacity for recovery, making ultra-marathon running an interesting field of investigation into athlete recovery [49]. It has been suggested that fatigue is task-dependant, such that an ultra-marathon has very specific effects on neuromuscular structures compared with a shorter duration of fatiguing exercise [34].

Selected studies [1,22,24,34,50–52] investigating various physiological consequences of ultra-marathon or marathon running have been outlined in Table 1. These studies have provided useful data regarding renal function [50], enzyme and biochemical activity [51], cardio-respiratory function [24,52], neuromuscular control [34], and muscle strength [22] , psychological and mood states [1] and exercise performance [11,53] after such events. One such endurance running race that has been investigated is the Comrades marathon [3]. The Comrades ultra-marathon is an approximately 90 km run between Durban and Pietermaritzburg, South Africa, the direction of which alternates every year resulting in an "up run" or a "down run" with the start of the race being in Durban or Pietermaritzburg respectively [2]. Recovery from this specific race has also already been investigated in various settings [2,11,22,24,49,52,54].

An initial response following an ultra-marathon run, such as the Comrades, may be characterized by acute increases in muscle soreness, total body fluid, decreases in muscle strength and increased circulating creatine kinase (CK) that are associated with EIMD and fatigue [11]. A compensatory physiological response and positive training adaption is observed in response to these acute disturbances if the athlete is relatively well trained prior to the ultra-marathon. In agreement with this hypothesis; runners may lack the ability to compensate in response to the stresses of an ultra-marathon event of this nature, and a negative physiological stress response may be observed [11].

Table 1: Physiological effects measured after a marathon or ultra-marathon.

Study	Ultra-marathon	Study participants	Field of interest	Outcomes	Conclusions drawn
Knechtle et al. (2009) [50]	100km ultra-marathon	41 ultra-marathon runners	Renal function and fluid levels	A decrease in body fat mass and skeletal muscle mass with an increase in total body water was observed in response to the ultra-marathon.	The increase in total body water observed may indicate the formation of oedema
Siegel et al. (2003) [51]	42km Boston marathon	37 well trained runners	Haematology and cardiology: Biochemical parameters, cardiac markers, and WBC	Concentrations of biochemical markers such as creatine kinase, white blood cell (WBC) counts and myoglobin, increased after the marathon, in keep with effects of exertional rhabdomyolysis and haemolysis	The study suggested new safe parameters for these markers after a marathon. An increase in certain markers was due consistent with an inflammatory response to soft tissue injury
Peters et al. (2004) [24]	Comrades ultra-marathon	30 trained male runners	Haematological and cardiac markers	Changes in full blood counts, lymphocytes, serum cortisol, C-reactive protein and creatine kinase were seen in both groups but no difference between groups was observed	Changes in various biochemical, cardiac and WBC markers suggested the increased risks for illness such as URTIs during recovery from an ultra-marathon
Millet et al. (2002)[34]	65km ultra-marathon	9 well trained runners	Components of neuromuscular fatigue	Maximal voluntary muscle forces, maximal voluntary muscle activation, and mechanical twitch responses were significantly decreased by 65 km of running	Fatigue is thought to be task dependent such that an ultra-marathon has very specific effects on neuromuscular structures
Mann et al. (2015) [52]	Comrades ultra-marathon	10 well trained runners	Cardio-respiratory markers: heart rate markers, post exercise oxygen consumption and RPE during a sub-maximal run	Paradoxical increases in HRR after the sub-maximal test as well as decreased RPE during the test, were seen in testing after the ultra-marathon	A faster HRR either reflects an enhanced training status; or more likely can be because of recent training load and RPE during previous sub-maximal exercise
Chambers et al. (1998) [22]	Comrades ultra-marathon	Eight veteran endurance runners	Muscle function and heart rate responses measured	Muscle power (vertical jump height), is compromised in runners for up to 18 days and heart rate response to steady-state remained increased during running for up to 25 days after the ultra-marathon	Changes may result in a decrease in endurance running, components of performance may be negatively affected for several weeks after an ultra-marathon
Nicolas et al. (2011) [1]	24-hour ultra-marathon race	14 male participants	Psychological mood states and stress	Ultra-endurance racing induced perceived stress and led to a subsequent alteration in perceived recovery in physical, psychological and emotional dimensions	Recovery is dynamic and regular monitoring of psychological states of stress and recovery of ultra-endurance runners should be considered

2.2.1 Positive Effects of Endurance Running

The endurance training process, which includes competition and recovery, is associated with managing a complex interaction of adaptive physiological responses; which, if managed well, can result in positive training adaptations such as improved athletic performance and health outcomes [11,20]. It is also acknowledged that these athletes have an ability to continue exercising, even when their physiological capacities are stressed or even over-reached [48]. Despite this ability to push past physiological boundaries, Noakes (2003) [49] suggests that endurance runners have an incredible capacity and capability to recover; a notion supported by Millet et al (2011) [55], who showed that neuromuscular function, as measured by maximal force capacity, returned to baseline as early as two weeks after an ultra-marathon [55]. Therefore, positive cardio-respiratory [11], neurological [1] and muscular [56] training adaptations are fundamental in enabling endurance athletes to run economically and improve competition performance [11,57].

Regular endurance running has the potential to improve metabolic function and oxidative capacity of muscles, which in theory would allow for a more economical expenditure of energy and therefore experience less fatigue [57]. Regular eccentric loading as experienced in downhill or ultra-marathon running may also help improve an athlete's running economy as well as performance [58]. Muscles that are exposed to this form of repeated mechanical overload can be strengthened and positively remodelled [56]. The notion of a long-term tissue adaptation in response to training has subsequently been well accepted [25].

It has been proposed [11] that for endurance runners, who are moderately trained and experienced, adequate recovery after an ultra-marathon could result in an overall positive adaptive response to the stressors induced by all their distance running training efforts [11]. These training adaptations may result in improved running performance and are said to be aided by previous training and racing experience, the runners' muscle wisdom, and a concept known as the repeated bout effect [4]. Training adaptations may be associated with a reduction in the overall physiological cost of exercise, as well as various protective mechanisms that could allow for better fatigue adaptations [11].

2.2.2 Negative Effects of Endurance Running

It is widely documented that muscle damage is a common occurrence associated with ultra-marathon running [22]. Exercise-induced muscle damage (EIMD) usually results from exercise associated with a combination of eccentric loading and unaccustomed high intensity of a repetitive nature, [4] the effects of which have been measured [2,7,9,47,51,59–61]. Exercise-induced muscle damage is characterized by morphological changes to the muscular system including a disturbance to the sarcolemma, contractile components of the myofibril, sarcotubular system, cytoskeleton and the extracellular matrix; as well as an inflammatory response [5,62]. These changes often result in an increase in muscle volume and thus increased limb circumference, with a consequent decrease in range of movement and muscular strength [7]. Athletes usually report these symptoms of EIMD as pain or soreness, muscle stiffness and swelling, which are collectively referred to as delayed-onset muscle soreness (DOMS) [7].

Following muscle damage, there is a disruption to homeostasis on various levels including changes in cardio-respiratory function, metabolic impairments, alterations in myology such as a decrease in the production of muscle force, variations in neuromuscular control [5] and central fatigue adaptions [6]. Due to these elevated physiological responses and disturbances, endurance running in the presence of EIMD is could result in an increase in subjective effort which is likely to impair athletic performance [63]. For endurance runners, these undesirable consequences may last for several weeks after a ultra-marathon race [22].

Therefore, in contrast to adapting positively, an endurance runner could develop a “negative” stress reaction which may be associated with a delayed ability to re-establish homeostasis. This negative adaptation to endurance training and competition could be associated with an inability to fully recover from the effects of EIMD. A poor adaptation could therefore be related to an increase in the energy cost of exercise, decrease in economy of running, fatigue during stretch shortening cycle exercise, and an overall reduction in endurance running performance.[11]

2.2.3 Physiology of Exercise-Induced Muscle Damage

Several hypotheses have been proposed for the exact mechanisms behind EIMD; and it has been hypothesized that a combination of these theories may contribute to the development various of associated symptoms of EIMD [5]. Suggested physiological factors contributing include direct muscle damage, lactic acid accumulation, muscle spasms, connective tissue damage, an influx of various enzymes [5], inflammation [24], as well as an accumulation of free radicals linked to oxidative stress during muscle damage [64]. Despite the various hypotheses that have been formulated around EIMD and the extensive research done in this field, the exact mechanisms responsible for damage, repair and appropriate adaptation still remain inconclusive [65]. It has been suggested that the mechanisms underlying EIMD can broadly be divided into mechanical and metabolic hypotheses [25]. A in depth description of these hypotheses is beyond the scope of this thesis however the proposed primary and secondary mechanisms of muscle damage have been well described by Howatson et al (2008) [65].

2.2.3.1 Mechanical Hypotheses

Repetitive exercise predisposes muscles to mechanical loading and strain, which can in turn, cause muscle damage [63]. Direct loading is observed on the whole muscle but also on the microfibers, specifically the cytoskeleton, sarcolemma and T-tubules [4,25] During eccentric muscle actions, the muscle fibres elongate while simultaneously generating tension. During elongation, the muscles ability to generate tension increases causing a high and uneven distribution of load or force mismatch across the muscle fibres. As a result, weaker sarcomeres tend to take up more stretch than others and become progressively weaker until the usually compliant actin and myosin cross-bridges are damaged and the myofibrils no longer overlap [65]. This means a disruption to the contractile component of the muscle tissue occurs and Z lines become out of register, known as Z-line streaming. There is also a loss in thick myofilaments, loss of mitochondria and derangement of filaments at the A-band in areas of damage when observed microscopically [7]. Pain that is experienced seems to be associated with a stimulation of nociceptors in the connective tissue, musculotendinous junction as well as blood vessels at the site of muscle damage [5]. Damage to the T-tubules and sarcolemma causes a rise in intracellular calcium concentration, which then causes a chain of metabolic events which eventually lead to muscle fibre degeneration [59]. As such, the mechanical hypothesis should only be recognized as a partial explanation of EIMD and metabolic consequences need to also be explored [5].

2.2.3.2 Metabolic Hypotheses

It has been proposed that EIMD is caused by metabolic deficiencies within the required muscle making it even more vulnerable to mechanical stress [59]. During any physical activity, there is a disruption of metabolic homeostasis when a reduction in adenosine triphosphate (ATP) concentrations occurs. Glycolytic and oxidative pathways make new ATP to continue to provide for the high energy demand during exercise. It has been suggested that ATP concentrations may in fact drop to a level that is low enough to induce muscle damage, particularly when severe glycogen depletion has occurred [64,66]. This notion is supported by a histological study on marathon runners that discovered muscle damage confined only to the muscle fibres in which complete glycogen depletion had occurred [67].

It has also been proposed that following damage to the sarcolemma, calcium that is usually stored in the sarcoplasmic reticulum, accumulates within injured tissues [68]. It is further suggested that this build-up of calcium inhibits cellular respiration at the mitochondria of muscle cells, which leads to a decrease in ATP regeneration. Adenosine triphosphate (ATP) is also needed to transport calcium back into the sarcoplasmic reticulum, therefore in the present of a reduced amount of available ATP, the removal of calcium is also delayed [5]. This large flux of calcium initiates a cascade of events which results in further muscle protein degradation and in a loss of membrane integrity. Intracellular proteins, such as creatine kinase, then leak through the membrane into the blood, which could occur for several days [5,65,69]. A subsequent chemical stimulation of nociceptors at the sites of metabolite accumulation could be a contributor to pain [70].

It seems that in response to EIMD, a sequential inflammatory response occurs, consisting of leukotrienes, prostaglandins, macrophages, neutrophil, free radicals, chemokines and growth factor cells infiltrating the affected site of muscle damage [56,71]. Although this response is complex and beyond the scope of this review, it is important to mention that prostaglandin release may contribute to pain sensation through chemical stimulation of type-three and -four afferent nerve fibres which could be linked to the development of DOMS [56, 70]. Neutrophils and macrophages have been associated with the promotion of muscle damage. It also seems that neutrophils may generate free radicals through their actions, which may exacerbate damage to the cell membrane [4]. This could also contribute to the leakage of intercellular proteins and fluid from the damaged muscle into the blood and interstitial spaces [5]. This increase in osmotic pressure could also contribute to the sensation of pain as well as explain increases in muscle oedema post EIMD [72].

2.2.4 Delayed-Onset Muscle Soreness

Delayed-onset muscle soreness (DOMS) is often used in studies to quantify EIMD [28,44]. Symptoms of DOMS are dependent on intensity and duration of exercise, but range from mildly tender or stiff muscles, which tends to disappear during daily activity, to severe almost debilitating pain that can restrict movement and alter muscle function [5]. Muscle soreness is most commonly measured using various forms of a visual analogue scale (VAS) [44]. The VAS has been validated as accurate, reliable and appropriate in evaluating the intensity of pain following EIMD when repeated measurement is involved [19] and its reliability and validity in the multi-dimensional pain scale version when assessing pain associated with EIMD, has been established [73,74].

The time course of the onset and then disappearance of reported pain or soreness reported after exposure to the bout of exercise varies depending on the type of exercise, duration of activity and muscle groups recruited. Studies [62,75] have suggested that this muscle pain typically appears between eight and 24 hours post-exercise, peaks at 24 to 48 hours, and can last up to seven days. The magnitude of the pain experienced does not necessarily correlate with the extent of the muscle damage, mainly due to the subjective nature of pain [44]. The mechanisms behind pain involve various poly-modal nociceptors that respond to chemical, pressure, and thermal stimuli [47,68]. Pain can therefore also occur as a result of swelling of the damaged muscles due the increase in intramuscular pressure associated with swelling and oedema and a subsequent stimulation of pressure-sensitive pain receptors [76].

Other symptoms studied in association with muscle soreness are muscle swelling, changes in muscle strength or power [4], muscle stiffness or decreased joint range of motion, and altered concentrations of intramuscular proteins [65] such as plasma creatine kinase (CK) [7]. The magnitude of the muscle decrement varies depending on the state of training, the type of activity, muscle group, and speed of movement [63]. These symptoms are also not necessarily associated with the time course and magnitude of pain [44]. For example, after an ultra-marathon such as the Comrades, impaired muscle function may persist for up to 18 days or longer, despite the fact that the athlete no longer experiences muscle soreness [22]. These various symptoms have been used to quantify the extent of EIMD caused in athletes after unaccustomed loading [62], and selected studies have been outlined in Table 2. It is important to be able to accurately quantify and monitor the amount of muscle damage that resulted from fatiguing exercise in order to understand the degree to which subsequent exercise performance may be affected [77,39].

Table 2: Symptoms of exercise-induced muscle damage and measurement tools frequently used to quantify EIMD.

Symptom	Effect and duration of symptoms	Measurements to quantify
Pain / Muscle soreness	Muscle pain usually subsides within 96 hours after exercise [2,62,75] but in some cases, may persist for up to seven days [5]	Visual analogue scale [19] VAS for muscle soreness [10,11,23,73,74,78]
Swelling / oedema	Increases in circumference of the affected limb have been measured following muscle damage. Peak swelling of muscles exposed to eccentric muscle actions occurs about 2–5 days later [5,50,76]	Girth measurements: Calves, Quadriceps, Hamstrings [28,36,45,50,79]
Loss of muscle strength or power	Decrements measured in strength and power can persist up to 18 days and depends on state of training of the athlete, the type and speed of fatiguing exercise or activity that was performed and the muscle group that used [7,22,34,63]	Vertical jump height [2,22,28,36] Electromyography [30,53,63] Maximal voluntary contraction [45,53,76,80]
Stiffness/ Decreased Range	Significant differences in range reduction in dorsiflexion, plantar flexion, hip flexion and knee flexion[7]	Range of movement [5,25,79,81–84]
Altered Intramuscular proteins	Plasma creatine kinase (CK) concentrations are commonly measured to objectively quantify of the extent of muscle damage. Circulating CK levels usually peak 48 hours after the exercise and tend to subside by 5–7 days [7,36]. Other examples of intramuscular proteins that are measured to quantify EIMD include C-reactive protein (CRP), interleukin-6 (IL-6), lactate dehydrogenase (LDH), myoglobin (Mb), superoxide dismutase (SOD) and malondialdehyde (MDA) [65,89]	Plasma CK, CRP, IL-6, LDH, Mb, SOD and MDA concentrations [2,4,11,18,23,24,64,65,67,68,80,85,89]

2.2.5 Effects of Exercise-Induced Muscle Damage on Performance

Structural alterations to muscle tissue are experienced functionally as a prolonged reduction of strength in the affected muscles [25]. There is evidence that EIMD has a negative effect on athletic performance that requires muscle power [7]. More recently, negative effects of EIMD on endurance running performance have also been confirmed when EIMD was induced through muscle damage protocols [9] and ultra-marathons [10,11,26]. This performance decrement seems to be primarily mediated by an increased perception of effort during running [26,61]. It has been suggested that this may be as a result of a central nervous system response to EIMD as a consequence of central fatigue during an endurance event [9]. This is supported by recent hypotheses suggesting that performance decrements observed after EIMD may be mediated by the central nervous system reducing neural drive to the already damaged peripheral muscles during a subsequent running effort, to protect against further injury [61,86]. Furthermore, it appears that a mental mechanisms may be necessary to produce similar running speeds with injured or sore muscles [87]. Additionally, EIMD from an ultra-marathon seemed to elicit an elevated response in heart rate during steady-state exercise for up to 25 days after the event [22]. It is therefore likely that consequences of EIMD also seem to disturb the homeostasis of musculoskeletal, metabolic, haematological, cardio-respiratory and neuromuscular systems [60,88]. If an athlete is unable to adapt to the disruption of homeostasis, a negative stress reaction could result in reduced running performance [11].

Marcora & Bosio (2007) [9] explored the effect of EIMD on the endurance performance in 30 moderately trained endurance runners. The researchers induced muscle damage in one group through one hundred drop jumps, while a control group did not receive any muscle damage protocol. Muscle soreness, plasma CK levels, mid-thigh swelling and knee extensor strength all confirmed that muscle damage was significantly induced in the experimental group. Running performance was measured in both groups before and 48 hours after, the muscle damage was induced. Performance outcomes used were a standardised run at a constant sub-maximal intensity, as well as a 30-minute self-paced time trial. Cardio-respiratory measures, heart rate (HR) and maximum oxygen consumption (VO_{2max}), and rating of perceived exertion (RPE) were measured during these two performance tests. Even though RPE during a maximal effort time trial was the same in both groups, self-paced time trial performance was significantly reduced by 4% in the EIMD group. It was concluded that muscle damage may have contributed to the significant decrease in endurance running performance observed in this study [9].

A similar study was conducted by Benney et al (2013) [10], with an aim to measure effects of EIMD and fatigue, induced by an ultra-marathon race (Comrades), on running performance during the recovery period after the race. An experimental group completed the Comrades 87 km ultra-marathon and a control group did not. Five-kilometer time trial measures were taken at seven days before as well as at six, 13, and 20 days after the ultra-marathon. Heart rate, muscle pain and rate of perceived exertion measures were taken during these time trials in a controlled setting. There was a significant improvement in the time trials over time for both groups but no significant differences in 5 km time trial performances between the experimental and control groups in this study [10], which contrasted to the findings of Marcora & Bosio (2007) [9]. It was suggested that these findings may have been affected by the role of prior experience and central regulation affecting performance in the presence of fatigue and muscle damage during the recovery period after an ultra-marathon race [10].

2.3 RECOVERY FROM EXERCISE-INDUCED MUSCLE DAMAGE

The ability to recover from an ultra-marathon event is of primary importance [1] and an essential component of training for subsequent competition. Although various symptoms of muscle soreness may subside after five to seven days, signs of muscle regeneration can still present for several weeks, especially after an ultra-marathon [22,67]. Recovery periods are needed to allow for physiological adaption to the stress of exercise, refuel energy stores, repair damaged tissues, clear lactate and therefore facilitate a positive training adaptation [30]. Many interventions have been introduced to speed up these physiological processes [15,18,21,30,89]. The main goals of these interventions are to alleviate the symptoms of EIMD and restore both muscular and cellular function to pre-exercise level [70].

Adequate recovery may therefore be viewed as the point at which the athlete is able to exercise again without the constraints of sore muscles or risk of injury, where as an optimal recovery strategy would also facilitate performance gains during training and after competition [7]. Inadequate recovery on the other hand, may lead to poor performance, injury, illness, or even the development of overtraining symptoms [28,63]. Nicolas et al. (2011) [1] stressed the importance of monitoring recovery after an ultra-marathon race subjectively, as it may help runners and coaches prevent overreaching and overtraining, as well as to plan the length of future recovery periods needed between competitions [1]. This also aids the development of various individual strategies to hasten the recovery process and develop the necessary training adaptations to improve performance [1].

Insufficient recovery from ultra-marathon events such as the Comrades ultra-marathon may be detrimental to athletic performance, may predispose an athlete to injury and can result in fatigue effects from EIMD induced during the event [21]. Therefore, strategies to optimise recovery from endurance running as well as other high running training volumes are of interest, as they allow for potential improved athletic performance for a longer duration [27,29].

2.3.1 Recovery Strategies

There is consensus that proper periodization of exercise training is one of the most effective ways to protect against the negative effects of eccentric exercise associated with EIMD [90]. Athletes should focus their efforts into applying gradual adaptations to eccentrically loaded and stressful exercise within training approaches [5,25,35,90] to allow for their muscles to adapt and subsequently allow for positive training effect [11]. This means that adequate recovery remains integral in any training process for these muscular adaptations and loading compensations to take place [29,35]. However, since competitive athletes are continually pushing past many physiological boundaries to improve performance, strategies to speed up this process are continually being investigated [21]. As a result, several recovery modalities have been implemented across many sporting disciplines in an attempt to minimize effects of EIMD, reduce pain, improve muscle function and speed up the natural recovery process [7]. Recovery interventions are used to allow an athlete to maintain training intensity and exercise adherence during a recovery period [65]. Strategies include passive approaches such as passive rest [29,30], nutritional approaches [64,65], pharmaceutical approaches [80,91], therapeutic modalities [4,5,21,65] and active recovery strategies [21,29–31,92].

Various recovery modalities, specifically to optimize recovery from changes associated with exercise-induced muscle damage, have been reviewed extensively across many endurance sporting fields [4,5,21,65]. Examples of these include: massage [81], ice water emersion [85], compression garments [79], foam-rolling [83], stretching [93], contrast heat therapy [45] and electrotherapy modalities such as ultrasound [94] or vibration therapy [95]. Mixed results of the effectiveness of these interventions implemented alone and in combinations, have been demonstrated [5].

Many athletes also make use of a variety of active recovery strategies in an attempt to enhance or accelerate the recovery process [21,27–29,31,92]. It is hypothesized that enhanced recovery may reduce injury risk, enable toleration of higher training loads, and improve the effect of a given training load. As a result, a more rapid return to, and perhaps even increase in pre-exercise performance levels could be observed over time[15,21].

2.4 ACTIVE RECOVERY MODALITIES

It has been argued that active exercise may be one of the most beneficial recovery strategies [5]. Active recovery has previously been described as balancing periods of passive recovery with periods of active recovery to enhance performance [49]. Active recovery generally involves performing aerobic exercise at a sub-maximal or low intensity in post-exercise period, the length of which depends on the nature and intensity of fatiguing exercise [30]. Light exercise as a recovery strategy after EIMD has previously been shown to decrease plasma creatine kinase levels [96].

Some support for active recovery over passive recovery has been demonstrated by Coffey et al. (2004)[29], who compared the effectiveness of passive recovery, active recovery and contrast temperature water immersion (CTW) strategies from high intensity treadmill exercise. The study participants performed two treadmill tests to exhaustion at 120% and 90% of their peak running speed (PRS), with 15 minutes between the two runs. Recovery modalities were then implemented: active running at 40% of PRS; passive recovery while standing stationary; and CTW, which alternated between 60 seconds cold and 120 seconds hot water immersion. Participants then repeated the two treadmill tests to exhaustion. Heart rate and RPE were measured during the tests and blood lactate concentrations were measured after the treadmill tests. Results indicated that post-exercise blood lactate concentrations were lower with active recovery and CTW as compared to passive recovery. However, there were no significant differences in treadmill performance with regards to time, heart rate or RPE. The results of this study suggest both active treadmill and CTW as recovery tools that produce similar results in enhancing blood lactate removal after exhaustive exercise [29]. Although these recovery findings are of importance, it must be noted that high intensity exercise results in higher production and accumulation of lactate than ultra-marathon running [32].

Physiotherapists, trainers and coaches often prescribe light or low intensity exercise as a recovery strategy; however there are many challenges regarding the practical applications of specific mode, intensity and duration of these strategies for recovery, mainly due to variations in training status of individuals [36,89]. Intensity and duration of recovery runs can be implemented and controlled in various ways [35,92,97–99]; whereas the mode (type) of recovery exercise during these periods can be walking [100], cycle ergometry [30] and more recently offloaded forms of running [89].

2.4.1 Intensity of Active Recovery

A decreased intensity of running during recovery periods is generally prescribed and expressed as a percentage of maximal heart rate (HR_{max}), maximum oxygen consumption (VO_{2max}), or rating of perceived exertion (RPE) [20,99,101] established through maximal or sub-maximal testing [102]. Heart rate monitoring is a widely used monitoring tool for endurance exercise intensity, with recovery sessions suggested to be performed at less than 70% of HR_{max} [97]. There are however many technical challenges related to the physiological precision, variability and objectivity of heart rate monitoring, including high intra-individual differences observed with heart rate monitoring in general, thus making accurate recovery prescriptions difficult [35,36,103]. Subsequently, percentages of VO_{2max} , HR_{max} and more recently RPE have been suggested as practical tools for monitoring intensity of exercise [35]. Low intensity aerobic exercise for recovery purposes has previously been defined as exercise at approximately 40% to 60% of VO_{2max} [23,31,92].

Chen et al (2008) [23] investigated the effects of various intensities of recovery running on muscle function. Fifty participants, who ran an unaccustomed bout of downhill running to induced muscle damage, were divided into five groups. Four of the groups completed 30-minute recovery runs at various sub-maximal intensities (40%, 50%, 60% and 70% VO_{2max}) for six days following the downhill running. The fifth group served as a control group performing no active recovery exercise. No significant differences in muscle soreness, maximal voluntary contraction (MVC) and plasma creatine kinase levels were observed in this study, both between groups of various exercise intensities and between active exercise groups collectively and the control group [23].

There are however discrepancies that arise when this study is reviewed. Firstly, it should be noted that the passive control group still performed stretching as well as 10 minutes of exercise on day two and day five post downhill running. This means that the control was not completely passive. Additionally, no information was given about the training status of the participants except a mean VO_{2max} of 55.3 ± 6.3 $ml.kg^{-1}.min^{-1}$. This is of importance as it has been previously been highlighted that well trained individuals have a better capacity to recover and this could have mitigated the treatments in the study [86].

Active running recovery has also been investigated by Tessitore et al. (2008) [100]. Ten well-trained male athletes were split into four recovery intervention groups including seated rest, electro-stimulation, shallow water aerobic exercises and low intensity running; and each intervention was performed for 20 minutes. No significant effects were observed in reported muscle soreness and anaerobic performance; however, it was discovered that the athletes seemed to perceive the most benefit from lower intensity running compared to the other recovery inventions [100].

2.4.2 Weight Supported Exercise

Weight supported exercise such as deep water running (DWR) has been shown an effective form of active recovery from exercise-induced muscle damage [15,18,38,78]. Deep water running has be used to supplement training [38,39], as a sub-maximal intensity form of exercise [104], to aid rehabilitation during injury, and maintain performance in endurance runners [39,40]. Deep water running exercise is conducted in the deep end of a standard swimming pool in which an athlete runs while their body is kept buoyant by means of a special buoyancy belt [38]. It is proposed that the reduction of impact and load on musculoskeletal structures facilitates recovery by preventing further soft-tissue and joint damage to the lower limbs [17,38]. Deep water running has therefore been implemented to continue training during musculoskeletal injury, and also as a form of light recovery or offloaded exercise in the days following competition [15,16].

During DWR, it has been suggested that the massage effect of the water results in an increase in circulation and oxygen transport into the lower limbs [18]. Deep water running offloads musculoskeletal structures, but still stresses the cardiovascular system to an intensity that is sufficient to maintain fitness and performance during recovery periods [37]. However, this response depends on how well accustomed the runner is to DWR [39]. Further, there is not necessarily a lowered physiological cost of running during DWR because the runner experiences drag during the exercise [37,105]. This seems to result in an increase in perceived exertion compared to land based running at the same exercise intensity [37].

Takahashi and colleagues (2006) [18] performed an experimental study on ten ultra-marathon runners who had to complete a high intensity downhill running protocol that induced muscle damage. The participants were then separated into an experimental group that performed 30-minute recovery runs in the water (DWR) for three consecutive days and a control group that performed no exercise (pure rest).

The study estimated that body weight support of up to 35% was achieved during DWR although the accuracy of this remains in question [18]. Recovery of lower limb function as measured by muscle soreness, muscle power, muscle stiffness, flexibility and reaction time, was quicker in the experimental group, suggesting that DWR could speed up the recovery of after EIMD [18]. This was attributed to increased circulation in the area of muscle damage. It was further suggested that buoyancy during the exercise and mild massage effects of water drag promoted the tissue healing [18].

Further support for deep water running as an offloaded recovery strategy from EIMD has been demonstrated by Reilly et al (2002) [78]. Thirty previously untrained individuals all performed drop jumps from a 50cm platform every seven seconds until exhaustion. Participants were then split into six different groups who performed five different recovery protocols for three consecutive days after the muscle damage protocol. These were rest for three days; rest for one day and DWR for two days; rest for one day and treadmill running for two days; treadmill running on all three days; and DWR on all three days. A 30-minute recovery run was performed for 30 minutes at 70 – 80% of the participants heart rate max. The most beneficial strategy seemed to be when DWR was incorporated in recovery protocol for all three days following EIMD. The study [78] found that DWR appeared to accelerate restoration of muscle strength and improve muscle soreness associated with EIMD. Plasma creatine kinase concentrations of the group recovering only through DWR peaked 24 hours earlier and at a lower value than the concentrations of all other groups.

It must be noted that muscle soreness was eliminated during the 30 minutes of DWR allowing them to perform the recovery intervention pain free however various level of muscle pain seemed to return post recovery exercise. As a result, it was suggested that this allowed for a small decline in leg strength that was observed in those who ran in deep water for three days after EIMD [78].

The effects of an offloaded recovery using body weight support as seen in DWR has also been suggested and investigated through the use of aquatic treadmills [106] and an anti-gravity or lower-body positive-pressure (LBPP) treadmill [89,107,108]. A more precise manipulation of body weight [13,109] to offload musculoskeletal structures [14,41,42] could potentially provide an additional approach to recovery [43].

2.5 OFFLOADED RUNNING USING AN ANTI-GRAVITY TREADMILL

The anti-gravity treadmill (Figure 2) is a rehabilitation tool for weight-supported ambulation [12] that allows for an incremental offloading of bodyweight, thus attenuating the ground reaction forces during running [42]. This device, also referred to as a G-trainer, Alter-G or lower body positive pressure (LBPP) treadmill, uses a regular treadmill that is enclosed in a sealed chamber that allows for lifting of the runner. This positive pressure chamber is attached to the athlete's waist via specifically designed shorts that zip the athlete in to the chamber making it airtight. After calibrated pressurization of the chamber based on the athlete's weight, positive pressure incrementally lifts the runner and allows them to run with up to 80% body weight support (BWS) [13,14]. The runner is still free to move normally in all directions with slightly limited horizontal restriction. Although the research on this device is very limited, specificity of its use in training and accuracy of the offloading process have both been shown to be high [12,109].

Figure 2: Two participants running on the anti-gravity treadmill used in the current study.

2.5.1 Physiological Effects of Offloaded Running on an Anti-Gravity Treadmill

It has been noted that stress on the cardiovascular and musculoskeletal systems in a weight bearing activity such as running is directly proportional to body weight if all other variables are kept constant. This means that if a runner is offloaded by 25%, in theory the runner will do 25% less work [54]. It seems that offloaded running on an anti-gravity treadmill provides similar reductions in ground reaction force (GRF) as experienced during DWR [107,110]. During DWR, the athlete must run against drag, which results in an increased effort and potentially altered gait biomechanics in order to propel the body forward against this resistance [43]. Offloaded running eliminates the component of water resistance while still achieving a form of buoyancy, resulting in an offloaded running style that is more similar to overland running [111]. It has subsequently been suggested that as with DWR, an overall reduction in physiological cost of running may be achieved by offloaded running [12,41].

This reduction in the physiological cost of running can in part be supported by studies that have demonstrated that if that is treadmill running speed is controlled; ground reaction forces (GRF), lower limb EMG [110], heart rate [41] and rating of perceived exertion [112] decrease during weight supported ambulation. However, there is uncertainty regarding the significance of these effects, especially when running at less than 20% offloaded [12,43]. There are also issues regarding changes in running biomechanics due to a large increase in flight time from 40% offloading onwards [113].

Nix et al. (2015) [89] suggested that understanding the mechanism of actions and physiological benefits of using an anti-gravity treadmill will also benefit future study designs [89]. Therefore, various studies that have investigated certain physiological markers when runners ran at different levels of body weight support on an anti-gravity as shown in Table 3. Heart rate (HR) [12,41,43,109,114], ground reaction forces (GRF) [12,36,113,114], rating of perceived exertion (RPE) [12,41–43,109,115], lower limb EMG [107,110,111] and maximal oxygen consumption (VO_{2max}) [42,109] have been measured in these studies. At this time some studies [13,42,54,112,115] suggest a decrease in overall physiological cost of running as offloading increases however findings are not necessarily proportional to the degree of offloading and there is much room for further research in this field [12,43].

Table 3: Effects of offloaded running, using an anti-gravity treadmill, on performance and physiological markers.

Study	Participants	% BW	Variable controlled	Outcomes measured					Conclusions drawn
				HR	GRF	RPE	EMG	VO_{2max}	
Gojanovic et al. (2012) [12]	14 Elite distance runners	100 95 90 85	Running time: 30-minute maximal test	↓	↓	0			The study showed that peak treadmill running speed increased significantly as the percentage of offloading increased. Maximum heart rate decreased with increased offloading and no change in RPE was observed
Hoffman et al. (2011) [41]	12 physically active males and females	100 75 50	VO_{2max} set to demine similar running speed	0		0			Body weight support did not alter the normal relationship between VO_{2max} and HR or RPE during offloaded running. This means at 50% body weight support; an athlete would run faster to achieve a set $V0_{2max}$ but the heart rate and RPE at that point were similar to normally loaded running
Figueroa et al. (2011) [43]	10 healthy participants, 5 males, 5 females	100 90 80	Treadmill speeds (Bruce protocol)	↓		0			Offloading of up to 20% bodyweight had no significant effects on metabolic responses of VO_{2max}, HR and RER during jogging at a set treadmill speeds
Hunter et al. (2014) [111]	11 elite college distance runners	100 80 60 40	Treadmill speed at (4.47 $m.s^{-1}$) for 2 min				↓		Lower muscle forces as measured by EMG were demonstrated in most muscles as body the degree of weight support increased
McNeill et al. (2015) [112]	6 elite distance runners	100 80 60	Treadmill speed 4 different set speeds	↓		↓		↓	Decreases in HR and RPE were measured as offloading increased. It was concluded that as body weight support increases, the metabolic cost of running decreased; however, this finding was not necessarily proportional to the amount of offloading
Patil et al. (2013) [116]	4 healthy participants	100 75 50 25	Treadmill speed		↓				The LBPP treadmill allowed for a controlled decrease in GRF and subsequent decrease in joint forces. It was proposed as tool in the rehabilitation of patients following lower-extremity injury

BW = body weight, HR = heart rate, GRF = ground reaction force, RPE = rate of perceived exertion, EMG = electromyogram, VO_{2max} = maximum oxygen consumption

** It should be noted that conclusions drawn are relevant to all percentages of body weight as listed were investigated during each respective study.*

Study	Participants	% BW	Variable controlled	Outcomes measured					Conclusions drawn *
				HR	GRF	RPE	EMG	VO_{2max}	
Liebenberg et al. (2011) [110]	9 physically active participants	100 90 80 70 60	Treadmill speed				↓		Reducing body weight leads to a significant reduction in muscle activity of all but two muscle groups measured. No changes in muscle activity patterns were observed
Sainton et al. (2013) [113]	15 physically active participants	100 80 60	Preferred treadmill speed (kept constant)		↓	↓			Although certain reductions in GRF and RPE were measured, these changes were not significantly decreased as offloading increased. There was not necessarily a decrease in work of running owing to a decrease in GRF as participants reacted differently to the offloading process
McKenna (2013) [114]	3 participants	100 90 80 70	Treadmill speed	↓					When treadmill speed was kept constant, a decrease in heart rate was observed as the percentage of offloading increased
Mercer et al. (2013) [107]	7 participants	100 50 40 30 20	Treadmill speed at 3 different speeds				↓		Muscle activity as measured by EMG significantly increased with speed and decreased by body weight reduction
Raffalt et al. (2011) [42]	12 well trained athletes	100 75 50 25	Treadmill speeds (high speeds)		↓	0		↓	The study proposed the anti-gravity treadmill as an appropriate tool for aerobic exercise or training where low joint load is required.

BW = body weight, HR = heart rate, GRF = ground reaction force, RPE = rate of perceived exertion, EMG = electromyogram, VO_{2max} = maximum oxygen consumption

** It should be noted that conclusions drawn are relevant to all percentages of body weight as listed were investigated during each respective study.*

2.5.2 Offloaded Running for Recovery

Currently, these notions of offloaded running, using an anti-gravity treadmill, have been suggested as an effective aid for rehabilitation and training [14] resulting in rehabilitation success demonstrated for certain loading specific injuries [111]. There is still much to be explored in this field, but it has been suggested that the use of a device such as the anti-gravity treadmill may assist in maintenance of cardiovascular fitness during rehabilitation and recovery after a myocardial event [43]. It may be hypothesized that the reduction in ground reaction forces during offloaded running may be associated with a reduction in eccentric loading during running [42,43]. This may provide athletes with an opportunity to perform sport-specific active recovery that closely mimics land-based running. However, there is currently limited evidence for the effects of offloaded running interventions on recovery after muscle damage.

To date, there are two studies that have investigated the effects of an anti-gravity treadmill as an offloaded recovery tool after endurance exercise [108] and EIMD [89]. The key components of these studies have been summarised in Table 4. West (2014) [108] explored the use of an anti-gravity treadmill compared to alternate forms of recovery strategies (cycling and standard static stretching) after a 29-km cycling time trial. There were no significant reductions in systemic inflammatory markers, blood lactate concentrations, anaerobic performance or psychological mood states following the offloaded running recovery intervention when compared to other recovery strategies[108].

Nix (2015) [89] explored the effects of an anti-gravity treadmill run compared to a recovery run on a normal treadmill and static stretching after a moderate intensity 45-minute downhill run. Twenty-five recreationally active males were recruited for this study and divided into the three groups. All groups performed 30-minute recovery sessions on three consecutive days. The stretching group performed 30 minutes of standardised static lower body stretches. The normal treadmill group ran for 30 minutes at 60% of their VO_{2max} at a 0% incline and the anti-gravity treadmill did the same, but at 70% of their body weight. There were no significant differences in markers of muscle damage and recovery in the offloaded running group when compared to the standard treadmill running group or the stretch group [89].

It apparent that there is currently limited evidence for the use of offloaded running as an effective recovery intervention [89,108]. However, more research is needed to explore the effects of different offloaded running protocols, particularly relating to the manipulation of variables such as exercise intensity and percentages of weight support. Further, the effects of offloaded running protocols on recovery following a marathon or ultra-marathon race require investigation [43] .

Table 4: Summary of two recovery studies investigating the use of an offloaded recovery intervention using an anti-gravity treadmill.

Study	Study participants	EIMD induction	Recovery interventions	Frequency	Outcome measure used	Effect of G-trainer
Nix et al. (2015) [89]	25 recreationally active males aged 18 – 35 years	45 minutes downhill running at -10% gradient, 60% VO_{2max} Significantly induce muscle damage	**Anti-gravity treadmill** 30 minutes, 60 % VO_{2max}, 0% incline, at 70% body weight (BW) **Normal treadmill** 30 minutes at 60% VO_{2max}, 0% incline **Static stretching** 30 minutes of stretching	30 minutes, 24, 48 and 72 hours post EIMD	Perceived muscle soreness Plasma creatine kinase and other markers of oxidative stress Isokinetic muscle torque POMS (mood state) Assessed at baselines, straight after EIMD and 24, 48, 72, and 96 hours post.	Besides a small improvement in mood state, Recovery on an anti-gravity treadmill was unable to create significant changes in any of the outcomes in the days following EIMD.
West et al. (2014) [108]	12 aerobically conditioned males aged 18 – 30 years	29 km maximal effort cycling time trial on a cycle ergometer	**Anti-gravity treadmill** 30 minutes at 40% of VO_{2max} at 75% BW **Cycle ergometry:** compu-trainer for 30 minutes at 40% VO_{2max}. **Static stretching** 30 minutes of traditional static stretches	Only once, straight after the fatiguing exercise	Isokinetic strength, Plasma creatine kinase, Serum cortisol Muscle soreness Mood states (POMS) Performance using a 30 second supra-maximal test 24 hours after fatiguing exercise Assessed at baseline, 15 minutes, 3, 24, hours post fatigue induction	No significant differences between recovery interventions were evident.

2.6 SUMMARY

Efforts to optimise athlete recovery after high training volumes are of interest as they may potentially facilitate improved athletic performance for a longer duration [27,29]. In contrast, insufficient recovery from high training volumes or competition may be detrimental to performance, may predispose an athlete to injury, and may result in fatigue effects from exercise-induced muscle damage [21]. For endurance runners, such as those participating in the Comrades marathon, these undesirable consequences may last for several weeks after a ultra-marathon race [22] and are most frequently reported as symptoms of stiffness, DOMS and swelling [7]. Exercise-induced muscle damage usually results from exercise associated with a combination of eccentric loading, unaccustomed high intensity and a repetitive nature,[4] the effects of which have been measured at various physiological levels. Subsequent changes in cardio-respiratory function [24,52], neuromuscular control [34], muscle strength [22], central fatigue adaptations [6], and psychological states [1] after such events, may all affect performance [5,11,53] and ability to adapt positively [11].

Adequate recovery remains integral in any training process and as a result, several recovery modalities (both passive and active) have been developed to minimize EIMD, accelerate the natural recovery process and increase positive training adaptations [7]. It has been argued that active exercise may be one of the most beneficial recovery strategies [5]. Physiotherapists and coaches often prescribe light exercise as a recovery strategy; however the are many challenges around the practical applications of specific mode, intensity and duration of these strategies for recovery [36]. More recently, offloaded forms of active recovery have been suggested in the forms of deep water running [18,78] and the use of an anti-gravity treadmill[89,108]; however, there is limited evidence for these recovery strategies.

Various physiological effects and benefits of offloaded running using an anti-gravity treadmill have been investigated [12,42,43,112,116]. On the basis of these effects, a suggestion for its use after a myocardial event [43] as well as two pioneering studies [89,108] exploring the use of the anti-gravity treadmill during recovery, it was hypothesized that an offloading treadmill apparatus, such as the anti-gravity treadmill, could provide well trained endurance athletes with an opportunity for recovery from the effects of exercise-induced muscle damage, such as those consequent of ultra-marathon running.

CHAPTER 3: THE EFFECTS OF AN OFFLOADED RUNNING INTERVENTION VERSUS ACTIVE RECOVERY ON RUNNING PERFORMANCE AFTER AN ULTRA-MARATHON RACE

3.1 INTRODUCTION AND STUDY SETTING

Ultra-marathon training and competition is commonly associated with the development of EIMD, DOMS and fatigue [5,11,20,26,47]. Adequate recovery is essential to enhance training and performance [5]. Numerous recovery interventions have been identified, but there is limited efficacy for many recovery interventions following endurance running training and performance [5,7,21,29]. Active recovery is a popular form of intervention [5,18,29,31,36,78,92]; however, there is low evidence for this recovery strategy in ultra-marathon runners, possibly because the presence of significant EIMD and DOMS limits the application of load during the recovery period post-race [2,10,22,89]. However, an offloaded running intervention, using an anti-gravity treadmill may assist in maintenance of cardiovascular fitness during rehabilitation [116] and recovery after an endurance event such as an ultra-marathon race [42,43]. There is also potential for a sports-specific intervention to maximally enhance recovery based on the principle of specificity [13,109]. Therefore, the aim of this study was to determine the effects of an offloaded running intervention compared to active recovery on running performance after an ultra-marathon race. The specific objectives of the study have been described in Section 1.2 (page 3).

The study was conducted at Prime Human Performance Centre (Prime) in Durban, South Africa, the location of an offloaded treadmill. The Prime Centre was also used for the assessment of time trial performance. It was a convenient location for participants in this study, who were recruited from local running clubs in Kwa-Zulu Natal, Durban.

3.2 METHODS

3.2.1 Participants and Research Design

The study had an experimental pre-test – post-test design. Participants were stratified into matched pair equivalents based on a pre-test 5 km time trial performance. Matched pair equivalents were then randomly assigned into either an experimental group (offloaded recovery group) or control group (standard active recovery group). This was done on completion of the ultra-marathon run.

3.2.2 Recruitment

A sample of 21 healthy male runners, who were entered to take part in the Comrades ultra-marathon, from Durban to Pietermaritzburg, in June 2017, and between the ages of 20 and 50 years, were recruited for this study. Participants were recruited through an advertising flyer (Appendix X) that was e-mailed to all the local running clubs in Durban and surrounding areas. The flyer was also put up at Prime Human Performance Institute, where the study was based. Additionally, participants were recruited at a pre-Comrades talk held at the centre.

3.2.2.1 Sample Size Determination:

A previous study [11] that used 5 km time trial performance time as a primary outcome measure during the recovery period after an ultra-marathon race was used to determine the required sample size to ensure sufficient statistical power. The sample size calculation was based on a smallest meaningful difference in 5 km time trial performance of 15 seconds, a within-subject standard deviation (typical error) of 7 seconds, and a proportion of 50% in the experimental group. With statistical significance accepted as $p < 0.05$; groups of 8, 10 and 12 participants provided 80%, 90% and 95% statistical power respectively.

3.2.2.2 Inclusion Criteria

All participants were required to have a current marathon (42.2 km) time of less than four hours, and a minimum average training mileage of 40 km per week. Female participants were excluded from this study, as one of the key outcome measures is exercise performance over a 5-km time trial. It is well-documented that hormonal changes associated with the menstrual cycle, specifically oestrogen levels, influence exercise performance [49]. Given the nature of the study design that involves pre- and post-race testing around the Comrades marathon, it was necessary to exclude female runners to avoid potential confounding factors that might influence performance.

3.2.2.3 Exclusion Criteria

Participants were excluded from the study if they develop any flu-like symptoms in the two weeks prior to the Comrades Marathon. Participants were excluded if they reported any relevant surgical or medical history, including a history of lumbar spine or lower limb injury or pathology. Participants were also excluded if they did not complete the Comrades marathon. The use of any intervention to facilitate recovery during the study resulted in further exclusion. This included the use of ice, foam rolling, compression garments or massage.

3.2.3 Study Procedure

Figure 3 shows a schematic representation of testing procedures for this study.

Day:	**-14**	**-14**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**10**
May/June 2017:	21st	21st	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
Measurements	☺	▣	■	★	■	■	■	■	■	■	■	▣
Experimental group						AG	AG	AG	AG			
Control group						AR	AR	AR	AR			

☺ = familiarisation; ▣ = Time trail testing; ■ = Muscle Pain (acute test) ★ = induction of fatigue by ultra-marathon; **AG** = 30-minute offloaded run (on an anti-gravity treadmill); **AR** = Active recovery strategy (walking)

Figure 3: Schematic representation and time line of testing procedures and interventions performed by participants in the experimental and control groups.

3.2.3.1 Familiarisation and Baseline Testing

A familiarisation session was conducted two weeks prior to the Comrades Marathon. The study outline, scope and timeline were explained to each participant and they were familiarised with all the testing procedures. Participants were presented with pedometers for daily step counting after the ultra-marathon and log books for pain ratings, medications taken and daily dietary information (Appendix V). At familiarisation, two objective measurements were performed after written informed consent was obtained; namely anthropometry and a baseline 5 km time trial.

3.2.3.1.1 Informed Consent Form and Baseline Questionnaire

All participants completed informed consent forms (Appendix I). The forms included a description of all study requirements and testing procedures, information regarding the attainment of formal ethical approval, benefits and potential risks of the study, significance of the study and their right to withdraw from the study at any time. Participants were also assured that individual privacy and confidentiality of data would be strictly maintained. In addition, participants filled in a Physical Activity Readiness Questionnaire [117] (ParQ) (Appendix II), as well as a Medical and Training History Questionnaire that established relevant medical, racing, pacing and training history (Appendix III). This questionnaire was based on a similar questionnaire used by UCT students to gather data for a study examining the recovery of athletes after the Two Oceans ultra-marathon). The questionnaire was validated as part of the Two Oceans ultra-marathon study [118]. The questionnaire was modified minimally to make it more specific for information regarding the Comrades marathon. All the questions essentially remained the same, but where relevant, references to 'Two Oceans marathon' were replaced with 'Comrades marathon'.

3.2.3.1.2 Anthropometry

All participants had their body composition estimated (Appendix IV). Body mass (kg) and stature (cm) were recorded using a calibrated scale and stadiometer respectively (Seca model, 708 Germany). Total body fat was calculated using the sum of seven skin fold measurements: Triceps, biceps, subscapular, supra-iliac, abdomen, thigh and calf [119]. Body fat was expressed as a percentage of body mass [120].

3.2.3.1.3 Time Trial Test

All participants performed a 5-km time trial between ten and 14 days before the Comrades Marathon as a pre-test measure and then repeated this procedure ten days after the Comrades Marathon as a post-test measure. The reliability of an indoor treadmill time trial as a measure of running performance has been previously demonstrated [121,122] and ensured that environmental factors are controlled between tests [123]. Both pre-and post-time trials were performed on the same treadmill, at 1% gradient [124], sea level, indoors and with only the built in treadmill fan blowing on the runner. The treadmill remained unmoved throughout the duration of the study. On both occasions participants ran having fasted for at least two hours prior to the run; were well hydrated; had rested one day prior to the time trial; and performed the time trial runs in the same shoes ensure repeatability of the trials [125].

Participants performed a 10-minute self-paced warm up of their choice on the treadmill prior to the time trial test. During the time trial, participants were instructed to run "as fast as possible" and standardised verbal encouragement was given during the time trials [77]. Continuous running time and distance covered as usually displayed on the treadmill were both concealed, but at every kilometer split, participants were given their split time, heart rate and total distance covered. The participant controlled the speed of the treadmill using a control button [121].

Runners rated their perceived exertion (RPE) using a modified Borg Scale, as previously used during time trial performance measures in endurance runners, [9] at every kilometer split (Appendix VII). Heart rate was recorded at one-kilometer intervals during the 5-km time trial using a TomTom watch (Runner Cardio 2 GPS) that used a build in heart rate monitor. Split times and total running times were recorded and average running speed calculated from these times (Appendix VIII).

3.2.3.2 The Ultra-Marathon Race

All recruited participants were then required to run and complete the Comrades 87 km ultra-marathon on 4th June 2017 from Durban to Pietermaritzburg to induce muscle damage and fatigue. The race profile of this event is included in Appendix XI. Participants were not required to wear a heart rate monitor during the event to avoid potential chafing problems, and because the time needed to complete the race could exceed the battery life of most heart rate monitoring devices. Race progress was followed on the day a smart-phone application (Comrades, 2017), official time was recorded and average running speed (ARS) calculated from the official Comrades results site [3]. An indication of race intensity was calculated as a percentage of running speed as established from their time trial efforts during baseline testing.

3.2.3.3 Group Allocations and Interventions

After the ultra-marathon, participants were assigned into matched pair equivalents based on their time trial efforts, and randomly allocated into the two groups by flip of an unweighted coin. The experimental group received an active offloaded treadmill recovery intervention [108] and the control group received an active recovery strategy. Daily step counts measured the amount of walking performed by both the groups. Most previous recovery intervention studies have administered their interventions on the first day after a fatiguing strategy (in this case the Comrades Marathon) was performed [5,21]. However, due to the nature and intensity of the ultra-marathon race, both groups were instructed to rest passively on the first day after the ultra-marathon race and recovery strategies commenced on day two post-race.

3.2.3.3.1 The Experimental Group

The experimental group received three to four consecutive sessions of an active recovery protocol on the anti-gravity treadmill within the first week after the Comrades ultra-marathon. This dosage and degree of offloading was selected based on a recent study by Nix et al (2015) [89] that also used an offloaded treadmill as a recovery strategy after EIMD. The anti-gravity treadmill was set at 0% gradient and 70% (30% offloaded) [89] of the participants' body weight as calibrated by the treadmill. During this calibration the participant had to cross their arms on their chest as to not hold onto the anti-gravity treadmill, which would affect their body weight calibration [14]. They ran for 30 minutes at a self-selected pace but below 70% [97] of their HR_{max} as calculated from the time trial test [35,89,97,126]

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Heart rate, RPE and distance covered were recorded at 10-minute intervals (Appendix IX). Participants' subjective comments regarding their experiences of the offloaded running intervention were documented (Appendix XIII). The participants' activity levels throughout the day were also monitored with a standard step count pedometer.

3.2.3.3.2 The Control Group

The control group were given an active recovery strategy, in which they were instructed not to run for a week after the ultra-marathon, but to walk as much as they wanted, and to continue their normal activities of daily living. Daily step counts were tracked using a standard step count pedometer and recorded.

A detailed description of the intervention for both groups, with attention to variables being controlled or manipulated, has been outlined in Table 5.

Table 5: Structure of the intervention and variables controlled.

Day	Intervention Description		Variables			Measurements
	Offloaded Group	*Normally loaded group*	*Controlled Variables for both groups*	*Manipulated Variable*	*Possible confounding factors*	
Day 0	Ultra-marathon	Ultra-marathon	Race profile		Prior training, injury development, fatigue	Split times Intensity/pace Total time
Day 1	Rest	Rest	No running, No other recovery interventions		Nutrition, Previous training	VAS Step counter
Day 2 **Day 3** **Day 4** **Day 5** **Day 6**	3-4 30-minute recovery runs on Anti-gravity at less than 70% HR_{max}	Current best practice of active recovery strategy (excluding all therapeutic assistance): no running, walking only, continued ADLS	Intensity: HR Environment temperature Incline at 0% Footwear Sleep prior to runs, No other exercising allowed No other recovery interventions.	Loading of active recovery Type of active recovery	Timing of intervention, participants to run at different times of day. Other daily activities	On waking: VAS *During intervention:* HR RPE Pre-and post VAS Step count
Day 7-9	Rest Normal activities of daily living	Rest Normal activities of daily living	As above		As above	none
Day 10	5 km time trial	5 km time trial	Nutrition prior to test Test environment same for all Rest the day before Footwear the same		Time on feet and ADLS differing for each participant, experience of running and natural ability to recover	Heart rate RPE Running speed

3.2.3.4 Muscle Pain

Muscle pain was recorded using the Visual Analogue Scale (VAS). Participants were asked to record daily ratings of muscle pain, 30 minutes after they wake up, one day before, and for seven days after the Comrades Ultra-marathon using a logbook given to them at the familiarisation (Appendix V). Participants were required to rate and record the pain in their right and left hamstring, quadriceps and gastrocnemius muscles by drawing a vertical line on a 10-cm pain rating scale, where 0 cm represented "*no pain*", and 10 cm represented "*maximal pain*". The distance along the pain rating scale to the vertical line drawn was measured and the numeric pain score recorded [19]. They were required to do this in four broad categories of "*general pain at rest*", "*pain during activities of daily living*", "*pain during a passive stretch*", and "*pressure pain*". For pressure pain, participants were requested to apply digital pressure to the mid-belly of each muscle until moderate tissue resistance was felt [74]. The VAS has been validated as accurate, reliable and appropriate in evaluating pain intensity following exercise-induced muscle damage when repeated measurement is involved [19] and its reliability and validity in the multi-dimensional pain scale version when assessing pain associated with EIMD, has been established [73,74] .

3.2.3.5 Follow-up Testing

3.2.3.5.1 Post-Race Time trial

A repeat 5 km time trial, as described in 3.2.3.1.3 Time Trial Test, was performed ten days after the ultra-marathon race. Participants were requested to perform the same procedure, in the same shoes, having followed the same the pre-time trial routine as previously described. The results of the post-race time trial were then compared to the baseline testing outcomes.

3.2.3.5.2 Compliance

All participants filled in a daily log book (Appendix V) where they recorded dietary information, any exercise done, if any other methods of recovery were used and if any medication was taken. This was done one day before and for seven days after the ultra-marathon. On completion of the interventions and final testing procedures, all participants also completed a short compliance questionnaire to establish any confounding variables that might have influenced the test results (Appendix VI).

3.2.5 Statistical Analyses

Statistical analysis of the collected data was performed using Statistica software [StatSoft, Inc. (2016). STATISTICA (data analysis software system), version 13.2. www.statsoft.com]. Data were tested for normality using the Shapiro-Wilkes test. Differences in descriptive variables between the two groups were assessed using an independent t-test. Statistical significance for the two main effects of group and time, and the interaction (group x time) of all other variables were assessed using a two-way analysis of variance (ANOVA) with repeated measures. Tukey's *post hoc* comparisons between groups were performed where necessary. A Mann-Whitney U test was used to assess differences in VAS pain scores between groups. A Friedman's ANOVA and Kendall's concordance was performed to assess differences in the pain scores within groups over time. All numerical data were presented as the mean ± standard deviation (SD) and statistical significance was accepted as $p < 0.05$.

3.2.6 Ethical Considerations

Principles outlined in the Declaration of Helsinki (Fortaleza, Brazil, 2013) [127] were adhered to throughout this study. Ethics approval was obtained from the University of Cape Town, Faculty of Health Sciences Human Research Ethics Committee prior to study commencement (HREC REF: 602/2016) (Appendix XII). After ethical approval was obtained, recruitment procedures started and informed consent forms were emailed to all participants. The purpose of the study, testing procedures, benefits and possible risks of the study were explained to the participants and the participants were given the opportunity to raise any questions or concerns they may have. The participants were also informed of their right to withdraw from the study at any stage. Individual privacy and confidentiality of data were maintained through coding of participant information. No personal identifying information was recorded. Hard copies of data were securely stored in a locked cupboard. The data spreadsheet was stored on the researcher's personal computers and was password-protected.

The potential risks and benefits of this study are outlined in Table 6. In addition, there were no conflicts of interest associated with this research study. The researchers do not have any vested interests in the anti-gravity treadmill that was used in this study. This study was also self-funded, and was not sponsored by the company that manufactures the anti-gravity treadmill that was used in this study.

Table 6: Risk-benefit analysis of the study.

Study Component	Potential Risk	Risk Management	Benefit
Familiarisation	Driving to the venue. Time constraints of participants.	Informed consent.	Information on Recovery. Presented to participants.
Body composition tests	Confidentiality of results, Minor discomfort of skin fold assessments	Files with participant information were kept at Prime Institute and on the researchers locked computer. Confidentiality ensured at familiarisation. Skin fold testing will be explained and demonstrated.	Information regarding body composition which may in turn improve performance and management of body composition for running.
5 km time trial	This is a maximal test placing participants in a category of increased risk of musculo-skeletal injuries.	A compulsory and self-paced pre-test warm up will be done prior to each test.	Pre-test – Post-test individualized comparisons will be given to each participant. Systematic Heart rating monitoring information during these efforts which will be given to all participants
Intervention: Anti-gravity treadmill	Treadmill associated risks: Falling is unlikely due to being zipped into the device Hamstring tightness due to increased flight time Infection control due to recycling of the zip in pants	Familiarisation with the treadmill for each Experimental group participant was performed. Testing was supervised by a qualified physiotherapist, experienced in using the anti-gravity treadmill. There were emergency medical services available on site. Participants ran at sub-maximal intensities – hamstring tightness and potential strains are only really a factor during speed work when coupled with increased flight time. Participant's running speeds will be controlled. Prime institute allowed the use of 6 different pairs of pants, these were washed every evening and between participants where necessary	Opportunity to try a rehabilitation tool. The opportunity was given to the control group to try the anti-gravity treadmill after the study is completed.
Researcher	Participant drop out due to: Tiresome testing procedures Weekend testing procedures	Explanation of compliance for the results at familiarisation. Good communication, well in advance during the testing procedures to ensure participants are well informed and can plan accordingly	An opportunity to comment on a new rehabilitation tool that could in turn provide clinically relevant information on the use of such a device.

3.3 RESULTS

3.3.1 Study Sample

A schematic diagram of the study is depicted in Figure 4. Twenty-one participants were recruited, met the inclusion criteria and were accepted into the study at the recruitment cut-off date. One participant dropped out before ultra-marathon race due to acute illness and a personal decision not to start the race. The participant was informed he would be excluded from the study but was sent his pre-race results. Twenty participants started the ultra-marathon; however, two participants did not complete the race. One participant developed chest pains and nausea 56 km into the race; and the other participant suffered severe diarrhoea and cramping. Both participants were contacted the next day and given contact information of relevant medical care. They were also informed that they were unfortunately excluded from the study and were sent their pre-race results. There were no further drop outs during the study. Thus, 18 participants completed the study testing procedures, with nine participants in each group. Therefore, in accordance with the sample size calculation (Section 3.2.2.1, page 36), the study had 85% statistical power.

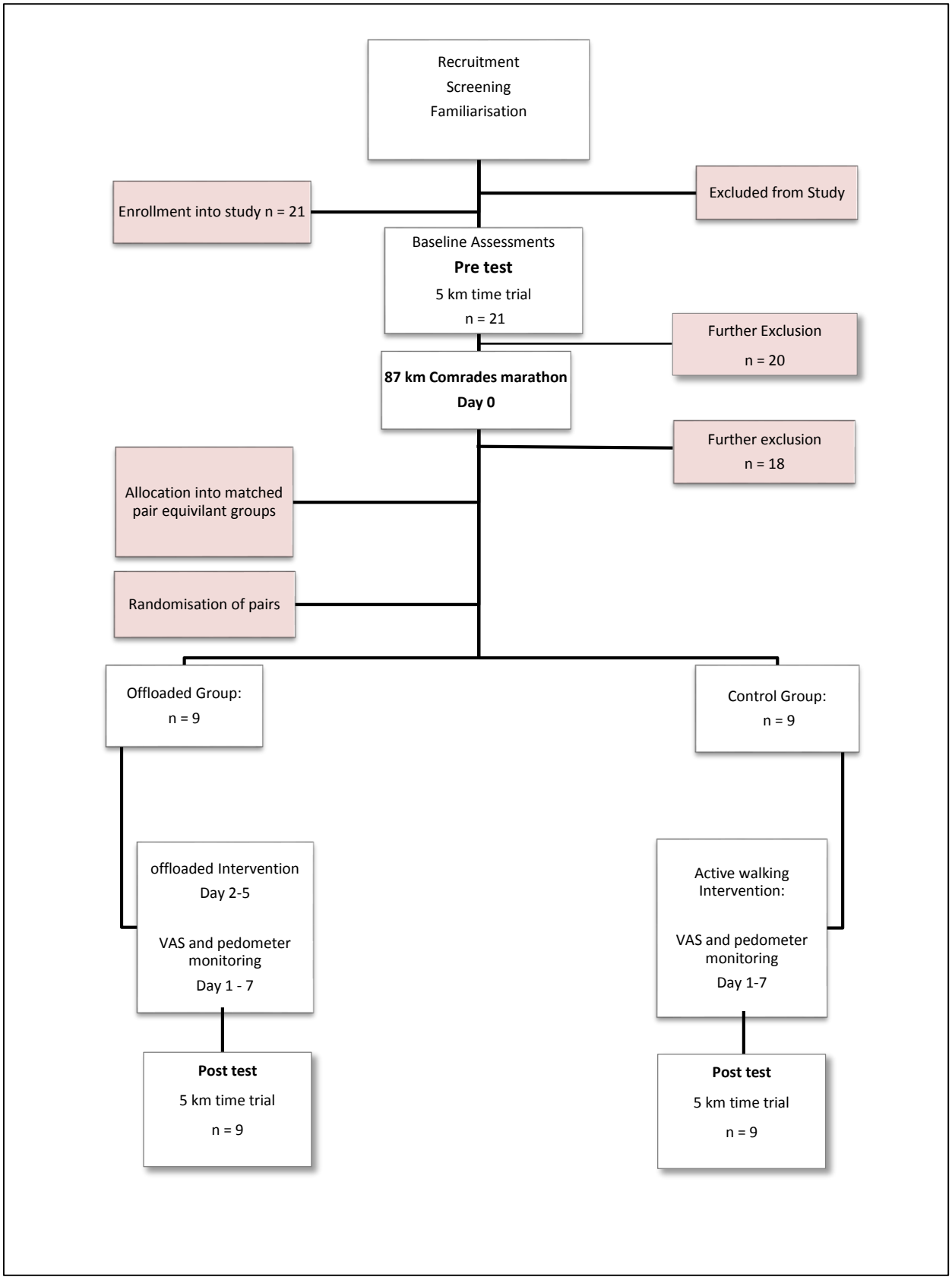

Figure 4: Study flow diagram of the study design.

3.3.2 Participants

The descriptive characteristics of participants in the experimental and control groups are shown in Table 7; and training and performance history of participants in both groups are outlined in Table 8. There were no significant differences between groups for any of these descriptive variables.

Table 7: Descriptive characteristics of participants in the experimental (n = 9) and control groups (n=9). Data are expressed as mean ± standard deviation.

Variable	Experimental (n=9)	Control (n=9)	t	p
Age (years)	34.7 ± 4.6	33.0 ± 7.9	0.5	0.6
Stature (cm)	178.6 ± 7.9	179.6 ± 5.4	-0.3	0.8
Body mass (kg)	73.2 ± 8.5	75.6 ± 8.9	-0.6	0.6
Body mass index ($kg.m^{-2}$)	22.9 ± 1.6	23.4 ± 2.4	-0.5	0.6
Body fat (%)	9.6 ± 2.8	11.1 ± 3.8	-1.0	0.4
Lean mass (kg)	66.1 ± 7.7	66.9 ± 5.9	-0.3	0.8
Maximum heart rate ($b.min^{-1}$)	184 ± 6.6	183 ± 6.5	0.5	0.7
Pre-test 5 km time trial average speed ($m.s^{-1}$)	4 ± 0.6	4 ± 0.6	0.1	0.9
Intensity of 5 km TT compared to reported 5 km PB (%)	93 ± 9.7	100 ± 11.3	1.3	0.2
PTRS during 5 km TT ($m.s^{-1}$)	4.8 ± 0.6	4.7 ± 0.5	0.1	0.9

Table 8: Season performance and running experience of experimental (n=9) and control (n=9) groups. Data are expressed as mean ± standard deviation.

Variable	Experimental (n=9)	Control (n=9)	t	p
5 km personal best PB ($m.s^{-1}$)	4.3 ± 0.6	4.0 ± 0.4	1.4	0.2
10 km PB ($m.s^{-1}$)	4.0 ± 0.6	4.0 ± 0.4	0.0	1.0
21 km PB ($m.s^{-1}$)	3.9 ± 0.7	3.8 ± 0.5	0.6	0.5
42.2 km PB ($m.s^{-1}$)	3.6 ± 0.4	3.4 ± 0.4	1.0	0.3
56 km PB ($m.s^{-1}$)	3.2 ± 0.4	3.1 ± 0.4	1.0	0.3
Number of 21 km races	18 ± 16	12 ± 6	1.1	0.3
Number of 42 km races	15 ± 12	11 ± 16	0.6	0.6
Number of 56 km races	7 ± 6	4.2 ± 6	1.1	0.3
Number of Comrades	3 ± 2	2 ± 3	1.1	0.3
long slow distance run training speed ($m.s^{-1}$)	3.3 ± 0.3	3.3 ± 0.2	0.4	0.7

It should be noted that six out of the nine participants in the control group were novice Comrades runners.

3.3.3 The Ultra-Marathon

Eighteen participants completed the Comrades Marathon. The experimental group and control group had a mean finishing time of 8 hours 33 minutes ($\pm$ 1 hour 27 minutes) and 9 hours 14 minutes ($\pm$ 1 hour 15 minutes) respectively (p = 0.6). Mean finishing speed, various split speeds and intensity have been outlined in Table 9. No significant differences between group performances were noted.

Table 9: Ultra-marathon (Comrades) performance of experimental (n=9) and control (n=9) groups. Data are expressed as mean ± standard deviation.

Variable	Experimental (n=9)	Control (n=9)	t	p
Mean running speed at 18.9 km ($m.s^{-1}$)	3.0 ± 0.6	2.9 ± 0.4	0.4	0.7
Mean running speed at 29.7 km ($m.s^{-1}$)	2.8 ± 0.5	2.7 ± 0.4	0.4	0.7
Mean running speed at 42.7 km ($m.s^{-1}$)	2.8 ± 0.5	2.7 ± 0.4	0.5	0.6
Mean running speed at 56.7 km ($m.s^{-1}$)	2.7 ± 0.5	2.6 ± 0.4	0.4	0.7
Mean running speed at 66 km ($m.s^{-1}$)	2.7 ± 0.5	2.6 ± 0.4	0.4	0.7
Mean running speed at 86.9 ($m.s^{-1}$)	2.7 ± 0.5	2.6 ± 0.3	0.5	0.6
Intensity of Comrades (%) *	66.4 ± 9.2	64.3 ± 6.1	0.6	0.6

*Intensity compared to the pre-Comrades 5 km time trial performance

3.4.4 Compliance

Eighteen participants completed the full study protocol. The experimental group all complied with the minimum of three sessions on the anti-gravity treadmill in the week following the ultra-marathon, except for one participant only completing two sessions. This was due to unforeseen transport problems in getting to his first offloaded recovery session on day two after the ultra-marathon and work requirements on his rescheduled session on day five post-race. It is recognised that this deviation from the planned may contribute to a reduction in the effect size of the experimental group intervention; however, given the relatively small sample size, a pragmatic decision was made to include this participant's data for analysis. All participants supplied their pain scores, step count, dietary information and whether they took medication, daily following a text message reminder every morning for seven days after the ultra-marathon. Three participants in the control group and one participant in the experimental group took pain medication on day one after the ultra-marathon. No other recovery methods were used for the rest of the study period.

3.3.5 Experimental Group Intervention

Participants in the experimental group ran for 30 minutes at 70% of their body weight, at a self-selected pace that had to be lower than 70% of their maximum heart rate as measured during their initial 5 km time trial performance 14 days before the ultra-marathon. Participants performed three to four recovery runs in the week after ultra-marathon. Details of daily offloaded running interventions (distance covered, mean running speed, RPE, heart rate and VAS scores during the 30-minute run) for individual participants in the experimental group are outlined in Table 10. Participants' comments about their individual, subjective experiences of the 30-minute offloaded recovery runs are documented in Appendix XIII.

Table 10: Measurements taken during 30-minute recovery runs on the anti-gravity treadmill performed only by the experimental group (n = 9).

Participant	Time run post ultra-marathon	Distance covered in 30 minutes	Mean recovery run speed in m.s-1	Mean RPE during recovery run	Mean HR during recovery run	VAS Hamstrings during run	VAS quadriceps during run	VAS calves during run
1	Day 2	4.82	2.7	5.7	119	20	0	0
	Day 4	5.61	3.2	6.7	124	5	0	0
	Day 5	6.01	3.3	6.3	126	5	0	0
2	Day 3	4.91	2.7	5.0	120	0	0	0
	Day 4	5.31	2.9	6.0	121	0	0	0
	Day 5	5.45	3.0	6.0	121	0	0	0
3	Day 2	3.5	1.9	10.0	115	0	0	0
	Day 3	3.93	2.2	8.3	98	0	0	0
	Day 4	4.83	2.7	10.0	99	0	0	0
4	Day 3	4.18	2.3	10.0	111	0	20	0
	Day 4	4.77	2.6	11.0	106	0	0	0
5	Day 2	4.30	2.4	11.3	116	30	0	0
	Day 3	4.98	2.8	9.0	119	0	0	0
	Day 4	5.61	3.1	10.3	125	0	0	0
	Day 5	5.59	3.1	8.0	127	0	0	0
6	Day 2	5.10	2.8	12.0	138	0	0	0
	Day 3	5.58	3.1	6.7	127	0	0	0
	Day 4	5.72	3.2	11.0	118	0	0	0
7	Day 2	3.11	1.7	8.7	114	20	5	5
	Day 3	3.72	2.1	11.7	117	0	0	0
	Day 4	4.57	2.5	11.7	113	0	0	0
	Day 5	5.98	2.8	14.7	117	0	0	0
8	Day 2	4.51	2.5	8.0	110	10	10	10
	Day 3	4.97	2.8	9.0	121	0	0	0
	Day 4	4.99	2.8	8.7	125	0	0	0
	Day 5	5.25	2.9	8.3	113	0	0	0
9	Day 2	4.38	2.4	10.0	128	0	0	10
	Day 4	4.65	2.6	7.7	126	0	0	0
	Day 5	6.47	3.4	10.0	159	0	0	0

3.3.6 Muscle Pain

Subjective pain scores of “general pain at rest” and “during a static stretch” are shown in Figure 5. Pain scores of “pressure pain” and “pain during activities of daily living” are shown in Figure 6.

There were significant main effects of time in general pain scores for the hamstrings (ANOVA Chi squared = 89.6 $p < 0.05$); quadriceps (ANOVA Chi squared = 93.3 $p < 0.05$); and gastrocnemius (ANOVA Chi squared = 105.1 $p < 0.05$) muscles for both groups. General pain for the quadriceps muscle was significantly higher in the experimental group than the control group on day 1 and 2 ($p = 0.004$, $U = 7.5$ and $p = 0.04$ and $U = 17$ respectively).

General pain for the gastrocnemius muscle was significantly higher in the control group than the experimental group ($p = 0.02$, $U = 12.5$) on day 3 after the ultra-marathon (Figure 5).

There were significant main effects of time in stretch pain scores for the hamstrings (ANOVA Chi squared = 115.2, $p < 0.05$); quadriceps (ANOVA Chi squared = 118.2, $p < 0.05$); and gastrocnemius (ANOVA Chi squared = 114.4, $p < 0.05$) muscles for both groups.

Stretch pain for the hamstrings was significantly higher in the control group compared to the experimental group in the hamstrings on day 4 ($p = 0.04$, $U = 16.5$) after the ultra-marathon. Stretch pain for the quadriceps was significantly higher in the control group than the experimental group on day 5 ($p = 0.03$, $U = 15.5$) after the ultra-marathon. Stretch pain for the gastrocnemius muscle was also higher in the control group than the experimental group on day 3 and 4 ($p < 0.04$, $U = 17$ and $p = 0.004$, $U = 7.5$ respectively) after the ultra-marathon (Figure 5).

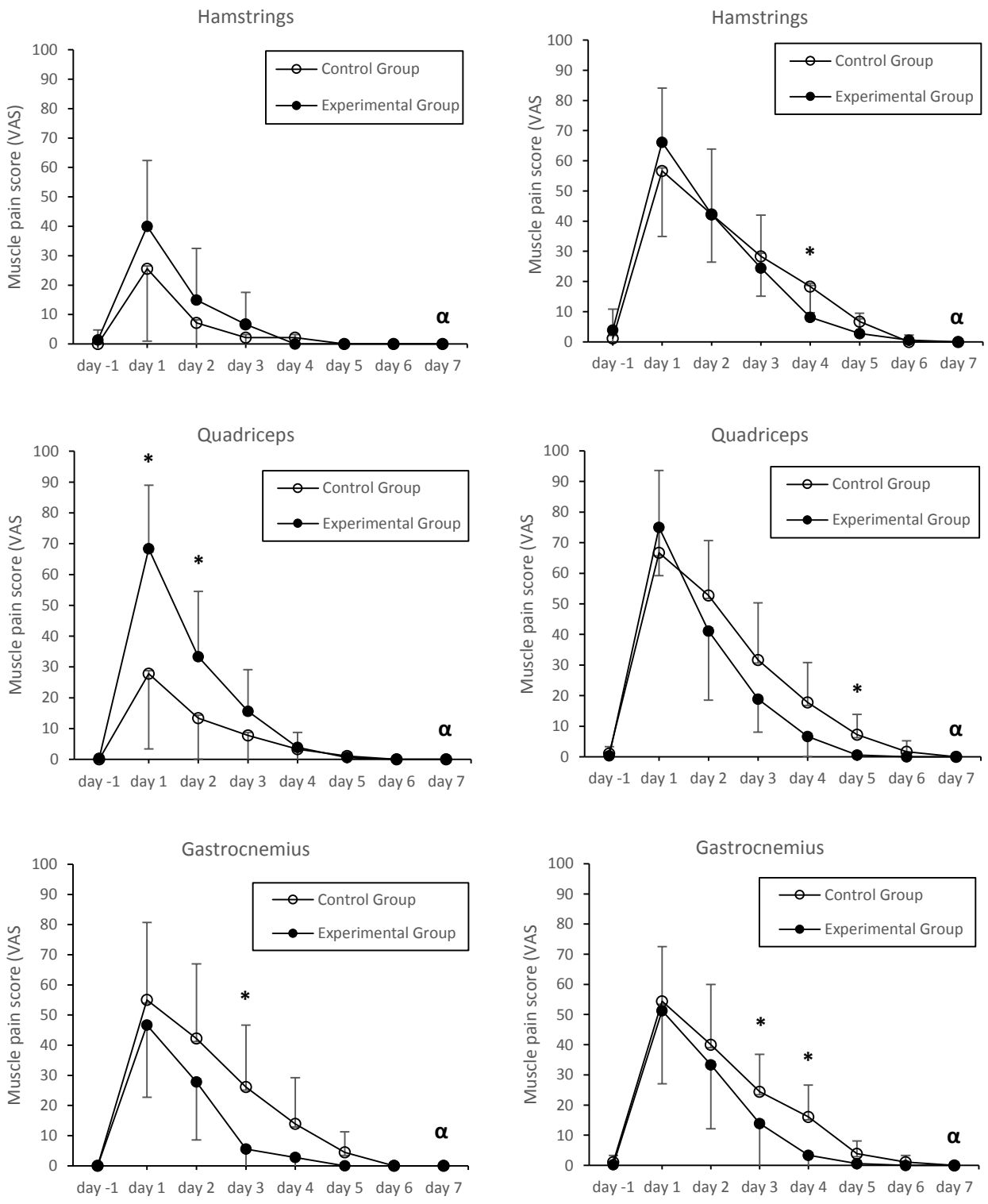

Figure 5: General pain and stretch pain scores (VAS) for the quadriceps, hamstring and gastrocnemius muscles of participants in the experimental (- ● -) and control groups (- o -) measured one day before and for seven days after the ultra-marathon. Higher scores indicate more pain.

Significant differences:

General Pain:	**α Main effect of time in all three muscle groups ($p < 0.05$)**
	*** Quadriceps: experimental day 1 and 2 vs. control day 1 and 2 ($p < 0.05$, $U = 7.5$ and $p < 0.05$ and $U = 17$ respectively)**
	*** Gastrocnemius: experimental days 3 vs. control day 3 ($p < 0.02$, $U = 12.5$)**
Stretch pain:	**α Main effect of time in all three muscle groups ($p < 0.05$)**
	*** Hamstrings: experimental day 4 vs. control day 4 ($p < 0.05$, $U = 16.5$)**
	*** Quadriceps: experimental day 5 vs. control day 5 ($p < 0.05$, $U = 15.5$)**
	*** Gastrocnemius: experimental days 3 vs. control days 3 ($p < 0.05$, $U = 17$) and experimental days 4 vs. control days 4 ($p < 0.05$, $U = 7.5$)**

There was a significant main effect of time on the pressure pain of the hamstrings (ANOVA Chi squared = 109.9, $p < 0.05$), quadriceps (ANOVA Chi squared = 117.8, $p < 0.05$) and gastrocnemius (ANOVA Chi squared = 113.2, $p < 0.05$) muscles for both groups.

Pressure pain for the quadriceps muscle was significantly higher in the control group compared to the experimental group on day 5 ($p < 0.05$, U = 11) after the ultra-marathon.

There was a significant main effect of time in the daily living pain of the hamstrings (ANOVA Chi squared = 105.5, $p < 0.05$), quadriceps (ANOVA Chi squared = 109.5, $p < 0.05$) and gastrocnemius (ANOVA Chi squared = 110.4, $p < 0.05$) muscles for both groups.

Daily living pain for the hamstring muscle was significantly higher in the control group compared to the experimental group on day 4 ($p < 0.05$, U = 16.5), and quadriceps on day 3 ($p < 0.05$U = 16.5) after the ultra-marathon. Daily living pain for the gastrocnemius muscle was also significantly higher in the control group than the experimental group on day 3 ($p < 0.05$, U = 16) after the ultra-marathon (Figure 6).

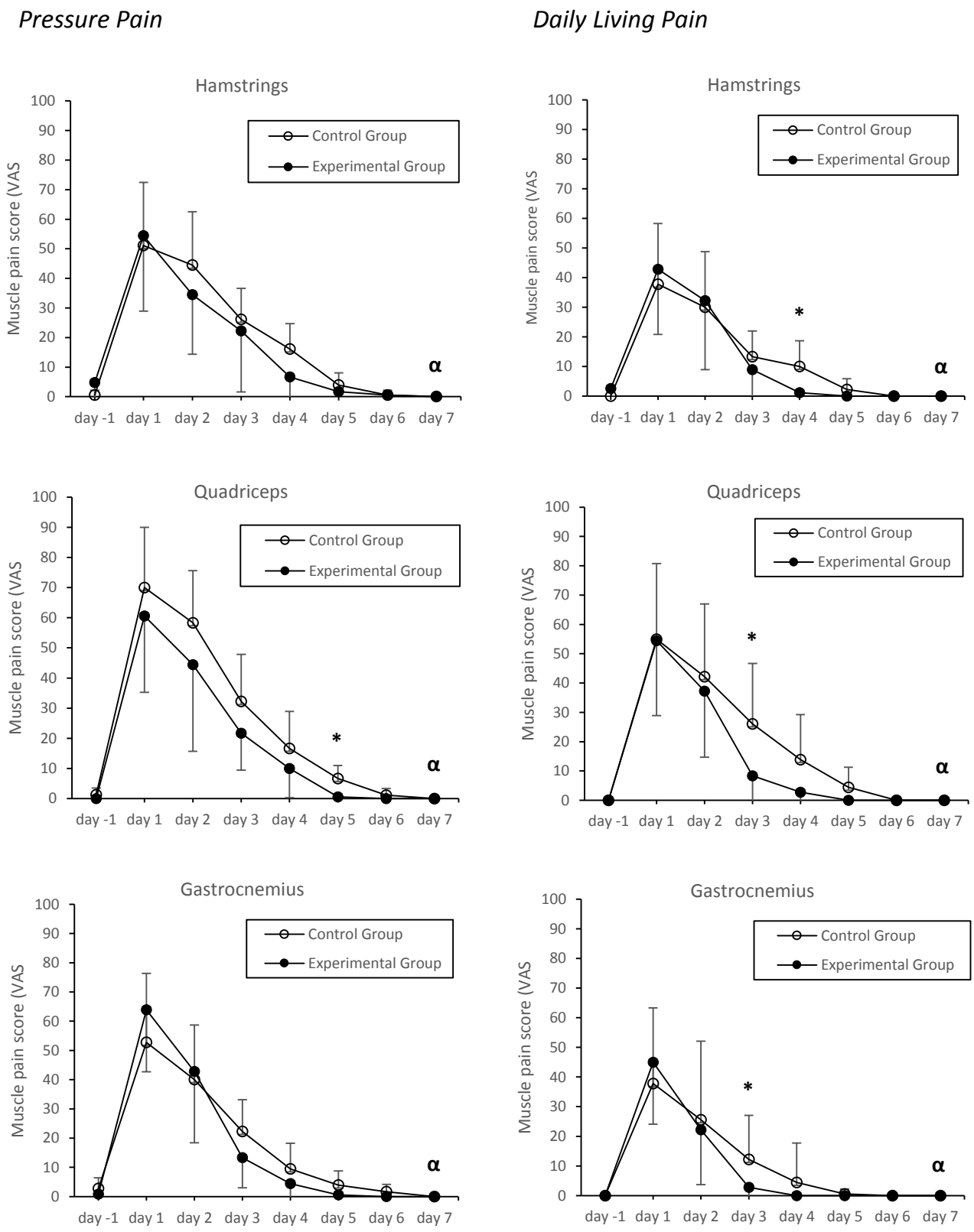

Figure 6: Pressure pain and daily living pain scores (VAS) for the quadriceps, hamstring and gastrocnemius muscles for experimental (- ● -) and control groups (- o -) measured one day before and for seven days after the ultra-marathon. Higher scores indicate more pain.

Significant differences:

Pressure pain:	**α Main effect of time in all three muscle groups ($p < 0.05$)**
	*** Quadriceps: experimental day 5 vs. control day 5 ($p < 0.05$, $U = 11$)**
Daily living pain:	**α Main effect of time in all three muscle groups ($p < 0.05$)**
	*** Hamstrings: experimental day 4 vs. control day 4 ($p < 0.05$, $U = 16.5$)**
	*** Quadriceps: experimental day 3 vs. control day 3 ($p < 0.05$, $U = 16.5$)**
	*** Gastrocnemius: experimental days 3 vs. control days 3 (< 0.05, $U = 16$)**

3.3.7 Step Counts

Objective step counts per day, as measured by a standard pedometer for seven days after the Comrades Marathon, are shown in Figure 7. There was a significant main effect over time for daily step counts ($F_{(6, 96)} = 3.411$, $p < 0.05$) for both groups, meaning that step counts significantly increased over the seven days. In the control group, step counts increased significantly ($p < 0.05$) on day 3 compared to day 1. No other significant differences were seen in daily step counts for seven days post Comrades.

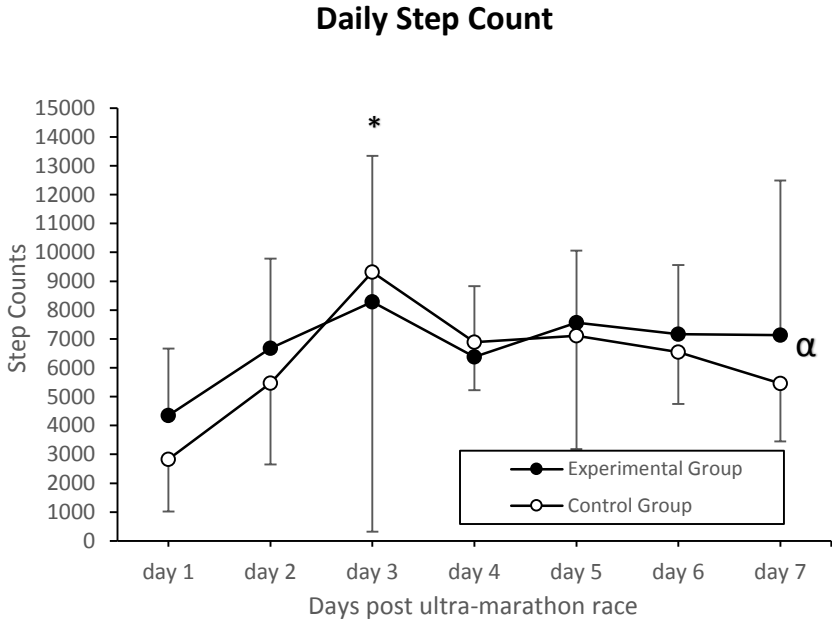

Figure 7: Daily step counts for experimental (- • -) and control groups (- o -) for seven days after the ultra-marathon.

Significant differences:

Main effects:	**α Main effect of time (p < 0.05)**
Experimental group:	*** day 3 vs. day 1 (p < 0.05)**

3.3.8 Time Trial

3.3.8.1 Performance

The differences in running speed ($m.s^{-1}$) during the 5-km time trial pre- and post- the ultra-marathon race for participants in the experimental and control groups are shown in Figure 8.

There were no significant differences in average running speed between groups, or pre-post the ultra-marathon race; however, there was a significant main effect of time ($F_{(4, 64)} = 13.4$; $p < 0.05$). There was also a significant interaction in time trial speed for both groups pre-post the ultra-marathon and over time ($F_{(4, 64)} = 40$, $p < 0.05$). These main and interactive effects reflect that running speed per kilometer significantly increased during the time trial (from km 1 to km 5) for both groups in pre-race and post-race time trials; but after the Comrades race, the rate of acceleration over the course of the time trial decreased significantly in both groups.

In the experimental group, post-race km 1 was significantly slower than pre-race km 2, 3, 4 and 5 ($p < 0.03$); post-race km 2 was significantly slower than pre-race km 5 ($p = 0.002$); and post-race km 3 was significantly slower than pre-race km 5 ($P = 0.01$). Running speed was increased at km 4 post-race compared to km 1 pre-race ($p < 0.05$) as well as increased at km 5 post race compared to km 1 and 2 pre-race ($p < 0.003$) (Figure 8)

In the control group, post-race km 1 was significantly slower than pre-race km 3, 4 and 5 ($p < 0.05$); post-race km 2 was significantly slower than pre-race km 4 and 5 ($p < 0.05$), and post-race km 3 was significantly slower than pre-race km 5 ($p < 0.05$). Running speed was increased at km 5 post race compared to km 1 pre-race ($p < 0.05$) (Figure 8).

Pre-race 5 km time trial times were 21.1 ± 3.1 minutes and 21.2 ± 3.1 minutes for the experimental and control groups respectively. Post-race 5 km time trial times were 21.4 ± 2.9 minutes and 22.3 ± 3.8 minutes for the experimental and control groups respectively. There were no significant differences in time trial times between groups; however, there were a significant main effect of time ($F_{(4, 64)} = 26.5$; $p < 0.05$) and pre-post the ultra-marathon race ($F_{(4, 64)} = 31$; $p < 0.05$). There was also a significant decrease in 5 km time trial time over time for both groups pre-post the ultra-marathon race ($F_{(4, 64)} = 17.7$; $p < 0.05$). On post-hoc analysis, identical significant differences were observed for 5 km time trial time as for running speed.

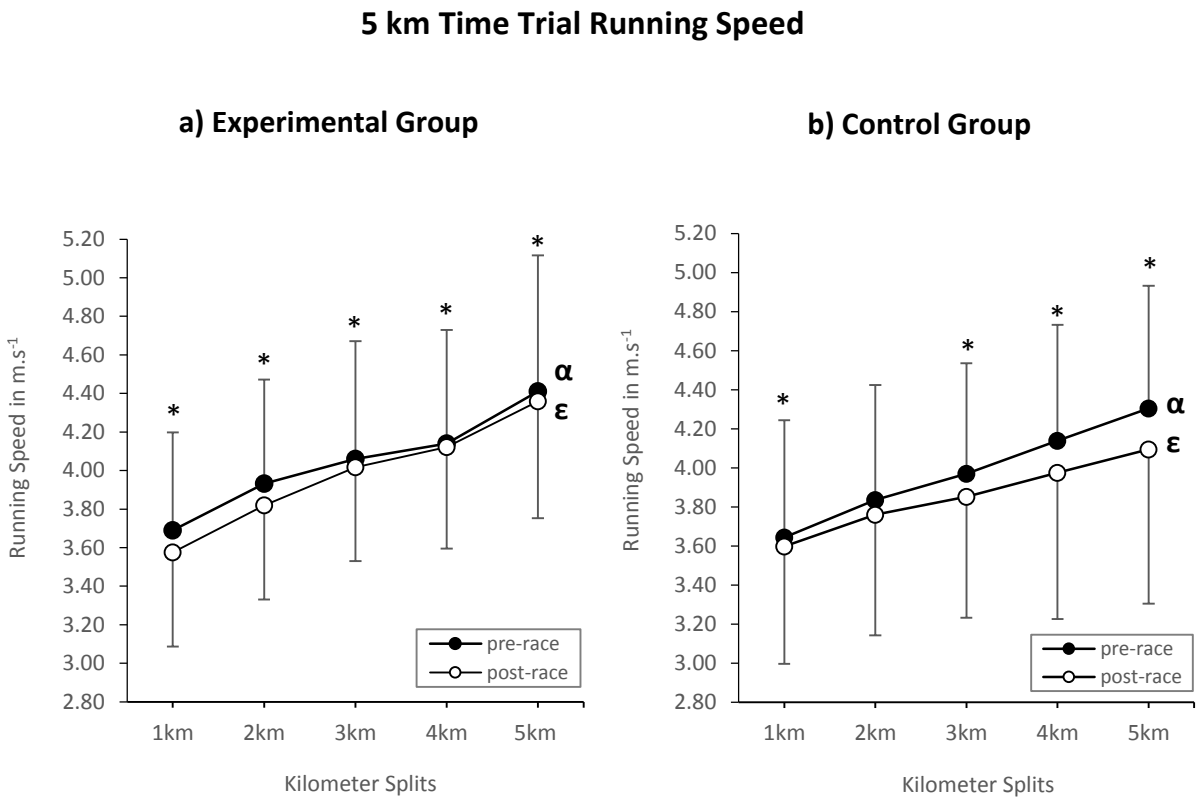

Figure 8: Running speed (m.s^{-1}) of participants in the (a) experimental (n = 9) and (b) control (n = 9) groups at kilometers 1 to 5 during the 5-km time trial, pre (- ● -) and post (- o -) the ultra-marathon race. Tests were conducted 14 days before, and 10 days after the race. Data are expressed as mean ± standard deviation.

Significant differences:

Main effects:	**α Main effect of time (p < 0.05)**
	ε Interactive effect of pre-post x time (p < 0.05)
Experimental group:	*** Post km 1 vs. pre km 2, 3, 4 and 5 (p < 0.05)**
	*** Post km 2 vs. pre km 5 (p < 0.05)**
	*** Post km 3 vs. pre km 5 (p < 0.05)**
	*** Post km 4 vs. pre km 1 (p < 0.05)**
	*** Post km 5 vs. pre km 1, and 2 (p < 0.05)**
Control group:	*** Post km 1 vs. pre km 3, 4 and 5 (p < 0.05)**
	*** Post km 2 vs. pre km 4 and 5 (p < 0.05)**
	*** Post km 3 vs. pre km 5 (p = 0.05)**
	*** Post km 5 vs. pre km 1 (p < 0.05)**

3.3.8.2 Heart Rate

The differences in heart rate ($b.min^{-1}$) during the 5-km time trial pre- and post- the ultra-marathon race for participants in the experimental and control groups are shown in Figure 9.

There was a significant interaction between groups over time pre-post the ultra-marathon race for heart rate during the 5-km time trial ($F_{(4, 64)} = 3.8$; $p < 0.05$). There were also significant interactions between groups and pre-post the ultra-marathon ($F_{(4, 64)} = 5.1$; $p < 0.05$) as well as pre-post the ultra-marathon and over time ($F_{(4, 64)} = 70.9$; $p < 0.05$). There was also a significant main effect for heart rate during the 5-km time trial over time ($F_{(4, 64)} = 20.4$; $p < 0.05$). These main and interactive effects reflect that heart rate increased significantly from km 1 to km 5 during the time trial in both groups for both pre- and post-race time trials; but that after the Comrades race, heart rate was significantly lower for the post-race test for the experimental group compared to the control group.

In the experimental group, heart rate was significantly increased at post-race km 3, 4, and 5 compared to pre-race km 1 ($p < 0.05$); post-race km 4 and 5 compared to pre-race km 2 ($p < 0.05$); post-race km 4 compared to pre-race km 1 and 2 ($p < 0.05$); and at post-race km 5 compared to pre-race km 2, 3, 4, and 5 ($p < 0.05$) (Figure 9).

In the control group, heart rate was significantly increased at post-race km 2, 3, 4, and 5 compared to pre-race km 1 ($p = 0.003$); post-race km 5 compared tom pre-race km 2 ($p < 0.05$); post-race km 5 compared to pre-race km 3 ($p < 0.05$); pre-race km 4 compared to post race km 1 ($p < 0.05$); and at pre-race km 5 compared to post-race km 1 and 2 ($p < 0.05$) (Figure 9).

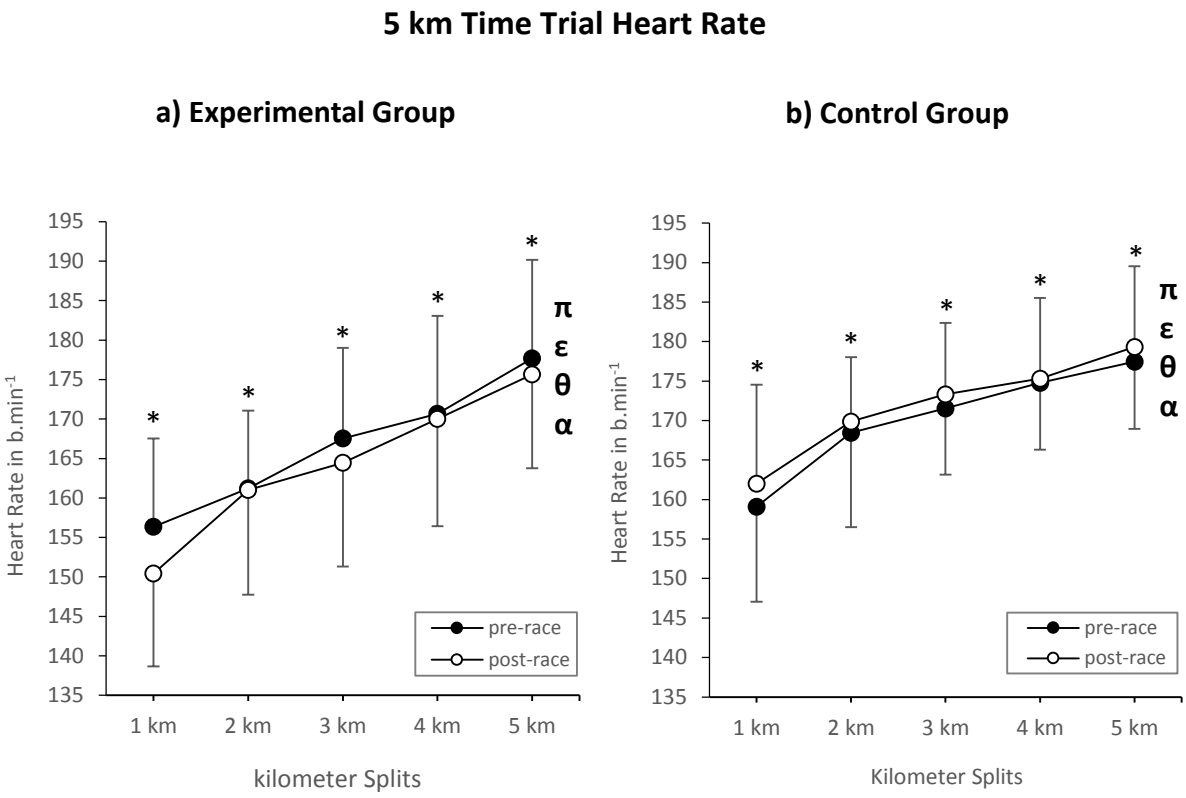

Figure 9: Heart rate (b.min^{-1}) of participants in the (a) experimental (n = 9) and (b) control (n = 9) groups at kilometers 1 to 5 during the 5-km time trial, pre (- ● -) and post (- o -) the ultra-marathon race. Tests were conducted 14 days before, and 10 days after the race. Data are expressed as mean ± standard deviation.

Significant differences:

Main effects:	**π Interactive effect of group x pre-post x time ($p < 0.05$)**
	ε Interactive effect of pre-post x time ($p < 0.05$)
	θ Interactive effect of pre-post x group ($p < 0.05$)
	α Main effect of time ($p < 0.05$)
Experimental group:	*** Pre km 1 vs. post km 3, 4 and 5 ($p < 0.05$)**
	*** Pre km 2 vs. post km 1, 4 and 5 ($p < 0.05$)**
	*** Pre km 3 vs. post km 1 and 5 ($p < 0.05$)**
	*** Pre km 4 vs. post km 1 and 2 ($p < 0.05$)**
	*** Pre km 5 vs. post km 1, 2, 3 and 4 ($p < 0.05$)**
Control group:	*** Pre km 1 vs. post km 2, 3, 4 and 5 ($p < 0.05$)**
	*** Pre km 2 vs. post km 5 ($p < 0.05$)**
	*** Pre km 3 vs. post km 1 and 5 ($p < 0.05$)**
	*** Pre km 4 vs. post km 1 ($p < 0.05$)**
	*** Pre km 5 vs post km 1 and 2 ($p < 0.05$)**

3.3.8.3 Rating of Perceived Exertion

The differences in the rating of perceived exertion during the 5-km time trial pre- and post- the ultra-marathon race for participants in the experimental and control groups are shown in Figure 10.

There were significant interactions between groups over time pre-post the ultra-marathon race ($F_{(4, 64)} = 3.8$; $p < 0.05$); and between pre- post- race and over time ($F_{(4, 64)} = 53.3$; $p < 0.05$). There were no significant main effects of group or pre-post the ultra-marathon race; however, there was a significant main effect over time ($F_{(4, 64)} = 22.1$; $p < 0.05$) (Figure 10). These main and interactive effects reflect that RPE increased significantly from km 1 to km 5 during the time trial in both groups for both pre- and post-race time trials; but that after the Comrades race, RPE was significantly lower for the post-race test for the experimental group compared to the control group.

In the experimental group, RPE was significantly increased at post-race km 4 and 5 compared to pre-race km 1 ($p < 0.05$); at post-race km 4 and 5 compared to pre-race km 2 ($p < 0.05$); and at post-race km 5 to pre-race km 3 ($p < 0.05$). The RPE was also significantly increased at pre-race 2, 3, 4, and 5 compared to post-race km 1 ($p < 0.05$). The RPE was significantly decreased at post-race km 1 and 2 compared to pre-race km 4 ($p < 0.05$); as well as at post-race km 1, 2, 3 and 4 compared to pre-race km 5 ($p < 0.05$) (Figure 10).

In the control group, RPE was significantly increased at post-race km 2, 3, 4 and 5 compared to pre-race km 1 ($p < 0.05$); at post-race km 3, 4 and 5 compared to pre-race km 2 ($p < 0.05$); and at post-race km 5 compared to pre-race km 3 ($p < 0.05$). The RPE was significantly decreased at post km 1 and 2 compared to pre-race km 5 ($p < 0.05$) (Figure 10).

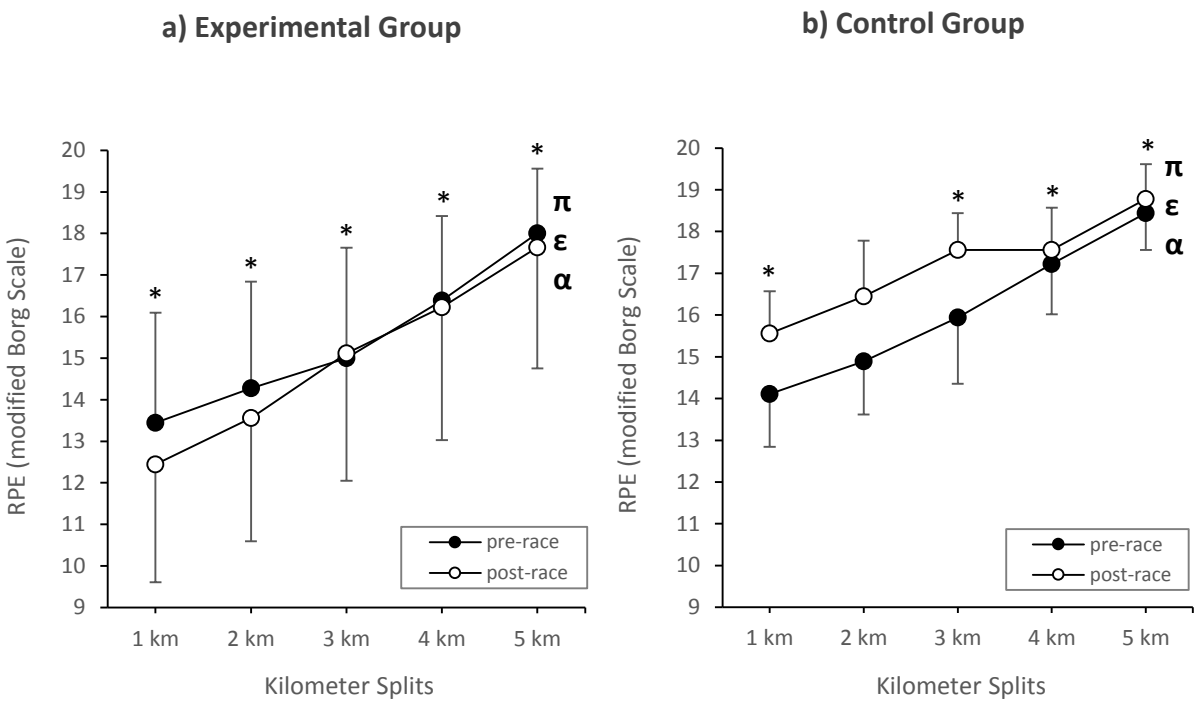

Figure 10: Rating of perceived exertion (modified Borg scale) of participants in the (a) experimental (n = 9) and (b) control (n = 9) groups at kilometers 1 to 5 during the 5-km time trial, pre (- ● -) and post (- o -) the ultra-marathon race. Tests were conducted 14 days before, and 10 days after the race. Data are expressed as mean ± standard deviation.

Significant differences:

Main effects:	**π Interactive effect of group x pre-post x time ($p < 0.05$)**
	α Main effect of time ($p < 0.05$)
	ε Interactive effect of pre-post x time ($p < 0.05$)
Experimental group:	*** Pre km 1 vs. post km 4 and 5 ($p < 0.05$)**
	*** Pre km 2 vs. post km 1, 4 and 5 ($p < 0.05$)**
	*** Pre km 3 vs. post km 1 and 5 ($p < 0.05$)**
	*** Pre km 4 vs. post km 1 and 2 ($p < 0.05$)**
	*** Pre km 5 vs. post km 1, 2, 3 and 4 ($p < 0.05$)**
Control group:	*** Pre km 1 vs. post km 2, 3, 4 and 5 ($p < 0.05$)**
	*** Pre km 2 vs. post km 3, 4 and 5 ($p < 0.05$)**
	*** Pre km 3 vs. post km 5 ($p < 0.05$)**
	*** Pre km 5 vs post km 1 and 2 ($p < 0.05$)**

3.4 DISCUSSION

3.4.1 Participants

The sample size of this study consisted of nine experimental and nine control participants, which provided a statistical power of 85%. Other studies investigating the effects of ultra-marathons on various recovery marker have had total sample sizes varying between 15 and 31 participants [2,10,11,22,45]. Intervention studies that specifically used an offloaded treadmill as a recovery intervention after inducing fatigue had sample sizes of 12 [108] and 25 [89] participants. The descriptive characteristics of the participants in this study showed the two groups were similar in age, height, body mass, lean body mass, BMI, and percentage body fat (Section 3.3.2, page 40). Both groups consisted of well-trained participants, had similar training and racing histories (Section 3.3.3, page 41). In comparison, previous studies of a similar nature evidenced some discrepancies in training status between groups [10,89].

3.4.2 Ultra-Marathon Performance

Both groups' overall Comrades Marathon performances and running speeds at various split distances were similar (Section 3.3.3, page 49). Intensity of the ultra-marathon run, expressed as a percentage of participants' baseline 5 km time trial speed, was also similar in both groups. As supported by other studies involving the Comrades ultra-marathon, intensity of the event was adequate to produce EIMD and fatigue [2,10,22]. The use of the Comrades 87 km run meant that the average time of the fatigue inducing exercise in this study, was of 8 hours 33 minutes (± 1 hour 27 minutes) for the experimental group and 9 hours 14 minutes (± 1 hour 15 minutes) for the control group. It has been previously been suggested that fatigue is task dependant such that an ultra-marathon has very specific effects on neuromuscular structures compared with fatiguing exercise of a shorter duration [34]. This makes it difficult to compare the results of this study to other studies that implemented offloaded recovery interventions (using an anti-gravity treadmill or DWR) as most of these studies used fatigue inducing exercise of consisting of downhill running of 45 minutes or less [18,89], repeated drop jumps [78] or a 29 km time trial using a cycle ergometer [108]. Therefore, this is the first study to use an offloaded treadmill as a recovery modality specifically after an ultra-marathon induced fatigue in participants. These previous studies that have investigated the use offloaded recovery running interventions on various markers of recovery and performance have been compared in Table 11.

Table 11: A comparison of recovery and performance outcomes of this study and previous intervention studies that used offloaded recovery strategies after muscle damage was induced.

Study	Study participants	Fatigue induction	Recovery interventions	Frequency	Outcome measures used to measure effect of the recovery intervention compared to the control group					
					Muscle soreness (VAS)	Performance (speed)	RPE	Heart rate	Muscle strength	CK or lactate levels
Current study	n = 18	Comrades 87 km ultra-marathon	**Anti-gravity treadmill and ADLS** Active Control: walking and ADLs	48, 72, 96 and 120 hours post ultra-marathon	↓ (pain significantly decreased on the days following the implementation of the anti-gravity treadmill. Cessation of pain during the intervention.)	↑ (some significant differences observed)	↓ (some significant differences observed)	↓ (some significant differences observed)	n/a	n/a
Nix et al (2013) [89]	n = 25	45 minutes downhill running at -10% gradient	**Anti-gravity treadmill** Normal treadmill runs Static stretching	30 minutes at 24, 48 and 72 hours post EIMD	↓ (pain significantly decreased on the days following the implementation of the anti-gravity treadmill.)	n/a	n/a	n/a	0 No significant differences observed	0 No significant differences observed
West et al (2014) [108]	n = 12	29km maximal effort cycling time trial	**Anti-gravity treadmill** Cycle ergometry Static stretching	Only once, straight after the fatiguing exercise.	n/a	0 No significant differences observed	n/a	n/a	0 No significant differences observed	Main effect of time for all 3 groups but not between groups.

Study	Study participants	Fatigue induction	Recovery interventions	Frequency	Outcome measures used to measure effect of the recovery intervention compared to the control group					
					Muscle soreness (VAS)	**Performance (speed)**	**RPE**	**Heart rate**	**Muscle strength**	**CK or lactate levels**
Reilly et al. (2002) [78]	n = 30	Repeated Drop jumps	**DWR** Normal treadmill runs	30-minute recovery run at 70–80% HR max, for 3 days	↓ (plus complete cessation of pain during recovery intervention)	n/a	n/a	n/a	↑	CK ↓ and Peaked earlier with DWR
Takahashi et al (2006) [18]	n = 10	Downhill treadmill running (3 X 5min at -10% gradient	**DWR** no recovery (pure rest)	Aqua jogging for 30 minutes for 3 days	↓ (significantly recovered faster in the DWR group)	n/a	n/a	n/a	↑ (significantly recovered faster in the DWR group)	CK ↓ in DWR group but not significantly.

3.4.3 Offloaded Recovery Running

The participants in the experimental group of this study ran at 70% of their body weight (30% offloaded). This degree, as well as the dosage, of offloading was selected based on a recent study by Nix et al (2015) [89] that also used an offloaded treadmill as a recovery strategy after EIMD; as well as a suggestion that deep water running offloads body weight by up to 35% [18] allowing for some form of comparison between the two offloaded recovery methods. Additionally, the degree of offloading chosen had to be sufficient enough to adequately reduce previously investigated ground reaction forces [14,41,42] and offload musculo-skeletal structures [110,111] during the run, especially after an event such as the Comrades ultra-marathon. Lastly, caution was taken not to offload the participants to a degree that would alter gait biomechanics too much, as suggested by Sainton et al. (2015) [115]. These detailed specifications make it difficult to generalize the results of this study; however, they do provide a baseline for future studies of this nature. As previously noted [43], further investigations regarding how to accurately offload running for recovery purposes are required.

Participants in this study performed three to four recovery runs in the week following the Comrades at 30% offloaded, and running for 30 minutes at a self-selected pace that was below 70% [97] [36,103] of their HR_{max}. During these recovery runs it was observed that participants' heart rates and RPE remained low (Section 3.3.5, page 50); and their subjective comments (Appendix XIII) such as "*this is a nice way to get back into running without the heaviness and resistance*" were noted.

The most interesting finding pertaining to the 30-minute offloaded recovery runs however was that of muscle pain during the runs. Muscle pain was almost non-existent on day two after the ultra-marathon and non-existent from day three after the ultra-marathon. This meant that the experimental participants could perform the recovery runs almost completely pain free. This was observed despite those same participants' daily ratings of pain still being high on day two, three and four after the Comrades. Reilly and colleagues (2002) [78] also reported findings where the sensation of muscle pain was mostly eliminated during 30 minutes of DWR, allowing the participants to perform the recovery intervention pain free; however, various levels of muscle pain seemed to return post recovery exercise. Therefore, it could be suggested that offloaded running on an anti-gravity treadmill, or in deep water (DWR) can be used as a recovery modality that provides temporary relief in DOMS whilst still allowing benefit from the recovery process [78].

3.4.4 Muscle Pain

Eccentric exercise, such as downhill running [18,23] as well as ultra-marathon running [2,22], has been found to induce delayed muscle soreness and pain. DOMS is characterised by the subjective perception of pain starting approximately eight hours after exercise, peaking at 24 to 48 hours and then reducing after seven to ten days [62,75]. The current study observed a significant improvement in "general pain", "pain during static stretching", "pressure pain" and "pain during ADLS" of the hamstrings, quadriceps and gastrocnemius muscles for both groups in the week post-Comrades (Section 3.3.6, pages 52 – 57). It seemed that muscle pain, in all three muscle groups occurred within and peaked at 24 hours after the fatigue inducing exercise (the ultra-marathon) for both groups, and then returned to zero between six to seven days. This finding is in keeping with other studies of a similar nature [10,11,18,23,89].

In the current study, the offloaded recovery runs were implemented on day two after the ultra-marathon. An important finding is that nine different pain scores in the experimental group were significantly lower than the control group on day three, four and five (after fatigue induced by the ultra-marathon) for various muscles (Section 3.3.6, pages 52 – 57). This could suggest that the offloaded treadmill runs had some significant effect on muscle pain on these days once it was implemented. On review of the results of the offloaded intervention study by Nix et al (2015) [89] a similar finding was noted in that muscle pain scores were significantly lower on day two to five after fatigue was induced, but these effects were not strong enough to create a significant effect between groups over the seven day measurement.

Although these findings are of importance, the current study cannot claim that the use of an offloaded recovery run is able to significantly reduce pain associated with muscle damage after an ultra-marathon race compared to a normally loaded active intervention. This is contradictory to the findings of Takahashi et al (2006) [18] and Reilly et al (2002) [78] who both reported offloaded running in the form of DWR effective in reducing muscle pain associated with EIMD from downhill running and repeated drop jumps, respectively. The muscle pain findings of the current study could be attributed to the subjective nature of muscle soreness [73], the nature and intensity of an ultra-marathon race [2,10,22], and the many unfamiliar factors regarding offloaded running on an anti-gravity treadmill [12,43,89,112].

3.4.5 Performance

3.4.5.1 Running Speed

The current study compared 5 km treadmill time trials performed ten days after the ultra-marathon race to the same 5 km time trial done 14 days before the race. Both groups slowed down in their post-race 5-km time trial, the control group by 68 seconds and the experimental group by 20 seconds. Although these treads in time trial performance were observed, they were not significant between groups and it cannot be equivocally stated that the offloaded recovery running is more effective than a standard active recovery strategy in aiding the recovery of running speeds, as measured in a 5-km time trial test (Section 3.3.8.1, page 58). This could be due to the relatively small sample size and limitations in statistical power. It has also been suggested that well-trained endurance runners have a good ability to recover [86]. It should therefore be noted that a few individuals in the experimental group ran a faster time trial post-race. This could suggest an individual learning effect or a better individual capacity of some participants to recover this performance measure within 10 days of the ultra-marathon. These individual responses, within a small sample size could have mitigated these results. Further research is therefore required to confirm or negate these preliminary observations.

In this study, the rate at which participants could accelerate throughout their 5-km time trial decreased significantly in both groups after the ultra-marathon suggesting that the ultra-marathon may have had a negative effect on 5 km time trial performance (Section 3.3.8.1, pages 58-59). This finding is in part supports Marcora and Bosio (2007), who found that running performance was impaired in the recovery period follow the Comrades ultra-marathon. Their study [9] found that EIMD produced a significant reduction of 4% in a 30-minute time trial, which was attributed to alterations in a perception of effort (RPE) during the time trial. On the contrary, this finding does not support Benney et al (2013) [10] and Burgess (2009) [11], who found that the same ultra-marathon had no significant effect on 5 km time trial performance of runners who ran the Comrades compared to a control group of runners participants who did not. It was suggested that a 5 km performance may be affected by racing and training experience [11] as well as that the test may not be sensitive enough to pick up changes in performance after EIMD [10]. It is once again important to note intra-individual differences recovery processes [36], despite similarities in training and racing experiences, as these variations may have altered the post- time trial group effects.

The only other study to date that has measured the effects of the offloaded recovery running on a performance measure after EIMD was West et al (2014) [108] who found no significant improvement in performance in the group that received the offloaded recovery intervention. However, this outcome is not comparable to the current study as the performance measure was not a 5-km time trial, but rather an anaerobic 30 second Wingate test on a cycle ergometer that measured speed and power [108]. Running performance during the recovery period however has not been widely researched warranting further research into measuring the effects of fatigue and muscle damage, especially after an ultra-marathon, on performance.

3.4.5.2 Heart Rate

The current study demonstrated a small change in heart rate in that it was significantly lower during the 5-km time trial test done after the ultra-marathon, for the experimental group that received the offloaded recovery intervention compared the control group (Section 3.3.8.2, pages 60 – 61). This finding suggests that the offloaded treadmill intervention may have had some effect on heart rate during a 5-km time trial performance. Previous research on heart rate responses of fatigued individuals during maximal testing has been contradictory [10,11,22,23,52]. Chamber et al. (1998) [22] demonstrated an elevated response in heart rate in ultra-marathon runners during high intensity steady state exercise, a finding that seemed to remain elevated for up to 25 days [22]. Two other studies [10,11] saw no increase in heart rate, during a 5 km time trial, of participants who ran an ultra-marathon compared to those who did not. All of these studies used a similar performance test and the same ultra-marathon [3] as the current study.

It has however been advised that there are certain technical challenges related to precision, variability and objectivity of heart rate monitoring, including high intra-individual differences observed with heart rate monitoring, compromising the reliability of heart rate as a recovery marker [35,36,103]. It addition to this is has been proposed that heart rate should be considered in the context of additional factors such as recent training load and racing/training experience of the athlete[52]. Therefore , the heart rate results observed in this study should perhaps be interpreted cautiously since inter-individual variations of heart rate [11,22,103] combined with the small sample size of the current study could increase the risk of a type II analysis error. Additional research into the effects of post-ultra-marathon recovery runs, both offloaded and normally loaded, on heart rate is required.

3.4.5.3 Rating of Perceived Exertion

It is well documented that the RPE during stretch-shortening cycle [11] exercise is higher following EIMD [9,23] or a fatiguing event such as an ultra-marathon [11] such that a post-race time trial effort would be perceived harder. Burgess (2009)[11] found an increase in RPE during a 5 km time trial in participants who ran the Comrades ultra-marathon compared to those who did not. This notion of increased effort during exercise after a fatiguing event is confirmed by a study by Mann et al. (2015) [52] who found increased RPE values during a 20 minute treadmill run done two to four days after the Comrades ultra-marathon; but it should be noted that this was a run at 70% $V0_{2max}$ and not a maximal time-trial effort. The current study however, demonstrated a small change in RPE that was significantly lower during the 5-km time trial test done after the ultra-marathon, for the group that received the offloaded recovery intervention compared the control group (Section 3.3.8.3, pages 62 – 63). This suggests that the experimental group could have perceived their post-race time trial effort as easier than their pre-race time trial effort, suggesting some effect of the offloaded intervention. There was also a small increase in perception of effort during the time trial done after the ultra-marathon for the control group, a finding in keeping with previous research [11,52]. However, since no significant main effect in RPE between groups was observed, it cannot categorically be said that the use of an offloaded treadmill as a recovery tool, was more beneficial than a normally loaded active recovery strategy in reducing perception of exertion during a time trial effort performed within the recovery period from an ultramarathon. Since RPE has been suggested as a valid method of monitoring exercise training [99], an increase in its use in quantifying recovery running interventions is suggested for future research.

3.4.6 Step Counts

Due to the intensity of the event, clinical recommendations specifically after the Comrades ultra-marathon [3] have previously been not to run in the week following the race, but to continue moving through walking [100]; however this has not been quantified. Consequently, the current study measured activity levels of all participants through step counts (Section 3.3.7, page 57). The current study found no effect of offloaded recovery running compared to a normally-loaded active intervention on the amount of walking participants performed in the week following the ultra-marathon. It was observed that the amount of walking for both groups gradually increased after the ultra-marathon as participants recovered from the effects of the ultra-marathon. This increase could be credited to a recovery period in both groups that allowed for physiological adaption to the stress of exercise, refuel energy stores and repair damaged tissues [30].

3.4.7 Limitations of this Study and Recommendations for Future Research

A possible bias of the current study was that the control group only received instructions to walk and perform ADLS, and participants may have felt their intervention was inferior to the offloaded treadmill recovery runs. Although participants in the control group were given the opportunity to try the anti-gravity treadmill once the study procedures were completed, this was only done once all data had been collected and therefore would not have had any effect on the results of this study.

This study could also not compare the use of offloaded treadmill running at a low intensity due to the nature of the Comrades event. It would be unethical to request participants to run at 100% of their body weight on a normal treadmill in the week following the ultra-marathon race due to the presence of significant pain associated with EIMD, and the high potential risk of musculoskeletal injury. Current best clinical recommendations specifically after the Comrades marathon [3] are not to run in the week following the Comrades marathon, but to continue moving through walking [100] and normal daily activities; with supplementation of various other recovery modality tools such a stretching, ice-baths and massage being suggested [45,82].

The runners in this study were all well-trained. This is of importance as it has been previously been highlighted that well trained individuals have a better capacity to recover [86]. Regular eccentric loading as experienced in downhill or ultra-marathon training may also improve an athlete's running economy as well as performance [58]. Therefore, the ability of all runners in this study to potentially recover well, regardless of the recovery intervention, could have mitigated the treatments in the study. Results of this study are therefore limited to the sample size of well trained and relatively experienced male runners and therefore cannot be generalised to a larger population of different demographics. It is noted that intra-individual differences, in recovery capacity as well as responses to offloaded running, within a small sample size may have had some effect on the results of this study. Perhaps a similar study could be replicated with a larger and perhaps more diverse group of runners. It is also hoped that a larger sample size would more sensitively pick up the observed trends between groups that were not significant in this study.

Exercise-induced muscle damage is induced through downhill running [18,23,89] and although the nature and intensity of an ultra-marathon such as the Comrades is enough to adequately produce muscle damage, it could be suggested that replicating this study on a "down" run year (from Pietermaritzburg to Durban) would provide a greater extent of EIMD to recover from.

This study was the first to investigate the effects of an offloaded recovery intervention after the Comrades marathon, making the design of the study relatively novel. It is suggested that future studies investigate the use of an anti-gravity treadmill compared to deep water running to ascertain whether there are differences between the two offloaded strategies. Different percentages of offloading on the anti-gravity treadmill specifically for recovery purposes should also be investigated. Additionally, a larger study of a similar nature, that is conducted after an ultra-marathon and using offloaded recovery strategies compared to normally loaded strategies could perhaps identify differences between these two recovery methods. It is therefore hoped that this study could provide a base further investigation into the use of offloaded forms of running, specifically the use of an anti-gravity treadmill, as an active recovery intervention after ultra-marathon events.

CHAPTER 4: SUMMARY AND CONCLUSION

Adequate recovery from the effects of ultra-marathon running [5,11,20,26,47] remain essential to enhance training and performance [5]. Active recovery methods are a popular and beneficial form of intervention [5,18,29,31,36,78,92]; and recently an offloaded running intervention, using an anti-gravity treadmill, to maintain cardiovascular fitness during recovery after an endurance event such as an ultra-marathon race, has been suggested [42,43]. Recovery from the Comrades ultra-marathon specifically has also been investigated in various settings; however, no study has investigated any offloaded forms of running as a recovery intervention from an ultra-marathon. The aim of this study was therefore to determine the effects of an offloaded running intervention compared to active recovery on running performance after an ultra-marathon race, in well trained runners.

The primary objective of this study was to determine differences in 5-km time trial performance between a group of experimental runners (who received an offloaded recovery intervention) compared to those in a control group of runners (who received a standard active recovery protocol) before and after the Comrades ultra-marathon. The current study investigated speed, heart rate and RPE during these time trial efforts. When compared to a normally loaded active recovery strategy, the offloaded recovery runs had no significant effects on running speed. A small sample size, variability in individual responses, as well as a good recovery capacity of endurance runners [86]; could account for this finding. There were however, some significant improvements in heart rate and RPE were identified, suggesting some benefits that favour the use of offloaded runs for ultra-marathon recovery purposes.

A secondary objective of this study was to compare differences in self-reported muscle pain between the two groups over a seven-day period after the ultra-marathon race. The offloaded recovery strategy resulted in significantly lower ratings of muscle pain on day three, four and five after the ultra-marathon, suggesting that early post-race 30% offloaded recovery runs of 30 minutes may alleviate muscle pain during the recovery period following an ultra-marathon race.

A final objective was to measure heart rate, rate of perceived exertion, muscle pain and running speed of the experimental group runners during 30-minute offloaded recovery runs. The findings of this study suggest that there may be benefits in using the anti-gravity treadmill as a sports-specific recovery method that provides temporary relief in muscle pain during recovery runs with

stable effort levels; thereby potentially maximising benefits of an active, but offloaded, recovery intervention.

To date, studies investigating offloaded recovery strategies on the effects of EIMD have provided limited and conflicting results [18,78,89,108]. These studies all used different and shorter strategies than an ultra-marathon to induce muscle damage, so comparative analyses are limited. A future comparison of deep water running (DWR) and anti-gravity treadmill running, is suggested to further improve implementation of offloaded forms of running for recovery purposes.

In conclusion, the findings of this study suggest that there may be some benefit in using an anti-gravity treadmill as a recovery tool that a) provided temporary relief in muscle pain during a recovery run while still allowing benefit from the recovery process and, b) alleviated muscle pain during the recovery period following an ultra-marathon race. Improvements in some performance indicators, namely heart rate and RPE during a 5-km time trial, were observed, supporting the potential effectiveness of this offloaded recovery method in limiting some of the deleterious effects of EIMD after an ultra-marathon race. However, the benefits of using the anti-gravity treadmill, according to this study, are very limited and intra-individual differences in recovery potential as well as responses to this recovery intervention should be considered. It is hoped that this study could provide bases for further investigation into offloaded running with the endurance running field, as well as how to more accurately manipulate different percentages of body weight support, on an anti-gravity treadmill, for recovery and training purposes.

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APPENDICES

APPENDIX I

Informed Consent form:

The effects of an offloaded running intervention versus active recovery on running performance after an ultra-marathon race

Dear Participant

I am a Masters student in the Division of Physiotherapy, University of Cape Town. I will be conducting a study to determine the differences between offloaded recovery runs is and normally loaded recovery runs, for improving recovery in the after an ultra-marathon race. There are conflicting ideas regarding what methods of recovery are the most ideal for optimizing recovery from the effects of exercise-induced muscle damage and a frequently asked question is "At what load, intensity and duration should I be doing my recovery runs after an ultra-marathon race? This study aims to help coaches and athletes answer this question and identify the best way to implement recovery runs.

You have been selected to participate in this study as you are preparing to participate in the Comrades Marathon on 4 June 2017, are male between the ages of 20 and 50 and have been categorized as a well-trained athlete. The information obtained in this study will be used for the completion of a mini-dissertation as required for the partial fulfilment of the Masters in Exercise and Sports Physiotherapy (MSc Exercise and Sports Physiotherapy) from the University of Cape Town. This study has been given ethical approval by the University of Cape Town, Faculty of Health Sciences Human Research Ethics Committee (HREC).

For testing procedures, you will be asked to attend a total of four appointments lasting for approximately one hour. These will be conducted at the Westville Indoor Track of South Africa as it has an indoor track. You will be required to travel there at your own cost as there is minimal funding for this study. This study will be supervised by Dr Theresa Burgess, Senior lecturer in Physiotherapy at the University of Cape Town. Please take time to read through this form thoroughly and carefully before signing. If you have any questions regarding this form please feel free to ask.

The study has the following sessions:

1) Familiarisation session:

This will be run two weeks prior to the ultra-marathon. During this session you will be requested to complete a questionnaire detailing your medical history, previous injuries, and training and competition details. Your weight, height and skin fold thicknesses will be measured to calculate your body fat percentage. One base line test will be conducted here. It will be a maximal treadmill test in which we will determine your maximum heart rate and peak treadmill running speed. All the tests will be explained to you on the day and time will be allocated for any questions you may have.

At this session, you will be randomly split into matched pairs based on a self-reported time trial performance and then will either be assigned to the experimental group that will do 30-minute recovery runs on an anti-gravity treadmill at Prime Institute in Durban or a control group will be asked to not run for one week after the ultra-marathon but will be allowed to walk and continue with normal activities of daily living. Regardless of which group you are place into, you will be given a pedometer to measure the amount of activity you are performing during the recovery period after the ultra-marathon race. The pedometer will be available for use during the study period; but we will kindly ask you to return the pedometer to us on completion of testing.

I do request that you refrain from using any medication, recovery treatments, partaking in any strenuous training or racing, other than competing in the Comrades Marathon, for the duration of the study. It will also be required of you to maintain the same diet and training regime for 24 hours prior to a testing day and during the week of the intervention. Compliance to these instructions will be facilitated by completing a logbook for the duration of the study; this will be given to you at this session.

2) Test session 1:

This session will be carried out 14 days before the Comrades Marathon. You will be required to complete a compliance questionnaire, giving information about any exercise you have been doing, and any other factors that may affect your running performance in the 5-km time trial. The time trial will be performed at Prime Human performance centre. Time will be allocated for you to perform a 10-minute warm up. During the run, you will wear a heart rate monitor. At every 1km split your time will be given to you as well as the distance covered. You will be requested to rate your level of perceived exertion at every kilometer. A cool down period will be performed at the end of the test.

3) Comrades Marathon:

Everyone in the enrolled in the study will be requested to run and complete the Comrades Marathon (87 km). You will be required to wear a heart rate monitor during this race and your official time will be found on the race website. From the day after the race you will be requested to report your levels of muscle pain in the logbook provided at the familiarisation session, the muscle pain needs to be recorded for the ten days following the race.

4) Recovery interventions:

If you are assigned to the experimental group, you will be requested to perform 30-minute recovery runs at a pace of your choice on an anti-gravity treadmill on day two, three, four and five after the Comrades Marathon. If you are assigned to the control group you will be asked to perform a passive recovery session in which you will be allowed to walk but not run. For both groups, participants will be asked to refrain from any other methods of recovery.

5) Test session 2:

This will be conducted ten days after the Comrades Marathon, and the same procedure will be followed as test session 1.

Potential risks:

During the skin fold thickness test, you may feel slight and short-lived discomfort due to the use of the callipers. The 5-km time trial is a maximal performance test which requires you to exert yourself, during this type of test you are at risk of injuring yourself, but time will be allocated for you to carry out a warm up so that this risk is minimised. The participation in the Comrades Marathon has its own inherent risks associated with the performance of an endurance event. To minimise risks associated with this you will complete screening questionnaires. If any risks are identified you will be referred to your medical practitioner for a medical assessment.

Benefits to participating in this study:

You will receive all your data (anthropometric measurements, time trial results, heart rate and perceived exertion measures) in an information pack once the study is complete. This may help you understand your recovery better and how your performance is affected in the recovery period. You will also be given results of your maximal test as well as the monitoring during your ultra-marathon results which could help you train more efficiently. The final results of the study will also be given to you. You will be required to travel at your own cost as there is no funding for the study. You will also not receive any payment for taking part in this study.

You are under no obligation to take part in this study. Your participation is completely voluntary and you have the right to refuse to take part or withdraw from the study at any time. All personal information which you provide us will be kept confidential in separate medical folders stored on the premises of the testing. The test scores and measurements are also confidential, no names will be disclosed.

Concerns:

If you have any concerns or questions at any time during the study please feel free to contact myself, Amy Burger or one of my supervisors.

Amy Burger

Cell: 0731195314

Email: burger.bee@gmail.com

Should you have any further queries please contact:

Dr Theresa Burgess

Physical address: Division of physiotherapy
School of Health and Rehabilitation
University of Cape Town
Groote Schuur Hospital
Anzio Road
Observatory 7725

Tel number: 021 406 6171

If you have any questions or concerns about your rights or welfare as a research participant, please contact:

Professor Marc Blockman

Chairperson: Faculty of Health Sciences Research and Ethics Committee
Tel: 021 406 6492
E-mail: marc.blockman@uct.ac.za

Please note that UCT does offer a no-faults insurance that will cover all participants in the event that something may go wrong. This insurance will provide prompt payment of compensation for any trial-related injury in accordance with the Association of the British Pharmaceutical Industry (ABPI) guidelines (1991). These guidelines recommend that UCT, without any legal commitment, should compensate you without you having to prove that UCT is at fault. An injury is considered trial-related if, and to the extent that, it is caused by study activities. You must notify the study investigators immediately of any injuries during the trial, whether they are research-related or other related complications. UCT reserves the right not to provide compensation if, and to the extent that, your injury came about because you chose not to follow the instructions that you were given while taking part in the study. Your right in law to claim compensation for injury where you prove negligence is not affected. It is important to note that taking part in the Comrades marathon is not considered a specific study-related activity. Any injury that arises from taking part in the Comrades marathon will not be considered as research-related and will not be covered by UCT no-faults insurance.

By placing your signature below, it serves as confirmation that you have had adequate time to read through, have understood the consent form and that you are willing to participate in this study. You have the right to withdraw at any time. You may ask questions at any time during the study. All the information recorded will be confidential. Your signature is further confirmation that you are aware of the possible risks involved in this study.

_____	_____	_____
Signature of Volunteer	Name (Please Print)	Date
_____	_____	_____
Signature of Witness	Name (Please Print)	Date
_____	_____	_____
Signature of Investigator	Name (Please Print)	Date

APPENDIX II

PAR-Q

Physical Activity Readiness Questionnaire [117]

Regular exercise is growing in popularity. Being more active is very safe for most people, and for most should not pose any problem or hazard. However, some people should check with their doctor before they start becoming much more physically active. The following list of questions should be completed by anyone who is between the ages of 15 and 69, looking to increase their current activity level, or partake in a fitness testing assessment. The questionnaire helps to determine how safe it is for you. Common sense is your best guide in answering these questions. Read the questions carefully and answer each one honestly.

Yes	No	
☐	☐	Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
☐	☐	Do you feel pain in your chest when you do physical activity?
☐	☐	In the past month, have you had chest pain when you were not doing physical activity?
☐	☐	Do you lose your balance because of dizziness or do you ever lose consciousness?
☐	☐	Do you have a bone or joint problem that could be made worse by a change in your physical activity?
☐	☐	Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
☐	☐	Do you know of any other reason why you should not do physical activity?

If you answered YES

If you answered "yes" to one or more questions, talk with your doctor before you start becoming much more active or before you have a fitness test. Tell your doctor about the PAR-Q and which questions you answered "yes" to.

If you answered NO

If you answered "no" honestly to all the questions, you can be reasonably sure that you can start becoming much more physically active or take part in a physical fitness appraisal – begin slowly and build up gradually. This is the safest and easiest way to go.

Things Change

Even if you answered "no" to all questions, you should delay becoming more active if you are temporarily ill with a cold or a fever, or if you are or may be pregnant. If your health changes so that you then answer "yes" to any of the above questions, tell your fitness or health professional and ask whether you should change your physical activity plan.

APPENDIX III

2017 COMRADES MARATHON

Medical and Training Questionnaire [118]

Thank you for taking the time to complete this questionnaire, which will take 30-45 minutes of your valuable time to complete. The completion of the questionnaire is voluntary and all the information will be kept confidential. The information collected will only be used for research purposes.

Instructions

Please complete Sections A, B, C, D, E, F

Section A	Personal Details
Section B	Racing and Training History
Section C	Tapering History
Section D	Flexibility Training History
Section F	General Personal Medical History

Please complete only the relevant questions in the following section

Section G	Additional Detailed Medical History

Section A: Personal details			
2016 Comrades Race Number			
Surname			
First Name			
Postal Address		Postal/ Zip Code	
E-mail address		Phone (day time)	code number
Date of birth	y y y y - m m - d d	Cell	
Height	cm	Gender	Male ☐ Female ☐
Weight	kg	Age	
Occupation			
What **percentage** of your **working** day is spent in the following activities?	Sitting: _____ % Standing: _____ % Walking (Lower body activity) _____ % Manual Labour (upper and body activity) _____ %		

Section B: Racing and training history					
What is your predicted time for the 2017 Comrades Marathon?	_____hrs:min				
Type of running event	**5 km**	**10 km**	**21.1 km**	**42.2 km**	**Ultra**
Which races have you participated in?	Yes ☐ No☐	Yes ☐ No☐	Yes ☐ No☐	Yes ☐ No☐	Yes ☐ No☐
Year of first event					
How many events have you participated in?					
Personal best time	_____hrs:min	_____hrs:min	_____hrs:min	_____hrs:min	_____hrs:min
What is your best time, in a running race, in the **last 4 months**?	_____hrs:min	_____hrs:min	_____hrs:min	_____hrs:min	_____hrs:min
Type of event	**Two Oceans Marathon**	**Comrades Marathon**			
Which races have you participated in?	Yes ☐ No☐	Yes ☐ No☐			
Year of first event					
How many events have you participated in?					
Personal best time	_____hrs:min	_____hrs:min			
Pacing					
Do you use a pacing strategy when you run marathons?	Yes	No			
If yes please describe your pacing strategy.					

Section C: Tapering history							
Time until race day	16 – 13 weeks	12 - 9 weeks	8 – 5 weeks	4th week	3rd week	2nd week	Last week before the race
How many days a week did you train **during your taper period**?	days/week	days/week	days/week	days/week	days/week	days/week	days/week
How many **hours** did you train **during your taper period**?	_____ hours	_____ hours	_____ hours	_____ hours	_____ hours	_____ hours	_____ hours
What was the **duration** of your training **sessions**?	_____ min _____ max _____ average	_____ min _____ max _____ average	_____ min _____ max _____ average	_____ min _____ max _____ average	_____ min _____ max _____ average	_____ min _____ max _____ average	_____ min _____ max _____ average
What was the **distance** and **pace** of your **LSD runs**?	_____km _____min per km	_____km _____min per km	_____km _____min per km	_____km _____min per km	_____km _____min per km	_____km _____min per km	_____km _____min per km
What was your **slowest, average** and **fastest training pace**?	Slowest _____min per km Average _____min per km Fastest _____min per km	Slowest _____min per km Average _____min per km Fastest _____min per km	Slowest _____min per km Average _____min per km Fastest _____min per km	Slowest _____min per km Average _____min per km Fastest _____min per km	Slowest _____min per km Average _____min per km Fastest _____min per km	Slowest _____min per km Average _____min per km Fastest _____min per km	Slowest _____min per km Average _____min per km Fastest _____min per km
What was your **average training pace** in the last **three months**?	_____min per km						
What was your **average race pace** in the last **three months**?	_____min per km						

Section D: Flexibility training history	
Do you perform flexibility training (stretching exercises)?	Yes ☐ No ☐
If YES, please complete the rest of the flexibility training history section below:- If NO, continue completing the questionnaire from the top of page 5 (Fluid intake).	
On average, how many days a week do you perform a stretching session?	days/week
On average, how many times a day do you perform a stretching session?	times/day
Please tick which muscle groups do you include in your stretching session?	☐ Hamstrings ☐ Quadriceps ☐ Calf (gastrocnemius) ☐ Calf (soleus) ☐ Groin (inner thigh) ☐ Upper body limbs ☐ Other: _____
Please tick when you stretch? (Before, during and/or after exercising. You can tick more than one box)	☐ Before Exercise ☐ During Exercise ☐ After Exercise
When you stretch an individual muscle group, on average, **how long do you hold the stretch** for?	seconds
When you stretch an individual muscle group, on average, **how many times do you stretch the muscle for**?	☐ Once ☐ Twice ☐ 3 times ☐ 4 times ☐ 5 times ☐ 6 or more times

Section E: Fluid intake	
How do you best describe your fluid intake during a race?	(a) I drink to thirst ☐ (b) I drink as much as tolerable ☐ (c) I drink according to a predetermined fluid intake schedule ☐ (d)I drink to prevent any weight loss during exercise ☐ (e) I combine (a) with (c) ☐ (f)I combine (b) with (c) ☐ (g) Other: _____ ☐
What percentage of your fluid intake will consist of these beverages?	Water: ☐0-25% ☐26-50% ☐51-75% ☐76-100% Sports drink: ☐0-25% ☐26-50% ☐51-75% ☐76-100% Coke: ☐0-25% ☐26-51% ☐51-75% ☐76-100% Other: ☐0-25% ☐26-50% ☐51-75% ☐76-100% Specify other: _____
What will be your estimated **total** fluid intake be during the **run**?	ml
Rank the following sources of information on their importance in formulating your drinking strategy. (1 being most influential and the lowest number being least influential)	_____Fellow triathletes _____Coach / trainer _____Magazines / books _____Website (please specify: _____) _____Drinking guidelines from sports associations _____Adverts _____Self-experimentation _____Other: _____

Section F: Personal general medical history	
In this section, you are asked to read through 14 questions about your personal general medical history. If you answer "yes" to any of questions 1 to 12, please complete the additional questions at the end of the section (Section F).	
1. In the **6 weeks before this race** (from 1st February) did you suffer from any **symptoms of flu** (fever, sore throat, blocked or runny nose, cough, wheeze, muscle aches and pains)? **If you answer "yes", please complete the additional questions in Section G.**	Yes ☐ No ☐
2. Have you **ever** in your marathon career suffered from **muscle cramping** during or immediately (within 6 hours) after exercise (in training or competition)?	Yes ☐ No ☐
3. Have you **ever** in your marathon career suffered from **a tendon or ligament injury** (pain, swelling, stiffness) in any tendon (including Achilles tendon, knee tendons, and shoulder tendons) or ligaments (partial or complete tear)?	Yes ☐ No ☐
4. Have you **ever** in your marathon career **used medicines to treat injuries** in the week **before or during a race** – including anti-inflammatory drugs, cortisone (pills, or injection), or pain killers? **If you answer "yes", please complete the additional questions in Section G.**	Yes ☐ No ☐
5. Do you **currently** suffer from any **symptoms of injury** in the muscles, tendons, bones, ligaments or joints? **If you answer "yes", please complete the additional questions in Section G.**	Yes ☐ No ☐
6. Please tick in which anatomical area you ever had **surgery** performed.	☐ Head ☐ Finger ☐ Neck ☐ Lower back ☐ Face ☐ Hip ☐ Front chest ☐ Thigh ☐ Back chest ☐ Knee ☐ Shoulder ☐ Lower leg ☐ Upper arm ☐ Achilles ☐ Elbow ☐ Ankle ☐ Forearm ☐ Foot ☐ Wrist ☐ Abdomen ☐ Other (Specify: _____)

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

If you have answered **YES** to questions 1, 4, or 6 of the Personal General Medical History questionnaire (Section F) please complete the relevant additional questions that follow in Section G.

Section G: Additional detailed medical history

(Please complete all the sections to which you answered "Yes" in the Personal general medical history)

1. Flu symptoms in the last 6 weeks

If you answered **YES** to **question 1** in section E, please complete the following two questions related to flu symptoms in the last 6 weeks.

(1a) Please tick which of these flu symptoms you suffered from **in the last 6 weeks**.	☐ Fever ☐ Cough ☐ Joint pains ☐ Blocked nose ☐ Wheezing ☐ Runny nose ☐ Muscle aches ☐ Any other flu symptoms (Specify: _____)
(1b) Please tick which of these flu symptoms you suffered from **in the last 7 days**.	☐ Fever ☐ Cough ☐ Joint pains ☐ Blocked nose ☐ Wheezing ☐ Runny nose ☐ Muscle aches ☐ Any other flu symptoms (Specify: _____)

2. Use of medicines to treat an injury before or during participation If you answered **YES** to **question 4** in section E, please complete the following two questions related to medicine use for injuries before or during races.	
(2a) Which of the following medicines have you used in the past to treat an injury **in the week just before** a race?	☐ Paracetamol (e.g. Panado, Tylenol) ☐ Non-steroidal anti-inflammatories (e.g. Voltaren, Cataflam) ☐ Cortisone (pills) ☐ Cortisone injection ☐ Codeine ☐ Anti-inflammatory gels/creams/patches ☐ Any other pain killers (Specify: _____)
(2b) Which of the following medicines have you used in the past to treat an injury **during a race**?	☐ Paracetamol (e.g. Panado, Tylenol) ☐ Non-steroidal anti-inflammatories (e.g. Voltaren, Cataflam) ☐ Cortisone (pills) ☐ Cortisone injection ☐ Codeine ☐ Anti-inflammatory gels/creams/patches ☐ Any other pain killers (Specify: _____)

3. History of any current injury that you suffer from

If you answered **YES** to **question 11** in section E, please complete the following questions (11a. to 11g.) related to each of your current injury/ies (Space is provided for two injuries)

Injury 1	
(3a) What was the approximate date when you first became aware of the injury?	Month Year
(3b) Please indicate which side of your body is injured (if applicable)	☐ Right ☐ Left
(3c) Please indicate which anatomical area is currently injured	☐ Head ☐ Elbow ☐ Hamstring ☐ Neck ☐ Forearm ☐ Quadriceps ☐ Face ☐ Wrist ☐ Knee ☐ Front chest ☐ Finger ☐ Shin ☐ Back chest ☐ Lower back ☐ Achilles ☐ Shoulder ☐ Hip ☐ Ankle ☐ Upper arm ☐ Thigh ☐ Foot Other (Specify: _____)
(3d) Please indicate the type of structure that was injured	☐ Muscle ☐ Ligament ☐ Tendon ☐ Joint ☐ Bone Other (Specify: _____)
(3f) Please indicate the severity of the injury (tick one box please)	☐ I only experience symptoms after exercise - Grade 1 ☐ I experience symptoms during exercise, but it does not interfere with exercise - Grade 2 ☐ I experience symptoms during exercise that may interfere with my training/ competition - Grade 3 ☐ I am so painful that I may not be able to train or compete - Grade 4
(3g) Please indicate how your injury was treated to date (you can tick more than one)?	☐ Rest ☐ Tablets ☐ Stretches ☐ Cortisone injection ☐ Physiotherapy ☐ Other injection ☐ Surgery ☐ Orthotics ☐ Strengthening exercises ☐ Equipment change Other (Specify: _____)

Injury 2		
(3a) What was the approximate date when you first became aware of the injury?		Month Year
(3b) Please indicate which side of your body is injured (if applicable)		☐ Right ☐ Left
(3c) Please indicate which anatomical area is currently injured		☐ Head ☐ Elbow ☐ Hamstring ☐ Neck ☐ Forearm ☐ Quadriceps ☐ Face ☐ Wrist ☐ Knee ☐ Front chest ☐ Finger ☐ Shin ☐ Back chest ☐ Lower back ☐ Achilles ☐ Shoulder ☐ Hip ☐ Ankle ☐ Upper arm ☐ Thigh ☐ Foot Other (Specify: _____)
(3d) Please indicate the type of structure that was injured		☐ Muscle ☐ Ligament ☐ Tendon ☐ Joint ☐ Bone Other (Specify: _____)
(3f) Please indicate the severity of the injury (tick one box please)	☐ I only experience symptoms after exercise - Grade 1 ☐ I experience symptoms during exercise, but it does not interfere with exercise - Grade 2 ☐ I experience symptoms during exercise that may interfere with my training/ competition - Grade 3 ☐ I am so painful that I may not be able to train or compete - Grade 4	
(3g) Please indicate how your injury was treated to date (you can tick more than one)?		☐ Rest ☐ Tablets ☐ Stretches ☐ Cortisone injection ☐ Physiotherapy ☐ Other injection ☐ Surgery ☐ Orthotics ☐ Strengthening exercises ☐ Equipment change Other (Specify: _____)

APPENDIX IV

Anthropometry

Participants Name:_____

Body mass _____

Stature _____

BMI _____

Skinfold measurements (mm)	
Triceps	
Biceps	
Sub-scapular	
Supra-iliac	
Thigh	
Calf	
Abdominal	

Sum of 7 skinfolds _____

Predicted % body fat _____

Lean body mass _____

APPENDIX V

Logbook of Muscle pain measurement scores, Daily training and Dietary information

Multi-Dimensional Pain Scale

Quadriceps

No pain Maximal pain

Pain at rest

No pain Maximal pain

Pain during normal daily activities

No pain Maximal pain

Pain during passive stretch

No pain Maximal pain

Pressure pain

Hamstrings

No pain Maximal pain

Pain at rest

No pain Maximal pain

Pain during normal daily activities

No pain Maximal pain

Pain during passive stretch

No pain Maximal pain

Pressure pain

Gastrocnemius (Calf)

No pain Maximal pain

Pain at rest

No pain Maximal pain

Pain during normal daily activities

No pain Maximal pain

Pain during passive stretch

No pain Maximal pain

Pressure pain

(Seven days of these sheets will be provided in the logbook)

Daily Log of dietary details and training information:

Please fill out this table for the duration on the study:

Date	Breakfast	Lunch	Supper	Type of exercise if any	Medication taken	Use of any recovery methods/treatment (list)
Day 1 before comrades						
Day 0 Comrades						
Day 1						
Day 2						
Day 3						
Day 4						
Day 5						
Day 6						
Day 7						

APPENDIX VI

Compliance Questionnaire:

Name: _____

Please answer the questions as truthfully as possible.

	Yes	No
1) Have you participated in any type of exercise since the completion of the Comrades Marathon? If yes what have you done_____		
2) Have you used and medication to alleviate muscle pain?		
3) Have you massaged or rubbed your stiff and sore muscles?		
4) Have you put ice or heat-packs on your muscles?		
5) Have you stretched your stiff muscles?		
6) Have you made use of compression garments?		
7) Have you done anything else to alleviate stiff and sore muscles? If yes what have you done? _____		

Thank you for taking the time to complete this questionnaire.

APPENDIX VII

Modified Borg Scale: Rate of Perceived Exertion

Rating scores for relative perception of effort (RPE) (BORG, 1982)

Score	Description
6	
7	Very Very Light
8	
9	Very Light
10	
11	Fairly Light
12	
13	Somewhat Hard
14	
15	Hard
16	
17	Very Hard
18	
19	Very Very Hard
20	Maximal Exertion

APPENDIX VIII

Test session Data Sheet: Name-

_____

5 km Time Trail Results: (Kilometer splits)

	1km	2km	3km	4km	5km
Pre-test 1					
Post-test2					

Rate of Perceived exertion at 1km splits

	1km	2km	3km	4km	5km
Pre-test 1					
Post-test 2					

Heart rates during the time trials at 1km splits:

	1km	2km	3km	4km	5km
Pre-test 1					
Post-test 2					

Total Time Trial Times:

	Pre-test 1	Post Test 1	Season PB	All-time PB
Total Time				

APPENDIX IX

Intervention session Data Sheet: Name-

_____

Rate of Perceived exertion

	1km	2km	3km	4km	5km
Day 1					
Day 2					
Day 3					
Day 4					

Total distance covered in a 30-minute recovery run

	Day 1	Day 2	Day 3	Day 4
Total distance				

Total AHR within recovery zone in a 30-minute recovery run

	1km	2km	3km	4km	5km
Calculated Zone					
Day 1					
Day 2					
Day 3					
Day 4					

APPENDIX X

UCT/MRC Research Unit for Exercise Science and Sports Medicine
Department of Human Biology
Division of Physiotherapy, Department of Health & Rehabilitation Sciences
Faculty of Health Sciences
University of Cape Town, South Africa

MALE COMRADES MARATHON RUNNERS WANTED FOR UCT RESEARCH

For a study investigating the effects of loading during active recovery from an ultra-marathon

Study outline

I am a Masters student at UCT, investigating how altered loading during running in the week after an ultra-marathon effects recovery. The study aims to provide information regarding optimal recovery time before returning to competitive training and competition.
The study requires participants to complete a pre-race and two post-race 5 km treadmill time trials at Prime Human Performance Centre Durban. Muscle pain, heart rate and perception of effort will be measured during the time trials.
The study requires compliance to an active recovery protocol of one week after the Comrades marathon in 2017 which will be based at Prime Human Performance Centre of South Africa. It will be requested of you to keep a detailed training and general pain and stiffness diary over the testing period.

Requirements for those interested in enrolling in the study

- You need to be male, between the ages of 20 and 50 years
- Entered for the Comrades Marathon
- Have a current marathon (42.2 km) time of less than four hours
- Be healthy and injury free
- Be willing to drive to Prime, Durban, for testing procedures as well as if you are allocated to recover on the anti-gravity treadmill.

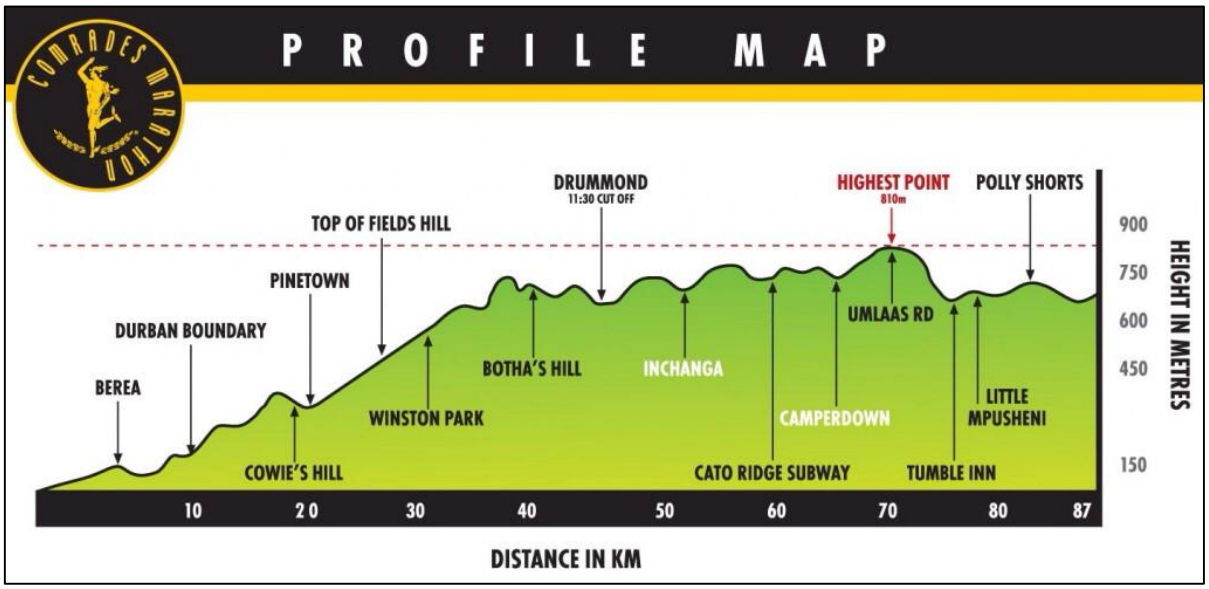
Benefits of participating in the study include

- Individual anthropometric measurements (Height, weight, BMI, body fat %)
- Maximal testing values that could help you establish heart rate zones for training
- Heart rate monitoring and race analysis of the ultra-marathon
- The chance to use an anti-gravity treadmill free of charge but as this is a comparison study only half of the participants will receive this opportunity
- 5 km time trial results which will help you to see when you have recovered after the race
- Feedback regarding the results of the study

DEADLINE FOR APPLICATIONS: 17 May 2017
If you are interested in taking part in the study and would like additional information, please contact:
Amy Burger: 0731195314 or **burger.bee@gmail.com**

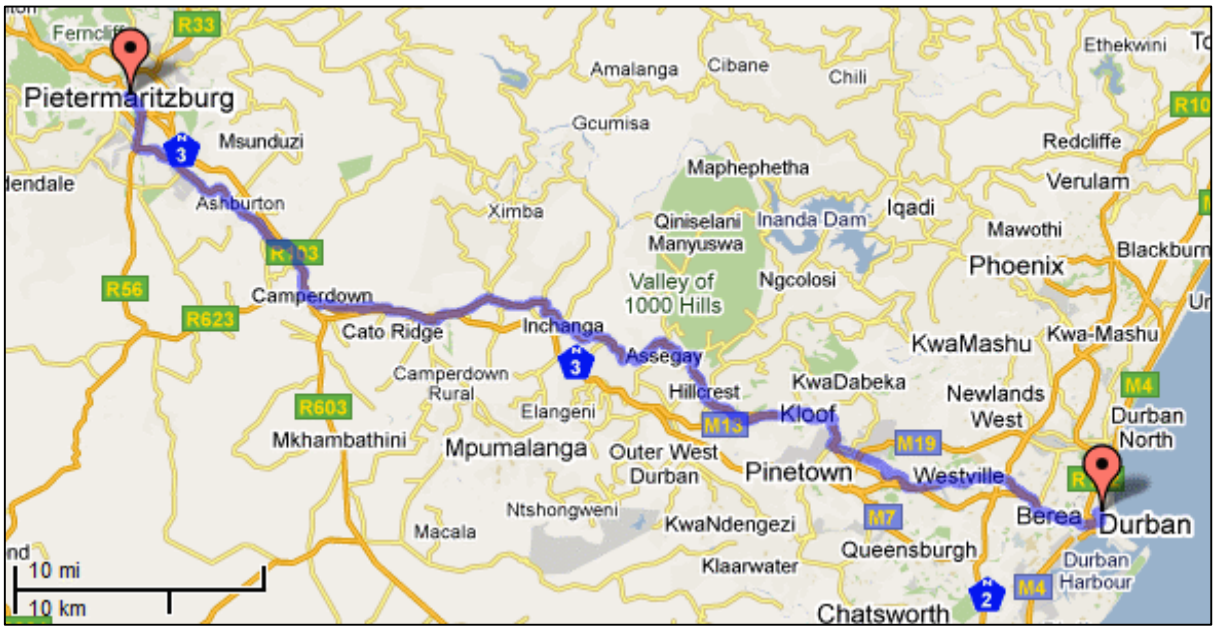
APPENDIX XI

A: Race profile of the Comrades Marathon:



Source: Comrades Marathon Website [3]

B: Race route of the Comrades A: Race profile of the Comrades Marathon:



Source: Comrades Marathon Website [3]

APPENDIX XII

Ethical approval of the study

UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Human Research Ethics Committee

Room E53-46 Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 406 6626
Email: shuretta.thomas@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

05 May 2017

HREC REF: 602/2016

Dr Theresa Burgess
Health & Rehab
F-Floor, OMB

Dear Dr Burgess

PROJECT TITLE: THE EFFECTS OF AN OFFLOADED RUNNING INTERVENTION VERSUS ACTIVE RECOVERY ON RUNNING PERFORMANCE AFTER AN ULTRAMARATHON RACE (MPhil-candidate- Ms A Burger)

Thank you for submitting your response to the Faculty of Health Sciences Human Research Ethics Committee dated 5 May 2017.

It is a pleasure to inform you that the HREC has **formally approved** the above-mentioned study.

Approval is granted for one year until the 30 May 2018.

Please submit a progress form, using the standardised Annual Report Form if the study continues beyond the approval period. Please submit a Standard Closure form if the study is completed within the approval period.
(Forms can be found on our website: www.health.uct.ac.za/fhs/research/humanethics/forms)

Please quote the HREC REF in all your correspondence.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please note that for all studies approved by the HREC, the principal investigator **must** obtain appropriate institutional approval before the research may occur.

The HREC acknowledge that the student Amy Burger will also be involved in this study.

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, FHS HUMAN RESEARCH ETHICS COMMITTEE
Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938
This serves to confirm that the University of Cape Town Human Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical

APPENDIX XIII

Subjective comments recoded during 30-minute recovery runs on the anti-gravity treadmill are recorded in Table 12 below. It be noted that all participants ran on an anti-gravity treadmill for the first time during this study,

Table 12: Comments of experimental group participants during their recovery runs on the anti-gravity treadmill.

Participant 1: after his first recovery run - "This feels great" - however, that afternoon he reported an increase in muscle tension that subsided by the evening, next day much felt much better.
Participant 2: "This feels nice and light, it hardly feels like I'm running." "It feels great having low impact, it feels like I'm on the moon, and over the moon too" ;)
Participant 4: reported "I can feel my ITB a little but the rest of my muscle feel great" His ITB tightness and discomfort settled during his second run. (ITB pain increased a little stepping off but the rest of his muscles felt better)
Participant 5: reported feeling good during his first recovery run but then an hour later felt very heavy which settled by next day. During his third run he reported "After yesterday's run I was feeling fresh, I could go for a run, I'm feeling so much better today, its madness."
Participant 6: "I'm feeling good - even the watch is saying it is easy"
Participant 7: "This is a nice way to get back into running without the heaviness and resistance, I would usually be scared to run again after Comrades because I don't know how bad it's going to be or what it's going to feel like."
Participant 8: "It feels really nice being able to run in the week after Comrades, perhaps the best I have felt after all 9 comrades. I'm aiming for a sub 3-hour marathon in Cape Town in 3 months' time, perhaps this will help me get there"
Participant 9 reported slight gluteus med tendon pain but still wanted to continue with his recovery runs. On day 2 post ultra-marathon he felt a slight pull in the left hip which settled as he ran. On day three he ran pain free. "it feels so easy to run and my hip is painless, I feel incredible"