Performance trends of seasoned Two Oceans Ultramarathon runners

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DECLARATION

I, Helena Noll (NLLHEL001), hereby declare that the work on which this dissertation is based is my original work (unless acknowledged as otherwise) and that neither the whole work, nor any part of it has been, is being or is to be submitted for another degree in this or any other university.

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ACKNOWLEDGEMENTS

This study would not have been possible were it not for a number of people who provided unmeasurable support and assistance. I would like to take this opportunity to thank those who have been of invaluable assistance, and without whom the completion of this study would not have been possible:

1) Dr Theresa Burgess, my supervisor, who conceptualized this study, provided endless support, patience and encouragement, and through her own expertise refined the study.
2) Kim Buchholtz, my co-supervisor, for her professional assistance.
3) Amy Mathew, my friend and colleague, for encouraging me to join this program, and continuously offering her guidance and support.
4) Martin and Susanne Noll, my parents, who not only motivated me from the very beginning, but who have continued to do so throughout this program. My mother also was an immense help with editing, and for that I am extremely grateful.
5) Fiona Bennin, for assisting me with editing.
6) Pip Mortlock, the most understanding and supportive husband I could have asked for.

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LIST OF ABBREVIATIONS

AF	Atrial Fibrilation
AGE	Advanced Glycation Endproducts
ATP	Adenosine Triphosphate
BMD	Bone Mineral Density
BNC	Blue Number Club
DE	Disordered Eating
DOMS	Delayed Onset Muscle Soreness
EIMD	Exercise-induced Muscle Damage
FAT	Female Athlete Triad
FFA	Free Fatty Acids
FHA	Functional Hypothalamic Amenorrhoea
MOMS	Motivation of Marathoners Scale
MRI	Magnetic Resonance Imaging
OA	Osteoarthritis
OTS	Overtraining Syndrome
PB	Personal Best

RED-S	Relative Energy Deficiency in Sport
RPE	Rate of Perceived Exertion
RRI	Running Related Injury
SD	Standard Deviation
URTI	Upper Respiratory Tract Infection
$VO2_{max}$	Maximum Volume of Oxygen Consumption

GLOSSARY OF TERMS

Blue Number Club	Runners who have completed 10 Two Oceans Ultramarathons qualify for a permanent number and are thereby invited to join the Blue Number Club (BNC) [1]
Neuromuscular Fatigue	Reduced force-generating capacity of the neuromuscular system induced by exercise, and accompanied by reduced force output by a particular muscle and/or the inability to recruit all motor units to complete a specific task [2]
Master Runner	Runners typically older than 35 years of age [3, 4]
Overtraining Syndrome	A state marked by performance deterioration, mood and hormonal disturbances and the inability to recover from these symptoms with rest [5]
Pacing	The distribution of work or energy expenditure during an exercise task by optimal management of resources. Can be divided into the following three categories: Positive pacing (decreasing speed throughout the duration of an event), negative pacing (increasing speed throughout the duration of an event) or even pacing (maintaining the same speed for the event) [6, 7]
Relative Energy Deficiency in Sport	Updated terminology on what was commonly known as the female athlete triad (FAT). A clinical syndrome including energy deficiency, bone health, disrupted functioning of the metabolic, endocrine, gastro-intestinal and cardiovascular systems [8]
Running Related Injury	Musculoskeletal pain in the lower limbs that causes a reduction or termination of training for either seven

	days or three consecutive training sessions, or pain that causes the individual to seek medical attention [9]
Teleoanticipatory System	The brain's ability to anticipate the physical requirements needed to reach a goal without compromising physiological homeostasis [10]
Ultramarathon	A running event exceeding the traditional marathon distance of 42.2 km [3]

ABSTRACT

Background

Endurance running is known to be a prevalent sport, due to well-understood health benefits. Ultramarathon running, particularly in master athletes, has been increasingly popular. Various parameters of an individual's ability to participate in numerous such events have been explored. The performance trends of such seasoned runners have been of interest to identify trends that could influence participation and running career longevity.

Aim

To identify performance trends of seasoned ultramarathon runners across their Two Oceans Ultramarathon running careers.

Specific Objectives

The specific objectives were to 1) describe the profile of seasoned ultramarathon runners who have completed 20 or more Two Oceans Ultramarathon races, including sex, number of ultramarathons completed, medal category of peak performance and age at debut Two Oceans Ultramarathon; 2) to determine average performance, peak performance, worst performance and the pattern of improvement or decline in performance in seasoned ultramarathon runners over 20 Ultramarathon races participated in; 3) to determine differences in factors that may influence performance trends, such as sex, number of ultramarathons completed, medal category of peak performance and age at debut Two Oceans Ultramarathon; and 4) to determine the variation in ultramarathon performance based on the sex, number of ultramarathons completed, medal category of peak performance and age at debut Two Oceans Ultramarathon.

Methods

Data from 625 runners who completed 20 or more Two Oceans Ultramarathons were extracted from a publicly available website (www.twooceansmarathon.org). Finishing times across their running careers were used to establish average speeds, peak and worst performances, changes in performance over time, and coefficients of variation in performance. Groups were compared according to a) sex, b) number of Two Oceans Ultramarathons completed (20 or more than 20), c) age category of debut race, and d) medal category of peak performance.

Results

The finishing times and running speed results showed that males ran significantly faster than females across their 20 year Two Oceans Ultramarathon running careers (p=0.00001). Runners who completed more than 20 races had faster finishing times and race paces than those who ran 20 Two Oceans Ultramarathons (p=0.00001). When performances of the participants were analysed according to age categories, the youngest age category, namely 16-19, had the fastest average finishing times across 20 years of racing (p=0.00002). Peak and worst performances showed that best personal efforts were attained in the first quarter of the Two Oceans Ultramarathon career, and worst performances toward the end of these running careers. It was observed that as running careers progressed over time, the groups compared showed a pattern of performance convergence as differences in finishing times and running speeds decreased.

Discussion and Conclusion

The findings of this study suggest that a decline in performance over time is a natural and inevitable progression of a running career. Peak performances are usually acquired within the first few years of running careers. Participation trends as well as improved performances of master runners has shown that advanced age may be favourable in successful long-term ultramarathon running. This study identified a unique cohort of athletes who have consistently maintained ultramarathon running for 20 or more years. There is an opportunity for more detailed investigation of factors contributing to the longevity of their running careers, with the goal of promoting continuity in endurance running participation and physical activity at large.

CHAPTER 1: INTRODUCTION AND SCOPE OF THE DISSERTATION

1.1 Introduction

The South African Two Oceans Ultramarathon has been anecdotally labelled as one of the most scenic road races in the world [11]. It was pioneered in 1970 by Dave Venter with a total of twenty-six runners. Today, this annual event hosts more than 29,000 runners, of which 13,000 participate in the 56 km ultramarathon race [1]. A global increase in endurance running participation over the past two decades has been attributed to the significant rise particularly in female and master athletes [12]. Apart from the well understood health benefits of running, many other reasons for taking part in this sport include accessibility, cost-effectiveness and personal motivation and social integration [13]. The physical and psychological demands of ultramarathon training have been thought to limit ongoing participation somewhat; however, a unique population of master runners are able to complete several of these events over many years [14, 15].

Some of the well understood health benefits associated with endurance running include cardiovascular fitness, general body conditioning and weight loss [16, 17]. Studies have revealed that runners tend to have lower incidence rates of cardiovascular disease (CVD), cancer and neurological conditions such as Parkinson’s and Alzheimer’s disease [17]. Lifestyle diseases are also significantly lower in individuals participating in endurance exercise when compared to their sedentary counterparts. Many authors have described how running has positive effects on oxidative capacities and bone mineral density [18-20]. Improved stress-resistance of collagen-rich tissues, such as tendons, has also been associated with long-term endurance running [21].

The positive physiological effects of running are training-related, and if the stimulus of regular training is removed, these benefits will be reversed [22]. This finding highlights the importance of ongoing participation. Particularly in the age group of master runners, referring to those who are 35 or more years of age, lifelong participation in running has been shown to slow the natural age-related decline in aerobic function and muscular strength [4, 23]. Older runners can maintain higher levels of function for longer when participating in exercise compared to their sedentary counterparts, as high-impact aerobic exercise has been shown to have a significant impact on bone health and other benefits [24].

Despite the evidence in favour of endurance running to promote longevity, extensive research investigating the potential negative effects of participating in this sport has been conducted.

These negative effects have been outlined in a number of studies and range from cardiovascular damage, as indicated by increased cardiac biomarkers after prolonged exercise, to immunosuppression [25]. Other effects include muscle damage, overtraining and the development of running related injuries (RRI) [9]. In addition to various previously identified risk factors, such as training load and previous injury, running pace may also predispose a runner to injury and medical complications [26].

The natural age-related decline in various biological systems and subsequent reduction in functional capacity is an inevitable phenomenon. It affects the performance abilities of endurance athletes at some stage in their running career [27]. It is therefore important to understand how running affects the body, and vice versa. The relationship between aging and running performance is influenced by factors that promote participation as well as those that obstruct ability to participate. Few studies have analyzed the performance trends over extended periods of time. Accordingly, the aim of this study is to identify participation and performance trends in seasoned ultramarathon running careers.

1.2 Aims and Objectives

1.2.1 Aim of the Study

The aim of this study was to identify trends in the performances of seasoned ultramarathon runners across their Two Oceans Ultramarathon running careers.

1.2.2 Specific Objectives

The specific objectives of this study were:

- To describe the profile of seasoned ultramarathon runners who have completed 20 or more Two Oceans Ultramarathon races, including sex, number of ultramarathons completed, medal category of peak performance and age at debut Two Oceans Ultramarathon;
- To determine average performance, peak performance, worst performance and the pattern of improvement or decline in performance in seasoned ultramarathon runners over 20 Ultramarathon races participated in;
- To determine differences in factors that may influence performance trends, such as sex, number of ultramarathons completed, medal category of peak performance and age at debut Two Oceans Ultramarathon; and
- To determine the variation in ultramarathon performance based on the sex, number of ultramarathons completed, medal category of peak performance and age at debut Two Oceans Ultramarathon.

1.2.3 Significance of Study

Because the present study is descriptive in nature, the aim is to identify any trends in running speed and performance throughout a runner's Two Oceans Ultramarathon career. While previous studies have investigated various aspects of performance in runners, these have not been established for the unique population of seasoned master athletes throughout their careers in a specific race. Determining significant trends could contribute to the understanding of lifelong participation in ultramarathon events. Opportunities for future research to identify factors that may influence these trends could further contribute to this field of research.

1.3 Plan of Development

In preparation for this dissertation, an extensive review of literature on ultramarathon running and training factors, as well as injury and performance profiles, was completed. Key concepts are outlined and presented in the literature review in Chapter 2. The online database available on the Two Oceans website was used to extract the data used in this study. The methods are outlined in Chapter 3, and the results are presented, analyzed and discussed in Chapter 4. The discussion, significance and limitations of this study are found in Chapter 5. Finally, Chapter 6 includes the summary and conclusion.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

An ultramarathon is defined as a running race longer than the distance of 42.2 km; the distances covered can range vastly between the traditional marathon distance to thousands of kilometres [28]. The increase in participation amongst both elite and amateur runners in the past few decades has resulted in an extensive field of research exploring various associations between training load, injury risk and performance [29]. The impact of the vast training load associated with endurance running, which exceeds that of running for basic health benefits, can have both positive and negative effects on the body [30].

Endurance runners adopt a lifestyle which revolves around their commitment to training, where both physical and emotional demands are exerted on the athlete in great proportions [17]. Thus, the question of who is able to become an ultramarathon athlete has been comprehensively examined [31]. Extensive literature on demographic analyses of marathon and ultramarathon athletes is available. Although these runners come from a large variety of backgrounds, a recent demographic study by Roebuck and colleagues [32] has revealed that the majority of ultramarathon runners are males over the age of 45 years. Other areas of interest have been factors that could contribute to participation in ultramarathon running, such as training load, injury profile and cognitive influences [33]. More recently, the exploration of the longevity of ultramarathon running careers, where runners are able to complete several of these demanding events in their lifetime, have been explored in the literature. A consistent finding across numerous studies was that ongoing participation and successful completion are most prominent in more experienced master runners [34-36].

In the following review, literature on ultramarathon running will be explored. The effects that this sport has on the body, both positive and negative, will be debated. Finally, the unique dynamics around ultramarathon running in the aging population and the significant will be discussed.

The databases and online search engines EBSCO, Pubmed, Google Scholar and Ovid were consulted to search for relevant medical and scientific literature. Latest articles were prioritized over older ones, unless significant information was found in older papers, , or contemporary research in a specific field was not available. Manual searches were conducted where further clarification or information within a paper was needed. The following key words were used: "*Endurance running", "ultramarathon running", "ultradistance running", "marathon running", "distance running", "performance", "trend", "participation", "pacing", "speed", "variance", "age", "ageing", "master runner", "veteran runner", "running career", longevity", "Two Oceans", "training factors","experience", "benefits", "harmful effects", "injury", "physiology".*

In each section, certain search terms were prioritized over others. General research was conducted using the key words "ultramarathon running" or "marathon running" or "endurance running", "ultradistance running" or "distance running". The literature on the physiological effects of running included the terms "physiology" or "benefits" or "harmful effects" or "injury". While investigating the running performance, the terms "ultramarathon running" and "performance" were included. Research on the unique parameters of veteran runners included the search terms "master runner" or "veteran runner" or "aging" or "age" or "experience". Studies on pacing strategies were extracted with the use of the terms "pace" or "speed" or "variability".

2.2 Ultramarathon Running

Participation in ultramarathon running has recently grown significantly in popularity [37]. The ability to participate in and the subsequent outcome of such an event is influenced by a multitude of variables [38]. One of these popular ultramarathon races is the Two Oceans Ultramarathon, a 56 kilometer event held in Cape Town, South Africa. Previous studies have explored the economic value and participant profiles of this race [39, 40]. Other research has been based on risk factors for injuries [26, 41]. However, a gap in the literature on performance trends over several years of participation has been identified.

Personality traits, lifestyle commitments, motivations and other qualities specific to ultramarathon runners have also been studied [66, 95, 109, 114]. Leyk and colleagues [109] explain how the ability to train is dependent on various factors including time availability and social flexibility. Occupational commitments also have an influence on how much time can be invested into an ultramarathon running program. On a physiological level, ultramarathon runners have a distinct capacity to withstand the age-associated physical decline in cellular compliance [114]. Amongst others, these traits show the uniqueness of these ultramarathon runners.

Zaryski and colleagues [29] explain that the basic principles of training, such as overload, specificity, individualisation, reversibility and structural tolerance should be employed as with any other type of sport. Successful completion of an ultramarathon encourages continued participation. This is further positively influenced if the runner maintains physical and psychological wellbeing during training and competition [22]. A previous study has identified correlations between positive mood states, cognitive orientations and sport motivations amongst ultramarathon runners [38]. The authors of this qualitative analysis found strong themes related to a sense of belonging, personal achievement and psychological elation as the result of running ultramarathons. Therefore, it can be deduced that distance runners continue to take part in the sport, despite the physical challenges they may incur, for many years. This in turn introduces the concept of longevity of a running career, which is one that is multifactorial and complex. Some authors have suggested that running as an integral part of a lifestyle is frequently accompanied with other health-conscious habits, such as a positive diet as well as abstaining from alcohol consumption and smoking [17]. This cycle in turn reduced co-morbidities, which then allows an individual to continue to participate in endurance sport. The need for identification of factors that may be the cause of a terminated running career is crucial to enable and promote this longevity. These factors can be physical or psychological, and can have a rapid or a gradual onset [42]. Recommendations on optimal training load for longevity have been proposed in the literature [43]. Some of these recommendations include training consistency, cognitive adaptations to physical (age-related) changes, such as altered pacing strategies, as well as incorporating resistance training [44].

Running related injuries (RRI's) can be acute or chronic, and are often thought of as the primary cause for the cessation of a running career [45]. A RRI can be mild, where the athlete is able to continue training and racing, but in severe cases, the injury can be debilitating and require the runner to abstain from their sport entirely. The longer the athlete is unable to participate in their sport, the more profound the impact of detraining will be. This in turn plays an important role in the emotional management of injuries. Therefore many authors have explored the combination of physical and mental skills training to reduce injury risk [46, 47]. Because performance is influenced by an array of physical and psychological variables, mental preparation techniques have shown promising effects on injury prevention and management [48].

Lifelong participation in endurance events has been shown to improve aerobic capacity and functional reserve [24]. Trappe and Hayes [24] compared lifelong endurance athletes - individuals over the age of 80 years who have participated in endurance sport for over 50 years - with healthy but untrained controls. The results placed the trained group in the lowest mortality risk category, thereby emphasizing the significant beneficial effects on longevity with ongoing endurance exercise.

Other studies confirm these findings, and Galetta and colleagues [30] added that heart rate variability and exercise capacity is maintained into the later stages of life with lifelong endurance running. Generally, the findings in the literature suggest that the benefits tend to outweigh the potential harmful effects of endurance exercise.

2.3 Benefits of Endurance Running

An extensive number of studies have explored the benefits of running, which include promotion of physical fitness and prevention of disability and disease [17, 19, 49]. The accessibility and cost effectiveness in comparison to various other types of sport further contribute to the popularity of running [50]. Many studies have found a significant increase in participation in distance running particularly amongst master athletes. Endurance running has been associated with both physical and psychological health advances [51], both of which will be discussed below.

2.3.1 Physical Benefits

Endurance runners need to continuously modify their training to ensure optimal physical benefits. The cycle of training, competition and recovery requires dynamic management to yield favourable training adaptations and improved athletic performance. These are brought about by the physiological adaptations of the body's biological systems in response to the stimulus of exercise [52]. A multitude of physiological changes occur in the metabolic, muscular, cardiovascular, pulmonary and skeletal systems [21, 53].

2.3.1.1 Metabolic adaptations

Age and obesity have been found to be independent risk factors for metabolic dysfunction, and can lead to disability and mortality [54]. Stanford and colleagues [55] proposed that weight loss is the result of reduced lipid content as well as adipocyte size. In their study, the authors investigated the underlying mechanism for exercise-induced browning of white adipose tissue. They suggested that adipokines, which are produced by exercise-trained white adipose tissue, exert an endocrine effect on the body and thereby improve overall metabolism. Other authors support this theory and have added that during this exercise-induced process called "beiging" or browning", a polypeptide, Irisin, binds to white adipose tissue cells which are then converted into beige adipocytes [56]. This phenomenon causes a rise in total body energy expenditure and thermogenesis, contributing to increased cellular metabolism and ultimately to weight loss [56]. Therefore, it can be concluded that physical activity, in particular aerobic exercise, is one of the most effective means of sustainable weight loss.

Apart from the beneficial weight loss aspect of endurance exercise, a further favourable adaptation discussed by Fan and colleagues [57] is known as mitochondrial biogenesis. Because of the moderate-intensity nature at which endurance running is performed, free fatty acids (FFA) in the blood plasma and muscles are oxidized and provide an additional energy substrate other than glucose. The authors suggested that this shift in substrate utilisation reduces the onset of "hitting the wall", a state of exercise-induced complete energy depletion [57].

2.3.1.2 Muscular adaptations

Kenney and colleagues [52] describe the concept of muscular endurance as the ability of a single muscle or muscle group to maintain or repeat contractions effectively for the duration of the exercise task. This is believed to occur as the trained muscle becomes increasingly efficient in utilizing oxygen and fuel substrates. While the endurance muscle fibers, also referred to as Type II or slow-twitch fibers essentially do not change, they are able to maximize their aerobic potential in response to endurance exercise [57]. Because Type II fibers have superior fatigue resistance, these physiological adaptations are favourable in endurance athletes [58]. McArdle and colleagues further explain that another response to endurance training is specific hypertrophy in these individual fibers, which improves their capacity to generate Adenosine Triphosphate (ATP) in aerobic conditions [58]. There is also an increase in size and number of mitochondria, thereby improving energy production and supply to the myofiber. In their study on skeletal muscle in endurance runners, Rae and colleagues [59] found that veteran runners showed fibrotic changes in response to intercellular collagen deposition. Because no frank necrosis or inflammation was noted, it has been suggested that these processes facilitate adaptation to running.

2.3.1.3 Cardiovascular adaptations

The primary purpose of adaptations in cardiovascular function with endurance training is to increase the delivery of oxygen to the active muscle. Kenney and colleagues [52] have presented several changes that occur in the heart, both structural and functional. An example is the increase in the size of the cardiac muscle, particularly of the left ventricle. This is known as cardiac hypertrophy, or the "Athlete's Heart" [52]. The micro-RNA miR-222 is upregulated with exercise and thereby contributes to cardiac growth. Wasfy and colleagues [60] have suggested that cardiac remodelling is an exercise-induced process driven by increased intra-cardiac pressure and volume. This adaptation results in improved power output due to altered contractile properties of the cardiac muscle fibers. A lower resting heart rate and higher heart rate variability, traits which have been associated with improved cardiovascular fitness, are the result [30, 61].

2.3.1.4 Pulmonary adaptations

According to Kenney and colleagues [52], in the absence of pathophysiological processes, endurance performance is not hindered by pulmonary capacity. Ventilation can be increased to a much larger degree than cardiovascular system function. Although respiratory efficiency is largely affected by the cardiovascular system, the optimal functioning of the lungs in oxygenating the blood is essential. With submaximal aerobic training, the body achieves this goal by increasing the tidal volume and the respiratory rate [19, 52].

2.3.1.5 Skeletal adaptations

Scofield and colleagues [61] assessed bone health in endurance athletes and have established that weight-bearing exercise is known to improve bone mineral density (BMD). The process of bone remodelling is one that has also been of interest in the field of endurance running. Due to the high-impact nature of running, the bones of the lower limb are subjected to physical stress. With appropriate volumes and intensity, this can stimulate bone modelling and thereby increase the overall BMD. Findings from a past study strongly suggest that energy availability needs to be adequate for effective and efficient bone turnover [60]. The authors of this paper explain that in restricted caloric diets, the mismatch between available energy and expenditure may lead to unfavourable outcomes. However, when input and output are optimally balanced, bone health benefits can last into the later stages of life and reduce the risk of bone stress injury. This finding is particularly relevant when considering individuals who have been participating in endurance sport for a large portion of their lives, and continue to do so without significant skeletal complications [52, 61].

2.3.2 Psychological Benefits

An individual's psychological state is an essential determinant of their perceived life satisfaction. A study by Sato and colleagues [62] found strong correlations between exercise and enhanced life satisfaction. However, while the physical effects of exercise are well understood, the psychological benefits of endurance running are less objective and often anecdotal. Numerous studies have looked at the self-reported psychological experience derived from participation in endurance running as well as the neuropsychological effects of aerobic exercise on psychological well-being [47, 62-64].

2.3.2.1 Perceived Psychological Experiences

Some benefits reported in the literature include self-confidence and improved mental tolerance [65]. Runners frequently report lower levels of stress, improved sleep patterns and nutritional habits as well as reduced intake of alcohol [51]. These psychological experiences are believed to further encourage continued participation in an active lifestyle. However, because long-distance running requires commitment exceeding that required for basic health benefits, the presence of additional motives became a topic of interest in this field. Amongst many other tools, one developed by Masters and colleagues [66] the Motivation of Marathoners Scale (MOMS), has been used extensively in the literature. The questionnaire identified four categories of possible motives: 1) psychological, such as to improve self-esteem, 2) physical, aiming to gain fitness and lose weight, 3) achievement motives, which related to competition and ranking, and finally 4) the social aspect of endurance running. In their paper, Zach and colleagues [13] aimed to establish motivations for participation in marathon running in different demographic groups. The authors concluded that social reasons were most prominent amongst veteran and master runners.

2.3.2.2 Neuropsychological Effects

While these psychological benefits are self-reported and may be linked to the placebo effect, there is evidence to support the physiological processes behind the theory of the "runner's high", a state defined by DiLorenzo and colleagues [67] as a feeling of euphoria that results from long-distance running. The most popular theory associated with the psychophysiological changes occurring centrally is the "endorphin hypothesis". It ascribes the elated state of mood to the release of endogenous opioids from the frontolimbic brain region. Boecker and colleagues [63] have suggested that these neurochemical changes induced by regular aerobic exercise improve self-confidence, mental alertness, resilience and concentration and reduce depression, anxiety and pain perception.

The concept of exercise tolerance is both physical and psychological. Perrey and Mandrick [68] examined the brain's plasticity in response to distance running. The data were obtained from a study conducted by Freund and Faust [69], where seasoned distance runners underwent magnetic resonance imaging (MRI) scans before, during and after a multistage ultramarathon race. Apart from the evidence of brain volume reduction, the results suggested possible mental prerequisites on the participant's behalf. Furthermore, the impact of physical and mental fatigue on cortical matter, though not conclusive, proposed associations between positive neurophysiological adaptations and fatigue resistance [70].

2.4 Negative Effects of Endurance Running

Although the health benefits of running are well understood, numerous studies have investigated both the physical and the psychological potential negative effects of endurance training [25, 26, 71-73]. Exercise is a form of mechanical stress which requires various biological systems to continuously repair and appropriately adapt to micro-trauma. On a physiological level, the impact of repetitive high-intensity loading or unaccustomed volumes of exercise may have negative effects on the cardiovascular, skeletal and immune systems [25, 74]. Furthermore, psychological stress exerted on the athlete as a result of continued participation in endurance running may affect the runner's overall performance, participation and quality of life. Various studies have assessed the psychological impact that results from failure, inability to improve performance or discontinuation from running [32, 42, 47]. Finally, female distance runners in particular are often exposed to pressures related to maintaining a lean physique. This may increase the risk of developing disordered eating habits with resultant relative energy deficiency in sport (RED-S), amenorrhoea and bone mineral density loss (osteopenia/osteoporosis), a syndrome commonly known as the female athlete triad (FAT) [75].

2.4.1 Negative Physical Effects

The risk of injury increases when the rate of damage exceeds that of regeneration. Physical manifestations of this mismatch could include fatigue and the development of the overtraining syndrome (OTS) as well as musculoskeletal negative effects such as exercise-induced muscle damage (EIMD) and RRI's [45].

2.4.1.1 Negative Cardiovascular Effects

On a physiological level, many studies have addressed the cardiac changes that occur with training [16, 76-78]. Some have shown a transient increase in cardiac biomarkers after long-distance running, a finding which may indicate myocardial necrosis on a cellular level [16]. Right cardiac dysfunction, such as dilation of the chambers, is a common finding after marathon running; however, there is little evidence that indicates any necrotic damage to the myocardial tissue [79]. Despite this lack of conclusive evidence, several papers have found other unfavourable side-effects. For instance, Mont and Elosua [77] correlated the presence of increased vagal tone and cardiac remodelling, as found in the athletic population, with the risk of atrial fibrillation (AF). Furthermore, Trachsel and Carlen [78] established that middle-aged endurance athletes had a five-fold risk of developing AF when compared to the general population. This type of arrhythmia can not only impede performance but can also have detrimental consequences on an individual's health. Another cardiovascular parameter that endurance athletes may be at increased risk of is the development of endofibrosis of the iliac arteries or myocardial fibrosis [80].

This concern applies particularly to seasoned and master runners, who have been participating in the sport for many years. A significant decrease in the arterial compliance in older distance runners, as found by Burr and Drury [49], may be a contributing factor.

2.4.1.2 Negative Skeletal Effects

Due to the repetitive mechanical loading incurred with endurance running, bones of the lower limbs are exposed to bouts of loading. When recovery is inadequate or the mineral composition of the bone is compromised, this overload can lead to stress reactions or fractures. Hazelwood and Castillo [81] proposed that an underlying cause predisposing a runner to inefficient bone remodelling is related to inadequate energy availability, such as when there is a reduced caloric intake. An insulin-like growth factor contributes to bone remodelling; however, when the dietary requirements of an endurance athlete are not adequate, the serum concentration and synthesis of this protein are limited, and the individual is at risk of skeletal injury [82]. A pathology that has been associated with age is osteoarthritis (OA), particularly in the lower limb. The effects of running on bone, muscle and tendon has been thoroughly discussed in past research, but the impact on joints and cartilage remains unclear. A major risk factor related to the fatigue-failure principle of a stress fracture is that of repetitive overload as found in endurance running. In theory, the stress placed on the articular structures with repetitive loading could suggest that long distance running predispose an individual to osteoarthritis. Although Willick and Hansen [83] found limited evidence for this argument and that running in isolation may not be a significant cause of OA, additional cumulative factors may have a more detrimental effect.

A skeletal health concern previously thought to affect primarily the female population is what was referred to as the female athlete triad (FAT), a syndrome based on three components: disordered eating (DE), functional hypothalamic amenorrhoea (FHA) and osteoporosis. More contemporary research have suggested RED-S as a more encompassing definition [84]. It can affect both male and female elite and recreational athletes [85]. The long term effects can pose major health concerns later in the life of a runner, particularly due to the fact that the lost bone mass density cannot be reacquired. The updated terminology provided for this syndrome, as outlined by Mountjoy and colleagues [8], describes how all major bodily systems, including the gastro-intestinal, cardiovascular, immune, skeletal, haematological and endocrine systems, can be affected.

2.4.1.3 Immunology

A further aspect to consider as a potentially harmful effect of running is that of impaired immunology. While the processes occur on a physiological level, many conditions manifest as a physical limitation to participation in running. The acute immunosuppressive effect and consequent risk of infection and illness of strenuous exercise has been extensively studied [86, 87].

A number of factors lead to this immune response, and include neutrophil granule constitutes release as well as cytokines and C-reactive protein plasma level increase. The cause appears to be related to exercise-associated release of stress hormones and metabolic changes and hyperthermia, which are further aggravated by higher ambient temperatures [88]. When the release of FFA exceeds the uptake, a rise in plasma concentration occurs, which has been linked to impaired T-lymphocyte proliferation and haemolysis of the red blood cells. Humoral and mucosal immune function reductions were also linked to ultramarathon running, specifically in the "open window" period, which may be defined as a short-term immune suppression consequent to a bout of endurance exercise [89]. Ultimately, the symptoms that accompany an upper respiratory tract infection (URTI) lead to a decline in performance, and this in turn highlights the importance of prevention as well as identification of possible predisposing factors. Although the symptoms and conditions associated with suppressed immunity are reversible, they often require time off from the sport. When mismanaged, recovery time can be lengthened significantly [88].

Both physical and morphological differences between male and female athletes also need to be considered in this section as hormonal influences on immunity vary according to sex and age [81]. Because the hormones oestrogen and progesterone have an influence on immunity, resistance to infection can depend on the menstrual cycle, pregnancy and menopause. These hormonal fluctuations may expose females to periods of compromised immune function. Therefore, the female population may be more at risk to impaired immune function than their male counterparts [82].

2.4.1.4 DOMS and EIMD

Delayed-onset muscle soreness (DOMS), often used as the clinical quantification of EIMD, is a collection of symptoms frequently experienced by athletes starting around 6-12 hours, reach a peak at about 48-72 hours, and then steadily decrease until up to seven days post-exercise [83]. The principles of DOMS include mechanical damage to the skeletal myofiber as a result of eccentric or unaccustomed exercise. Metabolic depletion and ischaemia are also thought to contribute to the pain sensation. The syndrome is characterized by decreased range of motion, reduced muscle strength, intramuscular oedema and pain [67]. Although these signs and symptoms of EIMD are reversible, their presence can temporarily reduce running economy, increase perception of fatigue and have an overall undesirable impact on a runner's performance. The experience of EIMD is more transient and therefore arguably less severe than a RRI, yet it can often hinder a runner's ability to participate or compromise performance at a desired level, especially in the acute phase. In a study by Marcora and Bosio [90], the effect of EIMD on endurance performance was measured. Although the authors found no physiological reductions in performance at 70% of maximal volume of oxygen consumption ($VO2_{max}$) during running, they concluded that EIMD had a significant effect on a runner's sense of perceived effort. Therefore, the authors suggested that EIMD has an effect on central fatigue. Central fatigue has been identified as an adjunct to peripheral fatigue, which is understood to be reduced muscular power output. as defined by Meeussen and colleagues [91]. Central fatigue refers to chemical change resulting from extended periods of exercise that happen in the brain, such as the increase of the serotonin and dopamine concentration, which leads to fatigue [91].

2.4.1.5 Running Related Injuries

A variety of definitions of a RRI have been offered, and fundamentally these encompass the presence of pain in the lower limbs that causes a reduction or termination of training for either seven days or three consecutive training sessions, or pain that causes the individual to seek medical attention [92]. Despite the extensive amount of research that has been dedicated to the development and management of RRI's, definitive risk factors or prevention methods are not well established. The importance of understanding the aetiology of RRI's is essential in developing preventative or therapeutic interventions [45]. There are several risk factors that have been related to injuries sustained due to running. A recent systematic review presented by Hulme and colleagues [71] describe the impact of several modifiable factors, such as various components of training, different terrains and dietary practices, and non-modifiable risk factors, including sex, age and previous injury. The authors concluded that all the literature consulted in their systematic review seemed to be in accordance with certain primary risk factors for developing a RRI, such as rapidly increased weekly mileage or having sustained a previous injury. Most of the literature confirms a consistent correlation between both acute and chronic injuries with training intensity, volume and age [71, 72, 92].

2.4.1.6 Fatigue and the Overtraining Syndrome (OTS)

A number of definitions of fatigue are used in the literature. Fundamentally, it can be described as a reduced force-generating capacity of the neuromuscular system [2]. More recently, the impact of the central nervous system on the reduced muscle activation has been explored. Reduced maximal force production however stems from a combination of both central and peripheral fatigue [2, 70].

A positive adaptation to training occurs when the tissues have remodelled and regenerated after EIMD. Commonly, the process of exceeding the body's current level of ability is referred to as functional overreaching [5]. However, when the load exceeds the capacity to effectively accommodate these changes, structural failure can manifest either as physical injury or performance decrement. Fatigue as a result of training or competing can be the prelude to overtraining syndrome if early signs are not addressed adequately [29]. Additional symptoms include mood disturbances and prolonged maladaptation of various hormonal, neurochemical and biological mechanisms [93]. To differentiate from functional or transient overreaching, OTS does not resolve with rest and can take up to a year to subside. The implications of this on physical, emotional and social domains of an athlete's life can be extensive [58]. Some concerns that affect the conceptualization of this term include a poor understanding of the multifactorial aetiology, a lack of reliable diagnostic outcome measures and an inconsistency in the definitions used [94]. While many studies have attempted to define and diagnose the syndrome by studying performance tests, biomarkers and psychological states, these suggestions fall short in light of the complexity of OTS.

2.4.2 Psychological Stress

The psychological stress experienced by runners can have numerous causes and subsequent effects on the emotional as well as the physical state. Runners may experience psychological stress as a result of pressure to perform or to fulfil expectations [95]. When an athlete is not able to reach certain milestones or targets that have been pre-defined, the psychological impact can exert immense stress on the individual. The experienced perception of inadequacy and failure can also have negative effects on the athlete with regards to performance and general wellbeing. Evans and colleagues [64] describe this emotional experience as competitive suffering. The state is induced by underperformance or a mismatch between expectations and physical abilities, and can result in anxiety and a negative affective state.

Stress responses can act as predisposing factors to sport-induced injury. Nippert and Smith [47] discuss how the response to recovery is influenced by an array of personal as well as situational factors. Their integrated model of response to sports injury describes the interaction between physical, psychosocial and injury dynamics, and although the paper has only been applied to younger athletic populations, there may be value when adapted to adult and veteran athletes.

Being able to participate in lifelong endurance running requires both physical and mental resilience. Different injury profiles are often the contributing factor of an impaired ability to participate in running [96]. Alternatively, personal motives may be the reason for being unable to participate in the sport. Ronkainen and colleagues [97] conducted a qualitative study during which they aimed to identify factors that led to retirement from endurance running. Their findings demonstrated that some master runners reached a point where they were physically no longer able to improve performance, at which they accepted the natural path of age-associated retirement. Rather than a definite life event, this process is subtle and individuals experienced difficulties in its identification and acceptance. On the other hand, some of the other study participants continued to run at a reduced level of performance, explaining an increased sense of enjoyment with the reduction in competition induced anxiety. Often, the moment of acceptance or shift in state of mind is accompanied with “boundary situations”, which Ronkainen and Ryba describe as an experience disrupting everyday life [98]. According to the authors of this paper, these can occur suddenly or gradually, and can include injury, burnout or de-selection, thereby enforcing termination of participation.

Many other negative implications of running have been reported, which include interpersonal relationship problems due to extreme training requirements, stress related to training and tapering strategies as well as peer-related pressure [65]. Consequently, holistic management of endurance athletes is of utmost importance to ensure ongoing participation as well as positive performance outcomes.

2.5 Running Performance and Pacing

Many factors can have an impact on performance, including nutrition, sleep, training, injury profiles as well as environmental conditions. Performance in an ultramarathon race appears to be determined to a large degree by pacing, a quantifiable measurement frequently used. Pacing has been defined as the distribution of work or energy expenditure during an exercise task with the aim of achieving a personal goal [6, 99]. In endurance running, fatigue resistance is essential. By employing certain pacing strategies, an athlete may optimize their energy use to maintain adequate neuromuscular function until the end of the event [100]. While pacing is primarily thought of as the physical energy output, the psychological component is equally important. It is referred to as the teleoanticipatory system, whereby the brain processes the physical requirements to reach the end of the task and modifies exercise intensity to maintain physiological homeostasis [10]. An appropriate strategy is chosen depending on various factors, such as ambient temperature, terrain and gradient of the route as well as altitude [101].

Three pacing strategies have been identified in the literature: positive, negative and even pacing [102]. The former is marked by a gradual decrease in running speed throughout the event. This pacing profile has been associated with increased oxygen consumption and an accumulation of fatigue-related metabolites, and may be due to an inappropriate speed in the initial stages of the event. Athletes have also reported a higher rate of perceived exertion (RPE) [101]. Even pacing refers the maintenance of the same speed for the full event; this strategy has been found to be successful in short-duration events. Finally, negatively paced athletes increase their speed throughout the duration of an event. It is marked with decreased carbohydrate depletion, a lower concentration of blood lactate and improved overall performance, and motivation to complete a task is thought to play a role in this type of pacing [6].

Positive pacing is thought to be related to a lack of ability to anticipate exercise demands, and is commonly seen in children and amateur athletes [7]. It has been suggested by Gibson and colleagues [7] that more effective pacing develops with experience. High performing athletes and seasoned runners who have completed many similar exercise tasks, such as ultramarathons, have gained insight into the upcoming event. A study on pacing strategies in age group ultramarathoners by Knechtle and colleagues [103] revealed superior pacing in master runners between the ages of 40 and 45, versus the greatest decrease in running speed in the last segment of the race in the age category 18-24.

2.6 Age and Running

More recently, the field of research focusing on the master runners who are able to train for, participate and compete in endurance races has expanded [4, 12, 14, 96, 103, 104]. While many authors have explored the impact of training programs, injury profiles and psychological motivations on performance, the complexity of these falls beyond the scope of this paper. However, it is acknowledged that effective pacing strategies play an important role in performance, and therefore contribute to successful completion and continued participation in events. A multitude of factors and their complex interactions have been found to influence the ability to participate in ultramarathons at master level [4, 14, 73]. The age at which a runner is defined as a master has been accepted as 35 years [4, 101]. This age may frequently coincide with the turning point in a sporting career. According to a previous study, this milestone marks the start of an incessant decline in performance, which then rapidly accelerates after the age of 65 years. It has been suggested that performance peaks are often reached in the timeframe shortly before a runner enters the category of master or veteran athletes [53]. This process appears to be the result of normal chronological aging, which involves a complex interaction of numerous biological systems. Lazarus and Harridge [105] describe the trajectory of athletic performance decline as an integrated representation of aging. Their theory aims to predict the outcomes of the interaction between age, health and activity. It suggests an increasingly compromised physiological functioning, together with age and inactivity, and how exercise may reduce the consequences of the aging process. While death is the ultimate end point, the authors propose an optimal pathway with limited morbidity and an increased functional lifespan [105].

2.6.1 Metabolic Factors

The natural age-related decline in running performance has been established in existing literature [106]. A reduction in both aerobic and anaerobic performance has been identified [53]. According to Tanaka and Seals [107] endurance performance is determined by several key physiological determinants: maximal oxygen consumption, also known as $VO2_{max}$, running economy and lactate threshold as well as changes in muscle capillary density [107]. Body composition changes including a decrease in skeletal muscle and fat-free mass, body cell mass and total body potassium have also been linked to the well-established performance decline associated with age [108]. While strong correlations between these and performance decrements of older runners exist, many other contributing factors, such as musculoskeletal changes, need to be considered [107].

2.6.2 Musculoskeletal Factors

Arguably, it has been suggested that master runners reduce their training intensity, frequency and variety, thus leading to decreased overall performance [107]. Variables that can influence this decline include various lifestyle changes, such as occupational, social or financial demands, and can lead to less frequent training [109]. Some age-associated changes that might further affect participation and performance in older endurance runners include decreased joint range of motion (ROM), flexibility and coordination, resulting in altered endurance economy. However, the musculoskeletal changes that inevitably occur with advancing age are considered the most likely cause in deteriorating endurance capacity [73, 107].

The skeletal changes that occur as a normal process of aging further influence performance and may predispose older runners to overload [110]. Therefore, exertional and overuse injuries as a result of the degenerative process of aging are common amongst master athletes [73]. A correlation between the risk of developing a RRI and being over the age of 45 years has been demonstrated by Devita and colleagues [96]. It has been suggested that a contributing factor is the biomechanical alteration in running gait that occurs with age, which commonly includes a slower pace, shorter stride length and increased cadence. The authors conclude that by addressing these biomechanical changes, brought about by reduced ankle moment and power production in the stance phase of the running gait cycle, longevity of participation in running may be promoted [96].

According to Karamanidis and Arampatzis [111], function and performance of a muscle and its tendon depend on the mechanical and morphological composition. Evidence presented by several studies suggest that reduced muscle strength and changes in the muscle architecture and collagen properties are the results of the age-related degenerative process [4, 53, 112]. The effects of running on advanced glycation endproducts (AGE) production in the connective tissue has been associated with aging and the development of lifestyle-related diseases [113]. On the one hand, the outcomes of this study revealed a decrease in AGE cross-link density, drawing the conclusion that benefits to tendon integrity improve physical resistance to stress and injury. However, other studies have found that distance running experience exceeding 10 years placed an athlete at risk of tendinopathy development [72]. These contradictions throughout the literature are common and emphasize not only the need for ongoing research, but also point out the large extent of the research field of running, injury and age, and the interaction of these factors.

The concept of continued endurance training as a means of decelerating the progression of aging and age-related deconditioning has been thoroughly debated [105, 114]. Some studies are in favour of ongoing participation in endurance running due to the extensive benefits [21, 44, 51, 115]. However, others argue that the physical changes that naturally limit performance as the result of aging are inevitable drawbacks [98, 116]. It has been suggested that high volumes of training and racing may accelerate the age-related performance decrements [117].

2.7 Performance Trends in Master Runners

Although chronological age is generally thought of as a performance limiting variable, Zingg and colleagues [104] revealed that peaks in performance and running speed were acquired by older runners in ultramarathon distances. Where the top running speed of a 50-mile event was achieved by athletes between 35-37 years of age, that of a 1000-mile event was attained by averagely 45 year old master runners. A further noteworthy observation made by Lepers and colleagues [14] reveal a relative plateau in current performance in elite athletes under 40 years of age, whereas running performance seems to be continuously improving in master athletes. Despite a decline in absolute performance with age, it has been suggested that this is only evident when an older athletes current performance is compared to either their own previous achievements or to that of their younger counterparts. Instead, comparing age-group performance trends over time reveals a distinct improvement in the general group of more seasoned, master runners [53]. The literature suggests that this increase in overall performance may be attributed to a general rise in running and race participation of older athletes [36]. This ties in with the finding that previous experience has been correlated with race performance [118].

It also needs to be considered that studies predominantly discover these trends amongst male athletes. Historically, females started competing in long distance running long after males, and an initial rapid increase in the rate of performance in female athletes narrowed the gap to that of males [119]. This suggested that females could match or even exceed in their running performance. However, in an analysis of world rankings completed between 1980 and 1996 it was apparent that a plateau in performance has been reached. The remaining gap between males and females is thought to be of biological origin, and thus unlikely to narrow naturally. General running performance difference between males and females have been attributed to physiological and anthropometric characteristics [120]. Knechtle and colleagues [121] found that personal best (PB) times were achieved approximately six years earlier in males than in females, at the ages of 30 and 36 respectively.

Apart from the health-related recommendations advocating ongoing participation in endurance exercise, for many runners, the volume of training becomes part of a lifestyle. Such athletes repeatedly take part in endurance events, often for many years of their life, and frequently without being hindered by various limitations [122]. The evidence in favour of lifelong participation in running is compelling, and in a highly dynamic field of research, opportunities for future studies are abundant.

2.8 Summary

In summary, it is evident that the beneficial and negative effects of running in general as well as ultramarathon running in specific are abundant, and have been extensively explored in previous studies. The unique dynamics of ultramarathon running in terms of physical and psychological requirements have also been deliberated in the literature. The field of research focusing on the various factors that have an impact on performance is complex and, amongst many others, conceptualizes pacing. Pacing has been linked to performance, and many researchers have explored performance trends amongst various groups, including master runners. The effects of aging on seasoned endurance runners are multifactorial, as are the changes in performance over time.

CHAPTER 3: PERFORMANCE TRENDS IN SEASONED TWO OCEANS ULTRAMARATHON RUNNERS

3.1 Introduction and Study Setting

This study used data on the Two Oceans Ultramarathon, a 56 kilometer road running race based annually in Cape Town over the Easter weekend. The two different routes, Ou Kaapse Weg and Chapmans Peak. From the first race in 1970, the race followed the Chapmans Peak route. Due to environmental factors, the event had to be rerouted from the years 2000 until 2003 via Ou Kaapse Weg. Since then, the latter route is occasionally used should any complications arise with the original one. Data collection was conducted electronically with the assistance of the publicly available data provided on the Two Oceans website.

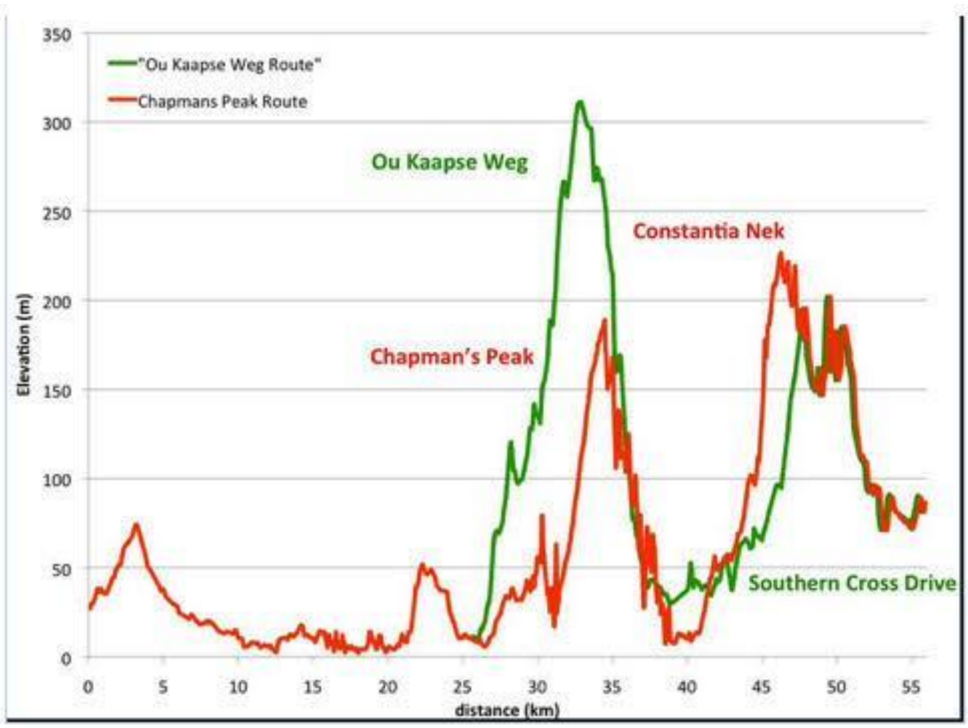

Figure 1: Profiles of the Two Oceans Ultramarathon routes (Ou Kaapse Weg Route and Chapmans Peak Route).

3.2 Methodology

3.2.1 Research Design

This study has a descriptive, retrospective design.

3.2.2 Sample

3.2.2.1 Inclusion criteria

Data from seasoned male and female endurance athletes, who have completed 20 or more non-consecutive 56 km Two Oceans Ultramarathons, were included in this study.

3.2.2.2 Exclusion criteria

Data from deceased runners were excluded from the study.

3.2.2.3 Sample technique and size

The sampling technique used was stratified convenience sampling. Due to the public availability of the data on the Two Oceans website, the entire population was included by stratified convenience sampling. The total number consisted of 635 runners, 52 females and 583 males. By using the whole population, sampling errors and bias were removed. No formal permission need to be obtained to use the data provided on the website.

3.2.3 Instruments

The data management instrument used was a Microsoft Excel spreadsheet (Appendix A: Data Extraction Sheet). This instrument was developed by the researcher and the study supervisors based on what information needed to be calculated for the purposes of the study objectives. The information gathered was categorized according to a self-developed table which aimed to extract the necessary information to adequately address the study objectives. All data were managed, stored and analysed from this program. The running paces were determined by using the marathon splits and finishing times in an online convertor.

3.2.4 Procedure

The study proposal was submitted for departmental review and ethical approval. All data obtained from the website were stored on the researcher's PC. The data were used for statistical purposes only. The publicly available Two Oceans website database (www.twooceansmarathon.org.za) was accessed from March 2017 to February 2020. Once those individuals who met the inclusion criteria were selected, the data on their participation history of the ultramarathon were extracted. The data of all participants were divided into and analysed in four sections: Sex (females and males), number of Two Oceans Ultramarathons completed (20 or more than 20), age category of debut race and medal category of personal best performance. The significant of this particular categorization enabled the researcher to draw comparisons between the different groups. In the case of the number of races completed (20 or more than 20), the aspect of longevity would be analysed, specifically to establish whether runners who sought to achieve a double-blue number performed differently from those who were able to continue racing for longer.

3.2.5 Statistical Analyses

Statistical analyses were performed using data analysis software system STATISTICA (StatSoft. Inc, 2016). Normality was assessed using the Shapiro-Wilkes test. Descriptive statistics, such as the mean and the standard deviation (SD) were calculated from the data. Independent t-tests and Chi-squared measures of association were used to determined differences between numeric and categorical data. An analysis of variance (ANOVA) with repeated measures was used to determine differences between groups over time. Unequal N HSD post-hoc testing was performed. Statistical significance was accepted as $p < 0.05$.

Variability in speed was determined by calculating the Coefficient of Variation in Speed ($Speed_{COV}$) with the formula:

$$SpeedCOV = \frac{Standard\ deviation\ (Speed)}{Mean\ (Speed)}(100)$$

Where:

Standard deviation (Speed) = The SD of speed throughout a running career

Mean (Speed) = average speed throughout a running career

3.2.6 Ethical Considerations

Ethical approval for this study was obtained from the Human Research Ethics Committee of the Faculty of Health Sciences, University of Cape Town (Appendix B: Ethics Approval Letter, Appendix C: Annual Progress Report). There were no risks or benefits to the study participants as no direct contact between the participants and the researcher was made. All data used in this study were available online for the public to view.

CHAPTER 4: RESULTS

4.1 Descriptive Characteristics

The descriptive characteristics of the sample can be seen in Table 1 (page 40). The study sample consisted of 635 runners, 92% of whom were male. Most runners were South African (n=602; 95%). Approximately three quarters of participants have run more than 20 Two Oceans Ultramarathons, males having completed significantly more than females (t=2.81, p=0.005). The age category 20-39 years is the largest as it ranges over 19 years rather than 10. Subsequently, most peak performances were achieved in this age category, with 61% in under 5 hours, thus falling into the Sainsbury category. The most recent race, the 2019 Two Oceans Ultramarathon, was completed by 250 runners of this sample, 228 were males and 22 were females.

Table 1: Descriptive characteristics of participants (n = 625). Data are expressed as the count (n) and percentage (%) of the total.

Variable	Category	Count (n)	Percent
Sex	Male	583	92%
	Female	52	8%
Nationality	South Africa	602	96%
	United Kingdom	11	2%
	Namibia	3	<1%
	Switzerland	1	<1%
	Belgium	1	<1%
	New Zealand	2	<1%
	Lesotho	1	<1%
	Germany	2	<1%
	Canada	1	<1%
	United States of America	1	<1%
Number of Two Oceans Ultramarathons completed	20	175	28%
	>20	450	72%
Age category (years) of debut Two Oceans Ultramarathon	16-19	7	1%
	20-39	529	85%
	40-49	87	14%
	50-59	2	<1%
Medal category[1] of peak performance	Bronze (sub 6 hours)	104	17%
	Sainsbury (sub 5 hours)	380	61%
	Silver (sub 4 hours)	132	21%
	Gold (top 10)	9	1%
2019 Two Oceans Ultramarathon finishers of study participants	Male	228	91%
	Female	22	9%

[1] The Blue medal category (sub 7 hours) was introduced in 1998. Data on this category were not included in this study.

4.2 Race History

The participants' race history was analysed using the rate of Two Oceans Ultramarathon career completion. Table 2 (page 42) shows details on the number of years of participation in Two Oceans Ultramarathons, the duration of the race running careers and the time taken to complete these careers. Both sexes completed their first 20 Two Oceans Ultramarathon races in an average period of 23 years. Overall, males completed more Two Oceans Ultramarathons than females. Therefore, the number years of race participation in males (n=27) is also significantly higher (t=-3.84; p=0.0001) than in females (n=25). There was no significant difference in the rate at which the participants completed their first 20 Two Oceans Ultramarathons. The 20 year running careers were analysed in four 5-year intervals in Table 3 (page 44). The data in this table show the rate at which the runners completed their 20 (or more than 20) Two Oceans Ultramarathons. Males ran more races (n=24), for more years (n=27), and took longer to complete 20 events (n=25) when compared to females (n=22, 25 and 22 respectively). The data on the number of races completed reveal that runners who stopped at 20 medals completed these in a shorter timeframe (n=23), where those that continued to run more than 20 races spread these out over more years (n=24). The age category data reveal that the youngest age category took longest to complete their 20 races (n=25), whereas the olderst age category completed their 20 runs in the shortest timeframe (n=21). The largest age category, 20-39, ran the most Two Oceans Ultramarathons over the largest time period (n=28). Finally, gold medal runners took the longest time to complete their 20 races (n=25) and ran the most races over the longest timeframe (n=38) when compared to the other medal categories.

Table 2: Rate of completion (years) of Two Oceans Ultramarathon careers. Data are presented according to grouping variables of: sex, number of races (20 or >20), age category of debut race, and medal category of peak performance. Data are presented as mean ± standard deviation. Ranges (minimum to maximum) are presented in the final column.

Variable	Category		Mean ± SD in years	Range (min-max) in years
Number of years taken to complete 20 Two Oceans Ultramarathons	Sex	Male (n=573)	23 ± 4	20-42
		Female (n=52)	22 ± 3	20-29
	Number of Two Oceans Ultramarathons completed	20 (n=175)	24 ± 4	20-42
		>20 (n=450)	23 ± 3	20-40
	Age category of peak performance	16-19 (n=7)	25 ± 4	20-29
		20-39 (n=529)	23 ± 4	20-42
		40-49 (n=87)	22 ± 2	20-30
		50-59 (n=2)	21 ± 1	20-22
	Medal category of peak performance	Bronze (n=104)	23 ± 3	20-32
		Sainsbury (n=380)	23 ± 3	20-41
		Silver (n=132)	23 ± 4	20-37
		Gold (n=9)	25 ± 7	20-42
Total number of years of Two Oceans Ultramarathon running	Sex	Male (n=573)	27 ± 5	20-49
		Female (n=52)	25 ± 3	20-32
	Number of Two Oceans Ultramarathons completed	20 (n=175)	24 ± 4	20-42
		>20 (n=450)	28 ± 5	21-49
	Age category of debut race	16-19 (n=7)	27 ± 5	21-32
		20-39 (n=529)	28 ± 5	20-49
		40-49 (n=87)	22 ± 2	20-37
		50-59 (n=2)	22 ± 3	20-24
	Medal category of peak performance	Bronze (n=104)	25 ± 4	20-35
		Sainsbury (n=380)	27 ± 5	20-41
		Silver (n=132)	30 ± 6	20-49
		Gold (n=9)	36 ± 6	29-47

Total number of Two Oceans Ultramarathons run	Sex	*Male (n=573)*	*24 ± 4*	*20-43*
		Female (n=52)	22 ± 2	20-29
	Number of Two Oceans Ultramarathons completed	20 (n=175)	20 ± 0	20-20
		>20 (n=450)	25 ± 4	21-43
	Age category of peak performance	16-19 (n=7)	22 ± 2	20-26
		20-39 (n=529)	24 ± 4	20-43
		40-49 (n=87)	22 ± 2	20-29
		50-59 (n=2)	21 ± 1	20-22
	Medal category of peak performance	Bronze (n=104)	23 ± 4	20-31
		Sainsbury (n=380)	23 ± 4	20-41
		Silver (n=132)	25 ± 6	20-43
		Gold (n=9)	28 ± 5	20-35

Table 3: Rate of completion (years) of Two Oceans Ultramarathon careers in 5-year intervals: 1-5, 6-10, 11-15 and 16-20. Data are presented according to grouping variables of: sex, number of races (20 or >20), age category of debut race, and medal category of peak performance. Data are presented as mean ± standard deviation. Ranges (minimum to maximum) are presented in the final column.

Variable		*Category*	*Mean ± SD in years*	*Range (min-max) in years*
Two Oceans Ultramarathon 1-5	Sex	Male (n=573)	6 ± 2	5-26
		Female (n=52)	6 ± 2	5-11
	Number of Two Oceans Ultramarathons completed	20 (n=175)	6 ± 3	5-26
		>20 (n=450)	6 ± 2	5-18
	Age category of peak performance	16-19 (n=7)	8 ± 4	5-14
		20-39 (n=529)	6 ± 2	5-26
		40-49 (n=87)	6 ± 2	5-13
		50-59 (n=2)	6 ± 1	5-7
	Medal category of peak performance	Bronze (n=104)	6 ± 2	5-13
		Sainsbury (n=380)	6 ± 2	5-26
		Silver (n=132)	6 ± 2	5-13
		Gold (n=9)	7 ± 3	5-13
Two Oceans Ultramarathon 6-10	Sex	Male (n=573)	5 ± 1	5-12
		Female (n=52)	5 ± 1	5-8
	Number of Two Oceans Ultramarathons completed	20 (n=175)	6 ± 1	5-12
		>20 (n=450)	5 ± 1	5-12
	Age category of peak performance	16-19 (n=7)	5 ± 0	5-5
		20-39 (n=529)	6 ± 1	5-12
		40-49 (n=87)	5 ± 1	5-12
		50-59 (n=2)	5 ± 0	5-5
	Medal category of peak performance	Bronze (n=104)	5 ± 1	5-8
		Sainsbury (n=380)	5 ± 1	5-12
		Silver (n=132)	6 ± 1	5-12
		Gold (n=9)	6 ± 1	5-8

Two Oceans Ultramarathon 11-15	*Sex*	*Male (n=573)*	*6 ± 2*	*5-19*
		Female (n=52)	6 ± 1	5-9
	Number of Two Oceans Ultramarathons completed	20 (n=175)	6 ± 2	5-19
		>20 (n=450)	6 ± 1	5-17
	Age category of peak performance	16-19 (n=7)	7 ± 3	5-12
		20-39 (n=529)	6 ± 1	5-19
		40-49 (n=87)	6 ± 1	5-12
		50-59 (n=2)	5 ± 0	5-5
	Medal category of peak performance	Bronze (n=104)	6 ± 2	5-17
		Sainsbury (380)	6 ± 2	5-19
		Silver (n=132)	6 ± 2	5-15
		Gold (n=9)	5 ± 0	5-6
Two Oceans Ultramarathon 16-20	Sex	Male (n=573)	6 ± 1	5-16
		Female (n=52)	6 ± 1	5-11
	Number of Two Oceans Ultramarathons completed	20 (n=175)	6 ± 2	5-16
		>20 (n=450)	6 ± 1	5-15
	Age category of peak performance	16-19 (n=7)	5 ± 1	5-6
		20-39 (n=529)	6 ± 2	5-16
		40-49 (n=87)	6 ± 1	5-10
		50-59 (n=2)	5 ± 0	5-5
	Medal category of peak performance	Bronze (n=104)	6 ± 1	5-11
		Sainsbury (n=380)	6 ± 1	5-14
		Silver (n=132)	6 ± 2	5-15
		Gold (n=9)	7 ± 4	5-16

4.3 Performance

4.3.1 Race Performance History over 20 Years

Males had significantly faster finishing times than females (p=0.00001) (Figure 2a). The results revealed significantly faster times between the first and fifth Two Oceans Ultramarathon race, after which times got progressively slower (p=0.00001). After the first race, there was a significant increase in finishing time from the second to seventh Two Oceans Ultramarathon. This trend applied to both sex groups. Finishing times indicated that races 17-20 were completed significantly slower than the previous races, particularly amongst females (p=0.00004). Post hoc findings revealed significantly faster finishing times amongst males in the first 7 races. Thereafter, the performance gap narrowed between males and females and no differences in performance were seen.

Amongst the groups of 20 or more than 20 race finishes, the latter group performed significantly better than the former (p=0.00001) (Figure 2b). A trend of an initial race time improvement is visible in both groups (p=0.00001). From the sixth Two Oceans Ultramarathon onwards, a gradual decline in performance can be identified. The group of runners completing 20 races had a significantly faster rate of decline from race 16 (p=0.00004). While no significant performance differences between the groups could be identified in the larger part of the running careers of both groups, from race 17 to 20 the performance gap opened up and runners in the >20 races group ran significantly faster.

Figure 2c shows a significant difference in performance amongst the age categories, with runners in the 16-19 group achieving the fastest finishing times (p=00002). The worst performance was identified in the age category 40-49. Outliers in the categories 16-19 and 50-59 could be due to smaller sample sizes. Over time, race finishing times slowed significantly (p=0.00001). Significant differences were also seen in the second half of the 20 year running careers between age categories 20-39 and 40-49 (p=0.00004), where the former group performed significantly better than the latter group.

Race times were ranked according to medal categories of personal best performances (Figure 2d). Performance improved for all groups after the first race up until race eight. A consistent increase in finishing times followed until the end of the 20 year race period (p=0.00001). Performance trends followed similar patterns for all medal categories, with significant differences in the interaction between group and time (p=0.00001). The gold medal category had a smaller size to the other categories. This medal category section clearly shows that performance over 20 years of Two Oceans Ultramarathon running followed the trend of the peak performance of the participants. Hence, there were significant differences (p=0.00004) between all groups, with Gold medalists having the fastest finishing times, followed by Silver, Sainsbury and Bronze medalists.

20 Year Running History

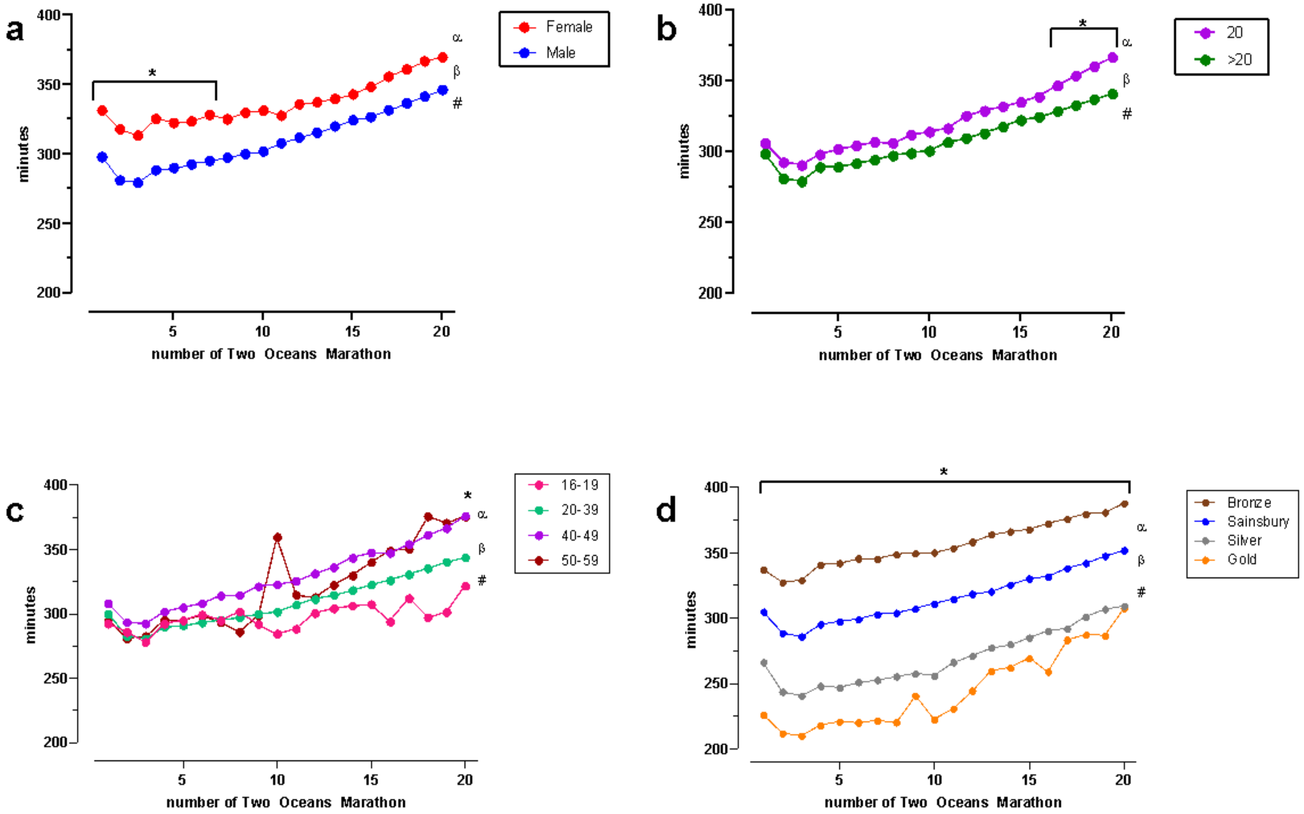

Figure 2 (a-d): A 20 Year Two Oceans Ultramarathon Running History. Data are presented according to grouping variables of: (a) sex, (b) number of races (20 or >20), (c) age category of debut race, and (d) medal category of peak performance. Race finishing times are recorded over 20 Two Oceans Ultramarathon events and measured in minutes.

Significant differences:

(a) *α Main effects of group $F_{(1,623)}$ = 30.7; p=0.00001*
β Main effects of time $F_{(19, 11837)}$ = 109.7; p=0.00001
 # Interaction of group x time $F_{(19, 11837)}$ = 2.9; p=0.00002
** Post hoc findings between males and females: races 1 and 3 (p=0.02); races 2, 4 and 5 (p=0.003) and race 7 (p=0.02)*

(b): *α Main effects of group $F_{(1,623)}$ = 21.4; p=0.00001*
β Main effects of time $F_{(19, 11837)}$ = 381.6; p=0.00001
 # Interaction of group x time $F_{(19, 11837)}$ = 5.0; p=0.00001
** Post hoc findings between 20 and >20 race groups: races 17 (p=0.02); race 18 (p=0.002), race 19 (p=0.0001) and race 20 (p=0.00004)*

(c): *α Main effects of group $F_{(3,621)}$ = 8.5; p=0.00002*
β Main effects of time $F_{(19, 11799)}$ = 18.1; p=0.00001
 # Interaction of group x time $F_{(57, 11799)}$ = 2.8; p=0.00001
** Post hoc findings between age categories 20-39 and 40-49: race 20 (p=0.0009)*

(d): *α Main effects of group $F_{(3,621)}$ = 362.1; p=0.00001*
β Main effects of time $F_{(19, 11799)}$ = 104.6; p=0.00001
 # Interaction of group x time $F_{(57, 11799)}$ = 2.7; p=0.00001
** Post hoc findings between Bronze and Sainsbury medalists: races 1-20 (p=0.00004)*
** Post hoc findings between Bronze and Silver medalists: races 1-20 (p=0.00004)*
** Post hoc findings between Bronze and Gold medalists: races 1-19 (p=0.00004); race 20 (p=0.0002)*
** Post hoc findings between Sainsbury and Gold medalists: races 1 and 6 (p=0.0003); race 2 (p=0.0005); race 3 (p=0.0008); race 4 (p=0.0004); race 5 (p=0.0006); race 7 (p=0.0001); race 8 and 11 (p=0.00007); race 9 (p=0.01); race 10 (p=0.00004); race 12 (p=0.001); race 14 (p=0.03); race 16 (p=0.002)*

4.3.2 Average Race Performance

Average race performance (Figure 3a), measured in speed ($m.s^{-1}$), was measured in four 5-year intervals. The results showed that males ran significantly faster than females (p=0.00001). Mean running pace decreased significantly over time (p=0.00001). The sex and time interaction also showed significant changes in race pace, with a more gradual decline in males and a more rapid decline in females (p=0.00001). A significantly slower pace in females occurred in the first (p=0.00005) and second 5-year intervals (p=0.003). No significant differences between males and females were evident in the second two intervals.

On average, the group who ran more than 20 Two Oceans Ultramarathons had significantly faster running speeds (p=0.00001) (Figure 3b). The pace decreased significantly over time (p=0.00001). A steady rate of decline occurred in both groups throughout their running careers (p=0.004). The third (p=0.01) and fourth (p=0.0001) intervals showed significant differences between the groups as runners in the >20 group performed better than those in the 20 race group.

Amongst the age categories (Figure 3c), there were significant differences in speed (p=0.00001). Running speed decreased significantly over time (p=0.00001). A significant interaction (p=0.006) occurred between the groups over time. Between the 20-39 and 40-49 age categories, the second (p=0.02), third (p=0.01) and last (p=0.005) intervals showed that runners in the latter group had significantly slower mean running speeds than those in the former. The post hoc findings showed significant differences between the age categories 20-39 and 40-49 in the second (p=0.02), third (p=0.01) and final intervals (p=0.005).

Performance of the different medal category runners (Figure 3d) also showed significant differences (p=0.00001), with a significant decline over time (p=0.00001). A statistical significance was also seen in the medal group and time interaction (p=0.00001). Significant differences were seen in the performances across all intervals between the groups (p=0.00003). The final two intervals showed no differences between the two higher performing groups, Silver and Gold.

Average Race Running Speed

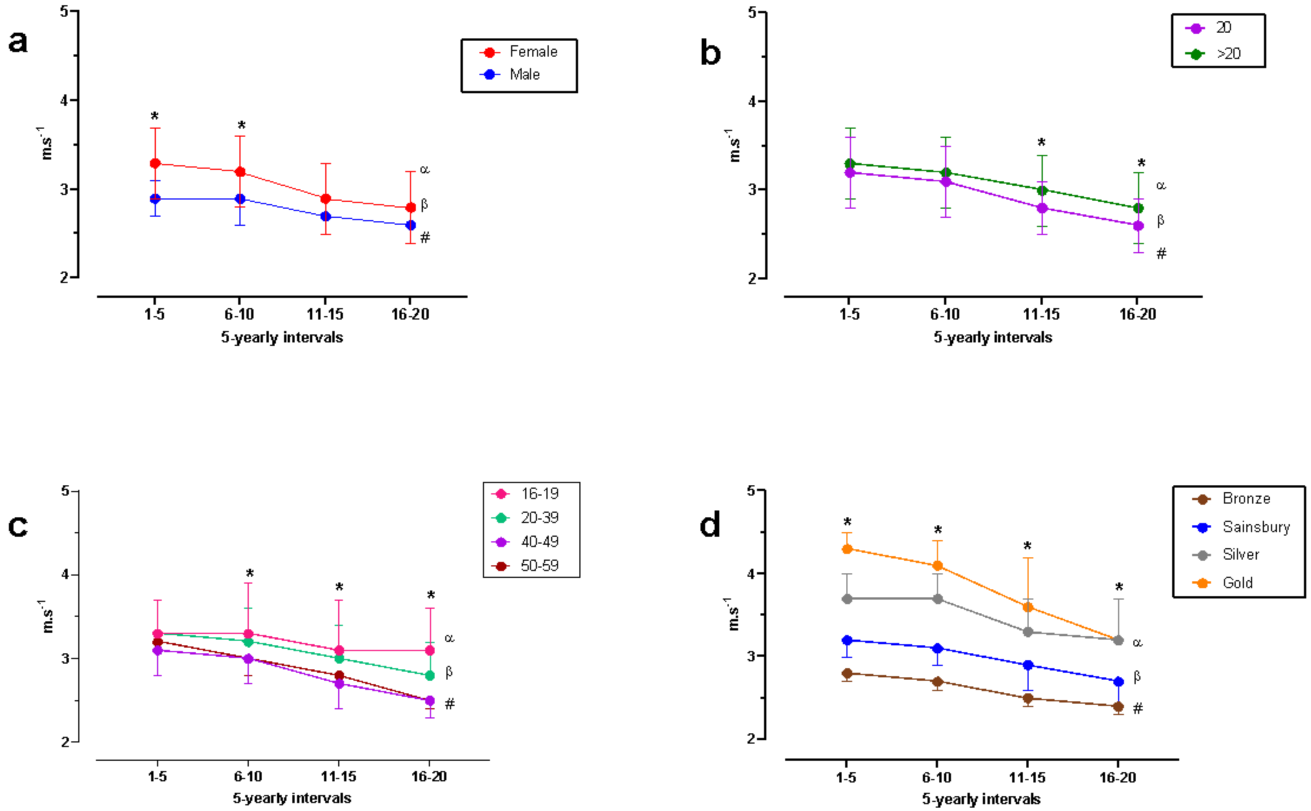

Figure 3 (a-d): Average Race Running Speed in 5-year Intervals for a 20 Year Two Oceans Ultramarathon Career. Data are presented according to grouping variables of: (a) sex, (b) number of races (20 or >20), (c) age category of debut race, and (d) medal category of peak performance. Performance is presented in running speed/pace (m.s^{-1}). Mean running speeds were compared in four 5-year intervals and recorded over 20 Two Oceans Ultramarathon events. Data are presented as mean ± SD.

Significant differences

(a) α *Main effects of group* $F_{(1,623)} = 29.2$; *p=0.00001*
β *Main effects of time* $F_{(3, 1869)} = 171.8$; *p=0.00001*
Interaction of group x time $F_{(3,1869)} = 8.7$; *p=0.00001*
* *Post hoc findings*
Males and females: interval 1 (p=0.00005) and interval 2 (p=0.003)

(b) α *Main effects of group* $F_{(1,623)} = 21.2$; *p=0.00001*
β *Main effects of time* $F_{(3, 1869)} = 660.1$; *p=0.00001*
Interaction of group x time $F_{(3, 1869)} = 4.5$; *p=0.004*
* *Post hoc findings*
20 and >20 race groups: interval 3 (p=0.01) and interval 4 (p=0.0001)

(c) α *Main effects of group* $F_{(3,621)} = 9.4$; *p=0.00001*
β *Main effects of time* $F_{(3, 1863)} = 28.5$; *p=0.00001*
Interaction of group x time $F_{(9, 1863)} = 2.6$; *p=0.006*
* *Post hoc findings*
Age categories 20-39 and 40-49: interval 2 (p=0.02), interval 3 (p=0.01) and interval 4 (p=0.005)

(d) α *Main effects of group* $F_{(3,621)} = 375.3$; *p=0.00001*
β *Main effects of time* $F_{(3, 1863)} = 274.0$; *p=0.00001*
Interaction of group x time $F_{(9, 1863)} = 20.6$; *p=0.00001*
* *Post hoc findings*
Bronze and Sainsbury medalists: intervals 1-4 (p=0.00003)
Sainsbury and Silver medalists: intervals 1-4 (p=0.00003)
Sainsbury and Gold medalists: intervals 1-3 (p=0.00003) and interval 4 (p=0.003)
Bronze and Silver medalists: intervals 1-4 (p=0.00003)
Bronze and Gold medalists: intervals 1-4 (p=0.00003)
Silver and Gold medalists: interval 1 (p=0.003) and interval 2 (p=0.02)

4.3.3 The Coefficient of Variation (CoV) for Average Race Performance

The CoV for average race performance values in Table 4 (page 53) indicate higher variability in the average pace in males in all four intervals. Values were similar for runners in the 20 and in the more than 20 groups for the first 2 intervals; thereafter, variability increased in the latter group by 2-3% when compared to the former. Runners in the 16-19 age category had the greatest variability rate, and runners in the 50-59 age category had the lowest. Bronze medalists increased variability by 0.5% from the first two to the second two 5-year intervals. The other medal categories increased their variability between 2-and 3-fold over the same intervals.

Table 4: The Coefficient of Variation (CoV) for average race performance was used to determine the variability in speed (m.s^{-1}). Data are presented according to grouping variables of: (a) sex, (b) number of races (20 or >20), (c) age category of debut race, and (d) medal category of peak performance. The variable used is average race performance.

Variable	*Category*		*Two Oceans Ultramarathon 5-race Interval*	*Coefficient of Variation (CoV) %*
Average Race Running Speed	Sex	Male (n=573)	1-5 6-10 11-15 16-20	12.1 12.5 13.8 14.3
		Female (n=52)	1-5 6-10 11-15 16-20	6.9 10.3 7.4 7.7
	Number of Two Oceans Ultramarathons completed	20 (n=175)	1-5 6-10 11-15 16-20	12.5 12.9 10.7 11.5
		>20 (n=450)	1-5 6-10 11-15 16-20	12.1 12.5 13.3 14.3
	Age category of debut race in years	16-19 (n=7)	1-5 6-10 11-15 16-20	12.1 18.2 19.4 16.1
		20-39 (n=529)	1-5 6-10 11-15 16-20	12.1 12.5 13.3 14.3
		40-49 (n=87)	1-5 6-10 11-15 16-20	9.7 10.0 11.1 8.0
		50-59 (n=2)	1-5 6-10 11-15 16-20	3.1 6.7 3.6 4.0

	Medal category of peak performance	*Bronze (n=104)*	*1-5* *6-10* *11-15* *16-20*	3.6 3.7 4.0 4.2
		Sainsbury (n=380)	1-5 6-10 11-15 16-20	6.3 6.5 10.3 11.1
		Silver (n=132)	*1-5* *6-10* *11-15* *16-20*	8.1 8.1 12.1 15.6
		Gold (n=9)	1-5 6-10 11-15 16-20	4.7 7.3 16.7 15.6

4.3.4 Peak Performance

Peak performances, the fastest finishing time within each 5-year interval measured in $m.s^{-1}$, were obtained at the second race by Silver medalists, race number three by males, runners who completed more than 20 events, age categories 20-39 and 40-49 and Sainsbury and Gold medalists and race number 4 by females and runners who completed 20 events. Silver medal runners reached their performance peak at race number 5, while athletes in the age category 50-59 reached theirs at race number 7 and those in the age category 16-19 at race number 9.

Peak performance (Figure 4a) showed significant differences between males and females in running speed throughout the 20 year running careers, analyzed in four 5-year intervals (p=0.00001). Over time, performance dropped significantly (p=0.00001), with the greatest decline occurring in the last interval. Between the groups and time, a significant interaction (p=0.00001) was established. In all four intervals, males ran a significantly faster pace than females in all four intervals (p=0.00003; p=0.0001; p=0.05 and p=0.03 respectively), with a gradual decrease in speed in both sexes.

A significant difference in running speed was found between runners in the 20 Two Oceans Ultramarathon group and those who completed more than 20 (p=0.00001) (Figure 4b). There was a significant decrease in speed over time (p=0.00001). The overall interaction over time showed no significant differences between the groups. There were significant differences in the third and fourth intervals between the two groups (p=0.02 and p=0.0006 respectively), with runners in the >20 race group outperforming the other group.

Significant differences were seen in the running speed of the different age categories (p=0.00006) (Figure 4c). An overall pattern of decline showed significant reduction in speed over time (p=0.00001). The interaction between time and the various age categories show a significant difference (p=0.009). The post hoc analysis showed significantly faster mean running speeds in the 20-39 age categories in comparison to runners in the 40-49 category in the second and third (p= 0.004) fourth interval (p=0.007).

In Figure 4d, the significant running speed variations between the medal categories was found (p=0.00001). A significant decrease in speed was seen over time in all intervals (p=0.00001). Significant interactions could be identified between time and medal category (p=0.00001). Bronze medalists had slower personal worst race paces than Sainsbury, Silver and Gold medalists in all four intervals (p=0.00003, p=0.00003 and p=0.00003). Further significant differences were seen between Sainsbury and Silver categories in all four intervals (p=0.00003), and between Sainsbury and Gold in the first and second (p=0.00003) and third intervals (p=0.0004). Further post hoc results revealed significant differences in speed between the Silver and Gold categories in the first (p=0.02) and second (p= 0.05) intervals.

Peak Performances

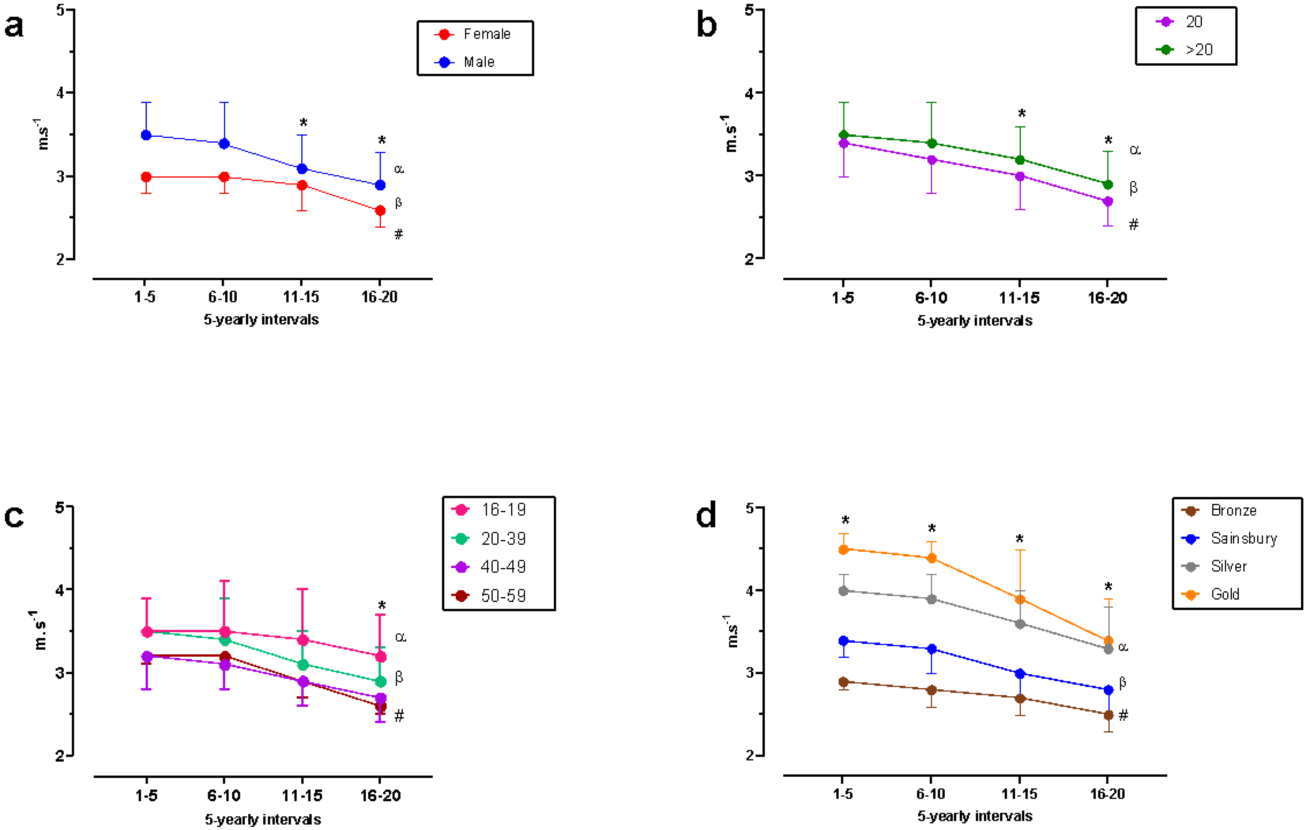

Figure 4 (a-d): Peak Performance Based on Running Speed in 5-year Intervals. Data are presented according to grouping variables of: (a) sex, (b) number of races (20 or >20), (c) age category of debut race, and (d) medal category of peak performance. Performance is presented in running speed/pace ($m.s^{-1}$). Mean race running speeds of worst performances were compared in four 5-year intervals and recorded over 20 Two Oceans Ultramarathon events. Data are presented as mean ± SD.

Significant differences

(a) α *Main effects of group* $F_{(1,623)} = 38.4$; *p=0.00001*
β *Main effects of time* $F_{(3, 1869)} = 207.4$; *p=0.00001*
 # Interaction of group x time $F_{(3, 1869)} = 10.4$; *p=0.00001*
** Post hoc findings*
Males and females: interval 3 (p=0.02) and interval 4 (p=0.0006)

(b) α *Main effects of group* $F_{(1,623)} = 20.6$; *p=0.00001*
β *Main effects of time* $F_{(3, 1869)} = 766.2$; *p=0.00001*
 # Interaction of group x time $F_{(3, 1869)} = 2.0$; *p=0.1*
** Post hoc findings*
20 and >20 race groups: interval 3 (p=0.03) and interval 4 (p=0.00007)

(c) α *Main effects of group* $F_{(3,621)} = 11.2$; *p=0.00001*
β *Main effects of time* $F_{(3, 1863)} = 30.5$; *p=0.00001*
 # Interaction of group x time $F_{(9, 1863)} = 2.5$; *p=0.009*
** Post hoc findings*
Age categories 20-39 and 40-49: interval 2 and 3 (p=0.004) and interval 4 (p=0.005)

(d) α *Main effects of group* $F_{(3,621)} = 489.1$; *p=0.00001*
β *Main effects of time* $F_{(3, 1863)} = 290.2$; *p=0.00001*
 # Interaction of group x time $F_{(9, 1863)} = 20.3$; *p=0.00001*
** Post hoc findings*
Bronze and Sainsbury medalists: intervals 1-4 (p=0.00003)
Sainsbury and Silver medalists: intervals 1-4 (p=0.00003)
Sainsbury and Gold medalists: intervals 1 and 2 (p=0.00003) and interval 3 (p=0.0004)
Bronze and Silver medalists: intervals 1-4 (p=0.00003)
Bronze and Gold medalists: intervals 1-3 (p=0.00003) and interval 4 (p= 0.00007)
Silver and Gold medalists: interval 1 (p=0.004) and interval 2 (p=0.05)

4.3.5 The Coefficient of Variation (CoV) for Peak Race Performance

The CoV value of peak performance in Table 5 (page 59) was used to measure variability in running pace. In peak performances, males showed higher values of variability in their race pace than females. Variability of running speed remained similar between the groups of runners having completed 20 or more than 20 Two Oceans Ultramarathons. Amongst the age categories, higher variability was seen in younger runners (16-19), with the lowest rates of variability in the last age category (50-59). In all four medal categories, the lowest variability in speed was in the first interval (<6%), and the highest rates were in the last interval (8-15.2%).

Table 5: The Coefficient of Variation (CoV) for peak performance was used to determine the variability in speed ($m.s^{-1}$). Data are presented according to grouping variables of: (a) sex, (b) number of races (20 or >20), (c) age category of debut race, and (d) medal category of peak performance. The variable used is peak performance.

Variable	Category		Two Oceans Ultramarathon 5-year Interval	Coefficient of Variation (CoV) %
Peak Performance	Sex	Male (n=573)	1-5	11.4
			6-10	14.7
			11-15	12.9
			16-20	13.8
		Female (n=52)	1-5	6.7
			6-10	6.7
			11-15	10.3
			16-20	7.7
	Number of Two Oceans Ultramarathons completed	20 (n=175)	1-5	11.8
			6-10	12.5
			11-15	13.3
			16-20	11.1
		>20 (n=450)	1-5	11.4
			6-10	14.7
			11-15	12.5
			16-20	13.8
	Age category of debut race	16-19 (n=7)	1-5	11.4
			6-10	17.1
			11-15	17.6
			16-20	15.6
		20-39 (n=529)	1-5	11.4
			6-10	14.7
			11-15	12.9
			16-20	13.8
		40-49 (n=87)	1-5	12.5
			6-10	9.7
			11-15	10.3
			16-20	11.1
		50-59 (n=2)	1-5	3.1
			6-10	3.1
			11-15	6.9
			16-20	3.8

	Medal category of peak performance	Bronze (n=104)	1-5 6-10 11-15 16-20	3.4 7.1 7.4 8.0
		Sainsbury (n=380)	1-5 6-10 11-15 16-20	5.9 9.1 10.0 10.7
		Silver (n=132)	1-5 6-10 11-15 16-20	5.0 7.7 11.1 15.2
		Gold (n=9)	1-5 6-10 11-15 16-20	4.4 4.5 15.4 14.7

4.3.6 Worst Performance

Worst performance was defined as the slowest finishing time in $m.s^{-1}$ of a runners' Two Oceans Ultramarathon race career. These were seen in the last Two Oceans Ultramarathon completed, race number 20, by participants of all groups except for the age category 50-59, who ran their slowest finishing time in race number 18.

As seen in Figure 5a, males and females showed significant differences in their worst performance (p=0.00001). Over time, running speed, measured in $m.s^{-1}$, was reduced significantly (p=0.00001). The interaction of both sex groups and time was also significant (p=0.00001); post hoc tests showed that females ran significantly slower than males in the first interval (p=0.004). The performance of both groups declines equally and gradually over the next three intervals.

In the groups of 20 or more than 20 Two Oceans Ultramarathons (Figure 5b), the former ran significantly slower than the latter (p=0.00002). There was a significant decrease in speed over time (p=0.00001). The group interaction over time showed significant changes in speed (p=0.0002). The final two intervals showed significantly slower paces in runners who completed 20 races in comparison to those who completed more than 20 (p=0.03 and p=0.00007 respectively).

Running speed of the different age categories (Figure 5c) varied significantly (p=0.00006). Significantly slower running speeds were identified with each subsequent interval (p=0.00001). There was also significance in the interaction between time and the various age categories (p=0.004). A significant difference between the age category of 20-39 and that of 40-49 was seen in the last interval (p=0.005) as the performance gap increased in the final interval.

There was also a significant difference in running speed between the medal categories (p=0.00001) (Figure 5d). A significant decrease in speed was seen over time, specifically between the second and third intervals (p=0.00001). Significant interactions between time and medal category were also established (p=0.00001). Bronze medalists ran significantly slower in all four intervals when compared to Sainsbury, Silver and Gold medal category runners (p=0.00003; p=0.00003 and p=0.00003 respectively). Silver medalists had significantly slower running speeds than the Gold medalists in the first interval (p=0.02).

Worst Performances

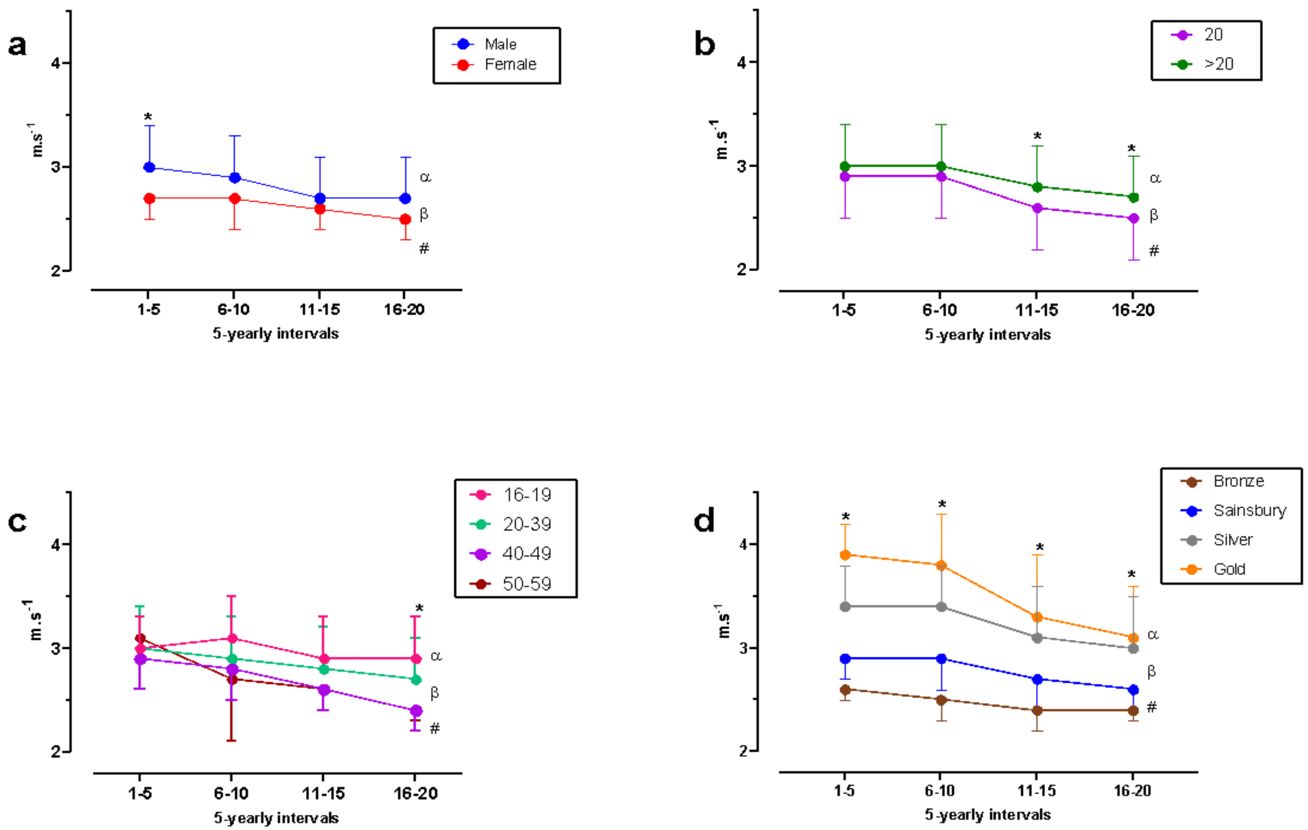

Figure 5 (a-d): Worst Performance Based on Running Speed in 5-year Intervals. Data are presented according to grouping variables of: (a) sex, (b) number of races (20 or >20), (c) age category of debut race, and (d) medal category of peak performance. Performance is presented in running speed/pace ($m.s^{-1}$). Mean race running speeds were compared in four 5-year intervals and recorded over 20 Two Oceans Ultramarathon events. Data are presented as mean ± SD.

Significant differences

(a) α *Main effects of group* $F_{(1,623)} = 19.0$; $p=0.00001$
β *Main effects of time* $F_{(3, 1869)} = 79.1$; $p=0.00001$
Interaction of group x time $F_{(3, 1869)} = 2.7$; $p=0.05$
* *Post hoc findings*
Males and females: interval 1 (p=0.004)

(b) α *Main effects of group* $F_{(1,623)} = 18.9$; $p=0.00002$
β *Main effects of time* $F_{(3, 1869)} = 302.8$; $p=0.00001$
Interaction of group x time $F_{(3, 1869)} = 6.5$; $p=0.0002$
* *Post hoc findings*
20 and >20 race groups: interval 3 (p=0.03) and interval 4 (p=0.00007)

(c) α *Main effects of group* $F_{(3,621)} = 7.5$; $p=0.00006$
β *Main effects of time* $F_{(3, 1863)} = 15.0$; $p=0.00001$
Interaction of group x time $F_{(9, 1863)} = 2.7$; $p=0.004$
* *Post hoc findings*
Age categories 20-39 and 40-49: interval 4 (p=0.005)

(d) α *Main effects of group* $F_{(3,621)} = 240.8$; $p=0.00001$
β *Main effects of time* $F_{(3, 1863)} = 127.0$; $p=0.00001$
Interaction of group x time $F_{(9, 1863)} = 8.5$; $p=0.00001$
* *Post hoc findings*
Bronze and Sainsbury medalists: intervals 1-4 (p=0.00003)
Sainsbury and Silver medalists: intervals 1-4 (p=0.00003)
Sainsbury and Gold medalists: intervals 1 and 2 (p=0.00003) and interval 3 (p=0.0004)
Bronze and Silver medalists: intervals 1-4 (p=0.00003)
Bronze and Gold medalists: intervals 1-3 (p=0.00003) and interval 4 (p= 0.00007)
Silver and Gold medalists: interval 1 (p=0.02)

4.3.7 The Coefficient of Variation (CoV) for Worst Performance

The CoV values for worst performances shown in Table 6 (page 65) showed more variability than the peak performance values, again with higher values amongst males than females. Runners in the 20 Two Oceans Ultramarathon group had approximately 0.5% for the first two and 1% for the last two intervals higher variability rates than those who ran more than 20 races. The age category of 20-39 had higher variability rates than the other age categories, with runners in the 50-59 group having the lowest rates. An exception was evident in the 6-10 race section, where the 50-59 group had the highest variability. This may be due to the small sample size of the group. In the medal categories, the least amount of variability in pace was seen in the Bronze category.

Table 6: The Coefficient of Variation (CoV) for worst performance was used to determine the variability in speed (m.s^{-1}). Data are presented according to grouping variables of: (a) sex, (b) number of races (20 or >20), (c) age category of debut race, and (d) medal category of peak performance. The variable used is worst performance.

Variable	Category		Two Oceans Ultramarathon 5-year Interval	Coefficient of Variation (CoV) %
Worst Performance	Sex	Male (n=573)	1-5 6-10 11-15 16-20	13.3 13.8 14.8 14.8
		Female (n=52)	1-5 6-10 11-15 16-20	7.4 11.1 7.7 8.0
	Number of Two Oceans Ultramarathons completed	20 (n=175)	1-5 6-10 11-15 16-20	13.8 13.8 15.4 16.0
		>20 (n=450)	1-5 6-10 11-15 16-20	13.3 13.3 14.3 14.8
	Age category of debut race	16-19 (n=7)	1-5 6-10 11-15 16-20	10.0 12.9 13.8 13.8
		20-39 (n=529)	1-5 6-10 11-15 16-20	13.3 13.8 14.3 14.8
		40-49 (n=87)	1-5 6-10 11-15 16-20	10.3 10.7 7.7 8.3
		50-59 (n=2)	1-5 6-10 11-15 16-20	3.2 22.2 7.7 4.2

	Medal category of peak performance	Bronze (n=104)	1-5 6-10 11-15 16-20	3.8 8.0 8.3 4.2
		Sainsbury (n=380)	1-5 6-10 11-15 16-20	6.9 10.3 11.1 11.5
		Silver (n=132)	1-5 6-10 11-15 16-20	11.8 11.8 16.1 16.7
		Gold (n=9)	1-5 6-10 11-15 16-20	7.7 13.2 18.2 16.1

4.3.8 Pattern of Performance Improvement/Decline

As seen in Figure 6a, the changes in running speed between males and females (p=0.00001) and over time (p=0.00001) were significant, with the greatest change occurring between the third and fourth intervals. The interaction between sex and time was also significant (p=0.02). In the first and second intervals, there were significant differences in the change in running speed between males and females (p=0.0008 and p=0.008), indicating a more gradual change in race pace amongst males. Over the last two intervals, both groups reduced their running speed consistently.

A significant change in speed between the groups of 20 and more than 20 Two Oceans Ultramarathons was identified (p=0.03) (Figure 6b). Over time, the delta in speed was also significantly different (p=0.00001). There was no statistical significance in running speed change between the two groups over time.

The age categories (Figure 6c) had significant changes in speed (p=0.0001) as all groups became slower with each interval. The results also showed significant changes over time (p=0.0006). The group and time interaction also showed significant differences in the change in pace between the intervals (p=0.01). Post hoc analyses showed no significant changes in running speed between the groups across the four intervals.

Amongst the four medal categories (Figure 6d), the change in speed as well as the changes over time were significant (p=0.00001 and p=0.00001). Significant changes in pace between the groups and time also yielded significant differences (p=0.00001). Bronze medalists had significantly greater deltas in running speed when compared to Sainsbury and Silver medal runners (p=0.00003 and p=0.00003). There was also a significant difference in the deltas between Sainsbury and Silver medalists as the latter group showed a faster rate of decline than the former (p=0.00003).

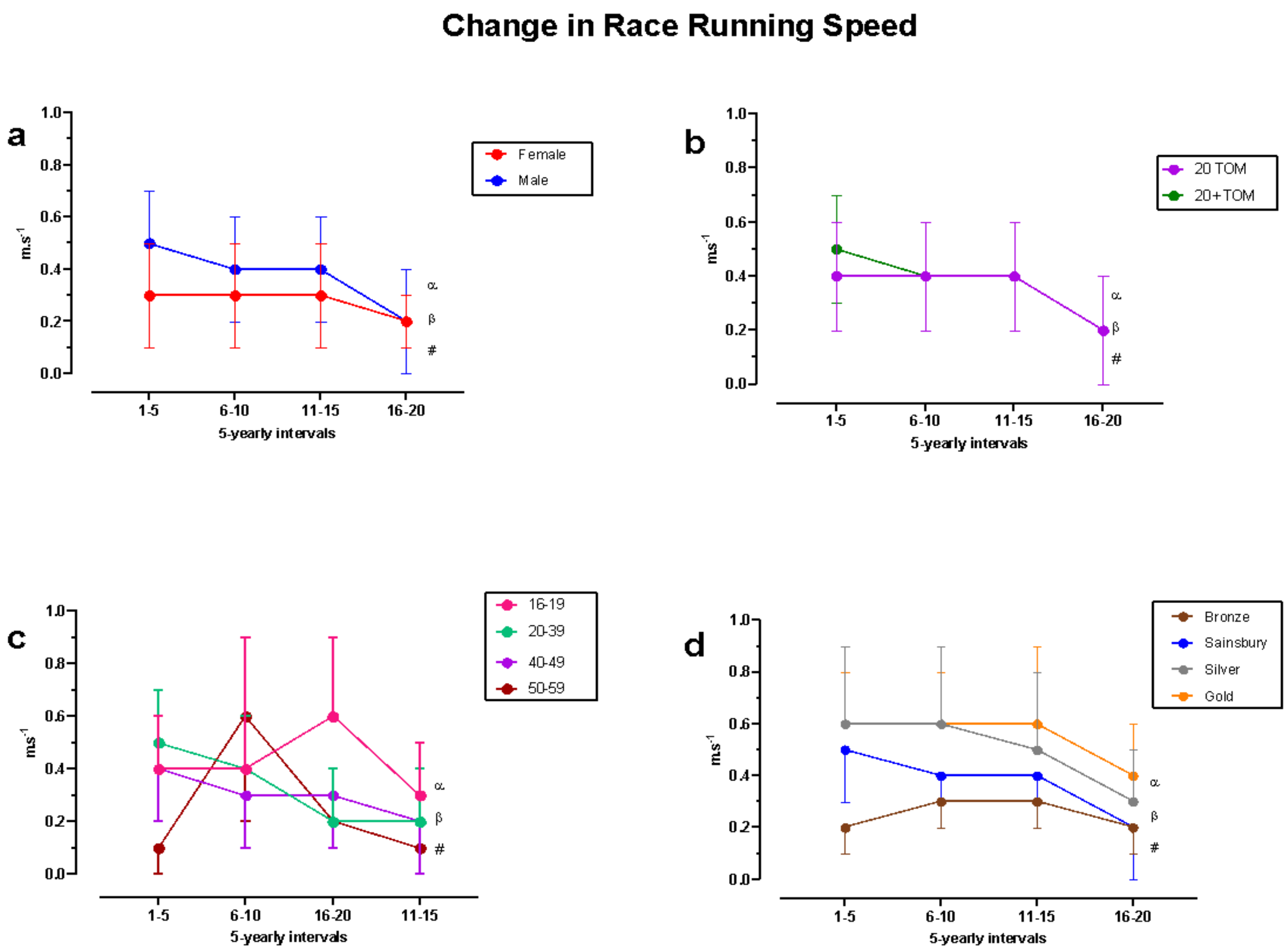

Figure 6 (a-d): Changes in Race Performance Based on Running Speed in 5-year Intervals. Data are presented according to grouping variables of: (a) sex, (b) number of races (20 or >20), (c) age category of debut race, and (d) medal category of peak performance. Change (delta) in performance is presented in running speed/pace ($m.s^{-1}$). Mean race running speeds were compared in four 5-year intervals and recorded over 20 Two Oceans Ultramarathon events. Data are presented as mean ± SD.

Significant differences:

(a) α *Main effects of group* $F_{(1,623)} = 43.5$; *p=0.00001*
β *Main effects of time* $F_{(3, 1869)} = 40.2$; *p=0.00001*
Interaction of group x time $F_{(3, 1869)} = 3.4$; *p=0.02*
* *Post hoc findings*
Males and females: interval 1 (p=0.0008) and interval 2 (p=0.008)

(b): α *Main effects of group* $F_{(1,623)} = 4.8$; *p=0.03*
β *Main effects of time* $F_{(3, 1869)} = 129.3$; *p=0.00001*
Interaction of group x time $F_{(3, 1869)} = 2.1$; *p=0.1*

(c): α *Main effects of group* $F_{(3,621)} = 7.0$; *p=0.0001*
β *Main effects of time* $F_{(3, 1863)} = 5.8$; *p=0.0006*
Interaction of group x time $F_{(9, 1863)} = 2.3$; *p=0.01*

(d): α *Main effects of group* $F_{(3,621)} = 11201$; *p=0.00001*
β *Main effects of time* $F_{(3, 1863)} = 34.2$; *p=0.00001*
Interaction of group x time $F_{(9, 1863)} = 5.6$; *p=0.00001*

4.3.9 Summary

In summary, the general trend of the results over a 20-year period was analysed and showed that finishing times, measured in minutes, increased as performance and running speed decreased. This trend was evident in all the groups. The subsequent sections, namely average, peak and worst performances, were examined in four 5-year intervals, and the unit of measurement used was $m.s^{-1}$. Average race performance followed a similar trend as that of the 20 year running career period. It was identified that for most groups, the peak performances occurred within the first five years of race participation. Thereafter, a steady decline in running speed followed until the last race included in the running career timeframe of this study. Worst performances showed that all groups had their slowest finishing times at the end of their 20 Two Oceans Ultramarathon running careers. The last measurement of performance analysed was the change in race pace. The results revealed that the greatest rate of change occurred in the last interval of the timeframe examined.

CHAPTER 5: DISCUSSION, SIGNIFICANCE AND RECOMMENDATIONS

5.1 Discussion

5.1.1 Descriptive Characteristics of Seasoned Two Oceans Ultramarathon Runners

A finding in line with previous research was that the majority of participants who qualified for this study in terms of number of races completed were male (Section 4.1, page 39). This finding is consistent with other literature on demographical data of ultramarathon runners [109, 123]. However, some studies have confirmed that the increase of female participation has outweighed that of males in the last decade [3, 124]. This has reduced the male-to-female ratio of ultramarathon running participation [125]. As suggested by Ronkainen and colleagues [97], a possible reason affecting the proportionally lower female participation relates to the prevailing notions of the incompatibility of motherhood and endurance sport. Although temporarily, pregnancy limits the ability to participate in regular long-distance running training and racing. Furthermore, a study has shown that after having children, mothers are frequently discouraged from taking part in time consuming training regimes due to feelings of guilt [126]. Many of the studies concerned with motherhood and athletic identity have used qualitative research methods to explore the topic [127, 128]. Additional quantitative data on this topic is essential for more conclusive interpretations. Another suggested reason for the still remaining higher male participation in endurance running could be that females are at higher risk of RED-S (relative energy deficiency in sport) [84]. Lower body weight is considered favourable in running, which results in both sexes being exposed to the risks of impaired physiological function associated with RED-S. However, it appears that females are at higher risk of lower bone mineral density and subsequent risk of injury [84, 129].

Approximately three-quarters of the participants in the present study completed more than 20 Two Oceans Ultramarathon events. Possible motivations for commitment to lifelong running careers may be attributed to two key factors: The physical ability for, and the mental satisfaction gained from ongoing participation [13, 15]. The first factor requires the athlete to have physical competency to run the distance of an ultramarathon. It is well established that a naturally occurring age-related decline affects physical performance of master runners [4, 116]. This knowledge suggests that reasons other than performance encourage athletes to continuously participate in these events. Despite a lower capacity for net improvement, master runners have superior pacing strategies, an ability linked to longevity of running careers [27, 101, 109]. With experience, consistency in training and repetitive racing, these runners apply the principles of teleoanticipation and are likely to successfully complete an event [73, 102]. A key component highlighted in the literature on long-term participation in distance running is the importance of remaining injury free.

Ongoing participation can be dictated by the physiological biomarkers found to have an effect on the body as the result of extended running periods, as well as the physical effects of EIMD and RRI's due to training and racing [18, 71, 108]. Although most runners may sustain injuries at some point in their running careers, it is suggested that the altered biomechanics of master runners, including a generally slower pace and reduced muscle power, reduces injury risk [4].

The second factor relates to the mental commitment and emotional benefits achieved from endurance running. Although master runners are often no longer at their personal performance peak, their participation in ultramarathons has been associated with consistency, reduced injury incidence and greater overall experience due to less emotional pressure [4, 97, 98, 130]. The literature has found that a personal sense of achievement outweighs the desire to reach performance targets, and participation on a recurring basis is a key motivation in taking part in these events.

5.1.2 Race History over 20 Years of Two Oceans Ultramarathon Running

A key finding of this study was that all groups displayed a clear initial performance improvement from the first to approximately the fifth race (Section 4.3.1, page 46). Most personal best achievements were acquired in this first quarter of the 20-year running period. Runners then plateaued in their performance up until about their tenth race, after which a gradual decline continued until the point of running career termination. In their study on the effects of aging on running performance, Rae and colleagues [27] also showed that approximately four years of training and racing were required to reach peak performance. The authors also revealed that all participants in their study, irrespective of age, were unable maintain their peak running speed for more than a few years. This finding is also reflected in the results of the present paper. Rae and colleagues [27] concluded that the combination of chronological aging and ultramarathon training were neither found to impede nor improve overall performance in the participants of their study. The multifactorial concept of performance over time is one many authors have explored, with several trends emerging: a) performance related physiological characteristics, such as maximum oxygen absorption and muscle strength, seem to decrease with advancing age; b) older runners employ better pacing strategies; c) a greater number of completed races yields improved finishing times; and d) the age of peak performances seems to increase with a greater number of finishes [101, 131-133].

Overall, the 20-year running history performance trends did not show convergence towards the end of this time period. This finding indicates that the groups compared have not reached an end point in their performances, and the mean length of an ultramarathon career has not been defined. Whether related to physical ability, cut-off times or other reasons, the Two Oceans Ultramarathon careers continue to progress in a gradually declining pattern without major deviations in the this trend.

While many studies have focused on the history of ultramarathon participation [12, 124, 133], there is no literature available on the mean length of an ultramarathon running career. This would require a point of termination, a finding that could yield valuable information for future studies. Hence, additional research extending the timeframe of these running careers could be warranted. Furthermore, prospective studies would add value to the understanding of whether participants are still taking part in other ultramarathons or shorter race distances.

From the results of the medal category section, it is evident that the higher performing groups, particularly the Gold medalists, had a greater extent of decline over 20 years of running. Presumably, the capability to perform better in the earlier stages of their running careers may allow these athletes to reduce their speed to larger degrees without compromising on relative performance. This could be due to the physiological inability to maintain a certain level of performance, or due to less psychological pressure experienced by older athletes, or a combination of both [95]. When comparing this trend to other medal categories, these too show reduced race finishing times but at a more gradual rate.

Breen and colleagues observed pacing and performance of master runners in a marathon [101]. The authors concluded that higher performance levels were correlated with lower variations in finishing time and pace. This was found to be true in the present study in that the lowest variation in average running performance over 20 years was found in the higher performing athletes. However, it needs to be noted that direct comparisons may not be applicable due to subtle differences in the methodology of the studies. Firstly, the paper by Breen and colleagues [101] compared athletes in a single event for variability, whereas the current study analysed multiple events over time. A second difference is that in the section on performance variation, our paper used the delta in race pace to analyse change in performance. The study by Breen and co-authors used the finishing time data to identify trends. It is evident that there is a significant difference when comparing pacing within a race and race pace strategies employed in consecutive races over time. Research on intra-race pacing strategies reveal important information on singular performances [101, 132]. They do however lack crucial insight into performance trends that occur as time, age and experience of the runners' progress. Investigating patterns over several years or events is essential when wanting to identify how a change within pacing is influenced by chronological aging. More research is warranted into how pacing within a race differs from pacing strategies over several races.

5.1.3 Average Race Performance

In Section 4.3.2 (page 49), the mean race performance of the different groups was highlighted. A key difference between the male and female groups was that females displayed a rapid time-related decline in their performance. Males on the other hand showed a more gradual performance decline over the same period. This pattern is more evident in the first half of the 20 year running period. Mean running speeds appeared to equalise somewhat in the second half, where differences in speed were smaller. This trend could suggest the narrowing of the performance gap between the two sexes, a phenomenon frequently discussed in the literature [119, 123, 134, 135]. The male-female performance gap referred to is in part the outcome of a longer ultramarathon participation and race history in males. Other contributing factors proposed by some authors include superior physiological capacities in males when compared to females as well as differing personal motivations [123, 134]. Waldvogel and colleagues [130] investigated performance trends between males and females specifically in ultramarathon running. The authors concluded that advancing age and distance were both factors that reduced the performance differences between the sexes. Another study confirmed the findings on smaller gaps with further race distances [136]. However, the authors theorized that this narrowing seen between the years 1980 and 2010 has reached a plateau. In their paper, it was apparent that both males and females seemed to improve their performances at the same rate in all distances investigated, the furthest of which was the marathon. Contemporary studies are currently investigating performance of female ultramarathon runners, and findings will provide further insight into this field of research [120, 124].

In the present study, data on the average performance of the age categories, who were categorized according to their debut race, were compared in terms of speed. A systematic decline in performance with advancing age was identified. A decline in mean performance was evident in all groups, however, it was noteworthy that the rate of decline was more gradual amongst the younger athletes (particularly group 16-19, but also group 20-39) with a steeper decline in the age categories 40-49 and 50-59. Findings in literature on performance and the impact of advancing age have been consistent with these of our study [14]. In their paper, Lepers and colleagues explain how the interaction between various physiological factors plays a role in the reduced performance capacities of aging athletes. According to Knechtle and colleagues [34], the physiological changes occurring from the age of 50 years contribute to this accelerated rate of decline [34]. Underlying mechanisms include a decrease in maximal oxygen consumption and muscle strength. Even though it has been argued that lifelong participation in running reduces age-related physiological decrements, these can never be entirely eliminated [27]. The impact of chronological aging can be slowed with endurance exercise participation, but the physical performance declines are inevitable.

In our paper, the results on mean speeds of runners, categorised according to their personal best finishing time (medal category), also followed the trend of an overall performance decline over time. This decline appeared to occur significantly faster in the top performing athletes. A suggested explanation for this observation is that these top performing master runners may experience less self-imposed pressure to complete the race before a cut-off time. They have a greater margin of race time and therefore have more freedom when it comes to timeous race completion. This observation needs to be interpreted with caution, as there is a lack of evidence in the research to support this. On the contrary, there appears to be well-established evidence supporting the notion that higher performing athletes show less variability in performance [132]. The authors found superior pace control in faster athletes within the race analysed. The current paper showed significantly faster rates of performance decline amongst Gold and Silver medalists; however, this can again be attributed to the intra- versus inter-race performance of the two studies at hand. It is therefore not feasible to draw direct comparisons between the results of these studies. Rather, a follow up study looking at data available on splits and pacing within a race could be conducted and compared with pacing strategies over several races.

5.1.4 Peak Performance

Peak performance (also referred to as personal best performance), is a universally accepted measure of accomplishment in sport. Factors that may have an influence on this achievement have been described and analysed in the literature [121, 125, 137]. Many of these studies have focused on the parameters of the race during which such peak performances are reached, which include age, running pace, training and physiological factors. While crucial considerations such as injury and training histories are beyond the scope of the present paper, this study examined the context within a running career that may influence peak running performance.

Peak performances in the Two Oceans Ultramarathon (Section 4.3.4, page 55) occurred within the first five years of the participants' running careers for most of the groups compared, a finding that was consistent with those by Rae and colleagues [27]. Exceptions were seen in the age categories 50-59 and 16-19, who attained their peak race finishing times at race numbers 7 and 9 respectively. Both of these groups had significantly smaller samples, which could be a reason for the outlying results. This finding reiterates what other studies have previously identified, namely that athletes tend to perform better in endurance events when they are older or have had considerable experience [26, 116]. More specifically, runners in the youngest age category presumably reach their optimal physical capabilities after several years of participation while the oldest of the athletes have the lowest values of speed variability, a finding consistent with that by Breen and colleagues [101]. Therefore, it is believed that master runners are able to reach performance peaks at various stages of their careers.

Another trend that was identified in these results was the inability of runners to maintain peak running capacities for more than a few years. This finding was consistent with those by Rae and colleagues [27] who looked at performance over a ten year ultramarathon running period. The results of the study established a declining pattern in speed over time, with a greater degree of change amongst younger athletes when compared to older ones. It is possible that the proposed age of peak performance identified by the authors, approximately 35 years, coincides with optimal experience and training volume as well as favourably adapted endurance physiology [44]. This particular age would also appear to be before the age-related decline and subsequent performance decrements begin, which some authors have speculated occurs from the age of 50 [4]. Therefore, performance peaks would likely occur between these two points of a running career, a timeframe which is finite and therefore does not allow for extended performance peak periods.

5.1.5 Worst Performance

The section on worst performance (Section 4.3.6, page 61) looked at the slowest speed across the 20 year running careers. In most groups, the worst performance was race number 20. One exception was the oldest of the age categories, runners of 50-59 years of age, where race number 18 was the slowest. The small size of the sample may have had an effect on this outcome, and conclusive interpretations cannot be made. The most evident result from this section is the overall trend of a progressive performance decline over time, and therefore most runners' worst race time occurs at the end of the 20 year running period. As 250 of the participants still completed the most recent event in 2019, the end point of their running careers is not definite, and races beyond the 20 year cut-off were not included in the analyses. However, the trajectory appears to indicate a downtrend with the slowest race performance at the last event completed.

There is limited available research on worst performances in a running career. One hypothesis proposed by Schwabe and colleagues [26] regarding the pattern of decline includes higher medical risk factors with slower running pace, as is evident in later stages of seasoned running careers. In their paper on risk factors for medical complications occurring during the Two Oceans Ultramarathon, the authors concluded that the slower runners (running >7 minutes/kilometer, or 2.4 $m.s^{-1}$) were at more risk that those running intermediate running speeds. Another study found the altered biomechanics in older, slower runners to be risk factors for injury [18]. Over and above these additional risks, slower athletes also experience the pressure of race cut-off times. The maximum capacity of some participants may be close to the minimum pace required to successfully complete the even before cut-off. When this time is exceeded, participants no longer qualify for an official finishing time.

The physical and psychological strain experienced by these runners may contribute to the termination of their running careers when they are unable to compete at a certain speed.

The results of our paper show a fairly equal decline in performance identified in both sexes. There is some evidence of a narrowing in the performance gap between the two groups, a phenomenon discussed in a previous section. The worst performance results show a pattern of convergence towards the end of the running career period, where the difference in speed between males and females is reduced. Another significant finding in this section is the lack of decline in the mean worst performances over time in the youngest age category, 16-19. This could be due to the fact that after 20 years of race participation, the age of these individuals may be coinciding with the performance plateau of their running careers. The age-associated performance decline affects the runners that are older at their debut race at an earlier point in their careers. Knechtle and colleagues [34] argue that competitive drive and achievement encourage younger runners to perform at a certain level. With increasing age, social interaction and enjoyment were found to be the most important motivators for running.

5.1.6 Pattern of Improvement or Decline

In our study, patterns of improvement or decline over time (Section 4.3.8, page 64) were analyzed by the variability in running speed measured over the 20 year period. Previous studies have focused on the variability of pacing within a single race, and how speed can be influenced by extraneous factors or have an impact on physiological homeostasis [26, 138]. By monitoring the change in running speed over four 5-year intervals in each of the groups, key trends related to the aging process could be established. The naturally occurring age-related decline in performance has commonly been attributed to physiological changes [105]. Changes in running economy, heart rate and stroke volume, muscle fibre type and maximal oxygen consumption have been shown to inevitably occur in the aging athlete [34]. The impact of reductions in training volume and intensity, which was found to be a major contributing factor to race pace reduction over an extended period [44]. Tanaka and colleagues [107] investigated endurance capacities in master runners and how physiological changes occurring with age impact performance. Time constraints, an increase in injury prevalence and less competitive drive all contributed to lower athletic performance.

In the different categories compared, a trend of convergence in the last interval was recognised. This showed smaller changes in running speed. These lower values in race pace changes towards the end of the 20 year running period could suggest reduced physical capacity, or a plateauing of performance, for increases in performance with advancing age [27].

The comparison between males and females made in the present study shows that final interval yielded the most significant decreases in the rate of running speed decline. Females showed superior ability to maintain the same pace for longer; no rate of change was evident across the first three intervals. Previous literature found that with advancing age, the sex difference in running velocity increased [123, 124]. The studies used association analyses to conclude that the lower number of female participants contributed to this outcome. Hence, the authors indicate that as female participation in ultramarathon events rises, the differences in speed is expected to be reduced. The approach of the present study differed from that of the above mentioned papers in that the rate of performance decline was analysed, rather than the unit measurement of performance. While the previous sections on performance showed various differences between the groups, the rate of change in running speed appeared to show less variability. Due to a lack of research on this specific performance parameter, meaningful conclusions cannot be made.

The groups of runners of 20 or more than 20 races showed no differences in the performance changes, with exception of a minor difference in the variability rate in the first interval. Thereafter, the race pace of both groups deteriorated at an equal rate. In their paper, Nikolaidis and Knechtle [139] confirmed the finding of the present study, namely that those who had more overall running experience had superior ability to maintain running paces over time.

The results of the age category section showed the greatest amount of variability in the rate of running speed change, particularly in the youngest and oldest age categories (16-19 and 50-59). While this observation may be attributed to the differences in the sample sizes of all the age categories, there may be other contributing factors. Even though there are small variations in the rate of change, the final interval shows least amount of variability. The present paper results are in accordance with a study on pacing strategies amongst differently aged runners [139]. The authors described how more running experience has been associated with less variability in pacing and thereby less change in race performance. Nikolaidis and Knechtle defined experienced runners as either faster runners due to more training at higher intensities, or older runners who have completed several ultramarathons [132].

The data on different medal categories from this study show small changes in variability of race pace in the first and last intervals, with a stable plateau evident in the middle of the Two Oceans Ultramarathon careers. All medal groups showed the greatest rate of decline from the third to the last interval. A previous study examining pacing variability in distance runners found that slower runners had higher variability in running speed [138]. The authors hypothesized that the reasons for this finding may be that faster runners are able to negotiate their own levels of fatigue better than slower runners. Superior neurophysiological capacity in faster athletes is suggested to be a key contributing factor [100].

When considering performance within a single race, Nikolaidis and colleagues [139] suggested that slower runners display larger changes in speed, possibly due to less training, poorer pacing strategies and frequent walking intervals. It needs to be emphasized that the field of knowledge on pacing is very complex. Different methods and research approaches would lead to different conclusions that may or may not be relevant to one another. On the one hand, inter-race pacing strategies using splits or tracking devices could be used to gain in-depth understanding on performance of a race. Factors which have been beyond the scope of this paper, such as nutrition during the race, injury histories or environmental factors, could be included for imperative insight [103]. On the other hand, future research focusing on intra-race pacing strategies could aid the understanding of how race pace changes across several races. It may also have an impact on performance, the point of reaching a peak within a running career and perhaps assist in predicting for running career longevity.

5.2 Significance of Study

Few studies have looked at performance and participation trends of ultramarathon runners taking part repetitively in the same event, and used the data to underline the significance seen in performance patterns over time. While the age of peak performance has been extensively explored, the point within a career timeframe has thus far not been the focus of many studies thus far [133]. Our study is descriptive in nature and therefore the aim was to identify any trends in pace and performance throughout a runner's Two Oceans Ultramarathon career. By determining these trends, the parameters affecting the performance over several years of participation could contribute to the understanding of lifelong participation in ultramarathon events. The present study is unique in that it looks exclusively at experienced master runners who have committed to participating in 20 or more Two Oceans Ultramarathon races.

5.3 Limitations and Recommendations

Participation trends can be more thoroughly explored by addressing certain characteristics in more details, such as the gaps in participation, where runners did not take part in consecutive races. The sample of this study was specifically selected due to the number of races completed; a minimum of 20 Two Oceans Ultramarathons was the main inclusion criterion for the purposes of this paper. There may be reasons why fewer or more races could be more appropriate for other parameters of research. In an attempt to attain a fair reflection of average race performance, it was essential to include all these participants. However, a smaller cohort to match the groups according to size could serve the purpose of extracting more detail from each specific group. Furthermore, our paper only uses publicly available data to assess the link between a seasoned runner and performance trends for this specific race. This allows a broad understanding of the topic. However, opportunity for a deeper understanding of motivation, nutrition, training, injury profile or physiological adaptations to this sport could be further explored. Because the study was retrospective, the lack of personal information on the website did not allow for the establishing of certain important performance parameters. As there was no direct interaction or contact with the runners, important factors that may contribute to a successful long-term running career, such as training and injury profiles, could not be considered.

The sampling technique used in the present study was stratified convenience sampling. As a result, the unequal sizes of the groups could have an impact on the interaction between the groups. The groups of the present study were not directly matched with one another in terms of sample size and participant specifics, resulting in potential biases. Future studies addressing these discrepancies may yield significant value, and opportunities for future research in the field could continue to build on, and expand from, the foundations of this study.

CHAPTER 6: SUMMARY AND CONCLUSION

Identification of various trends in performance over time in ultramarathon running careers holds value in determining factors which could enhance or inhibit successful longevity of participation in the sport [17, 43]. The recent rise in ultramarathon participation of master runners has motivated research into the unique attributes of this group. Pacing strategies and performance trends have been investigated extensively within a single race, but there has been little research available in long-term performance trends. Therefore, the aim of this study to identify performance trends in seasoned runners across their Two Oceans Ultramarathon running careers.

The objectives of the study, as described in Section 1.2.2 (page 15) were addressed as follows:

To describe the profile of seasoned ultramarathon runners who have completed 20 or more Two Oceans Ultramarathon races, including sex, number of ultramarathons completed, medal category of peak performance and age at debut Two Oceans Ultramarathon

The participants of this study were categorised according to their sex, number of ultramarathons completed, age categories of their debut race and medal categories of their peak performance. Race profiles of these seasoned athletes were analysed according to finishing times as well as race paces within these groups.

To determine average performance, peak performance, worst performance and the pattern of improvement or decline in performance in seasoned ultramarathon runners over 20 Ultramarathon races participated in

Data on average, peak and worst performances were analysed, and patterns of improvement or decline over the 20 year Two Oceans Ultramarathon running careers were established. The literature consulted explored the compounding impact of chronological aging, and the changes that were seen in our study have also been previously identified [14, 27, 105]. The assumption was made that the interaction of age-related changes over time with the physical impact of long-term distance running, as found in several previous studies, had an influence on the performance patterns of our study. A key finding of this study was that the different performances measured were superior in runners who had longer average running careers. Furthermore, the faster medal category groups showed greater variability in running speed, and thus in overall performance, than the slower groups. The differences in the sample sizes of the groups could have an influence on these findings, which therefore need to be interpreted with caution.

An overall decline in performance over time was identified across all groups; however, the rate of performance decline was greater in males, in runners who completed their running careers after their 20th race, in runners in the older age categories as well as in the faster runners. Although our findings do not correlate with some of those of past studies, differences could be accounted for on basis of subtle variations in study objectives [132, 137]. This is only one explanation for these findings, and potential others include different methods or different data collection processes used.

To determine differences in factors that may influence performance trends, such as sex, number of ultramarathons completed, medal category of peak performance and age at debut Two Oceans Ultramarathon

The various groups compared in different categories were defined according to the descriptive characteristics of the study participants. Various interactions between these factors affected the overall trends; however, significant differences in these performance trends were seen in all groups. As previously suggested, there was some evidence of a narrowing of the performance gap between males and females [130]; however, further investigations with matched group sizes and characteristics of the participants could provide valuable insight. The literature consulted in our paper provided extensive evidence of the impact of the aging process on running performance. This knowledge was used in our study to explain the trends of performance improvements or decline over time. Other research to date has focused on intra-race results, while the present study analyzed the trends of various events over several years of race participation [139].

To determine the variation in ultramarathon performance based on the sex, number of ultramarathons completed, medal category of peak performance and age at debut Two Oceans Ultramarathon

Variation in Two Oceans Ultramarathon career performance was analysed using the delta of the running speed and comparing these results over time. The results of our study showed that the changes became larger over time, and that the rate of decline showed more variation in the later stages of the running careers.

In conclusion, this study identified that the interaction of numerous factors has an impact on performance trends amongst seasoned ultramarathon runners. To date, extensive research has been conducted on endurance running, with a growing interest in the field of seasoned or master athletes [53, 105, 107]. When it comes to performance trends and race pace, many studies have compared sex, age and other demographic groups, and have frequently focused on a single event. However, while many of the studies have investigated various interactions of factors within a race, there is a lack of knowledge about how parameters of racing change over longer periods, or about repetitive participation in ultramarathon races.

In particular, the complexity of one specific measure of performance, namely that of pacing, is a multifactorial concept that requires in-depth understanding of all the contributing components. Key recommendations for future research on long-term performance and pacing in seasoned master ultramarathon runners include addressing other factors that may influence longevity of ultramarathon running careers. These factors could include injury profiles, training histories, the impact of nutrition as well as participation profiles across other races.

REFERENCES

1. Two Oceans Marathon. Blue Number Club. 2020 [cited 2020 6 January]; Available from: https://www.twooceansmarathon.org.za/about-two-oceans/blue-number-club/.

2. Millet, G. Y., Martin, V., & Temesi, J. (2018). The role of the nervous system in neuromuscular fatigue induced by ultra-endurance exercise. *Applied Physiology, Nutrition, and Metabolism*, *43*(11), 1151-1157.

3. Zingg, M. A., Knechtle, B., Rüst, C. A., Rosemann, T., & Lepers, R. (2013). Analysis of participation and performance in athletes by age group in ultramarathons of more than 200 km in length. *International Journal of General Medicine*, *6*, 209-220.

4. Willy, R. W., & Paquette, M. R. (2019). The physiology and biomechanics of the master runner. *Sports Medicine and Arthroscopy Review*, *27*(1), 15-21.

5. Meeusen, R., Duclos, M., Foster, C., Fry, A., Gleeson, M., Nieman, D., ... & Urhausen, A. (2013). Prevention, diagnosis and treatment of the overtraining syndrome: Joint consensus statement of the European College of Sport Science (ECSS) and the American College of Sports Medicine (ACSM). *European Journal of Sport Science*, *13*(1), 1-24.

6. Abbiss, C. R., & Laursen, P. B. (2008). Describing and understanding pacing strategies during athletic competition. *Sports Medicine*, *38*(3), 239-252.

7. Gibson, A. S. C., De Koning, J. J., Thompson, K. G., Roberts, W. O., Micklewright, D., Raglin, J., & Foster, C. (2013). Crawling to the finish line: why do endurance runners collapse?. *Sports Medicine*, *43*(6), 413-424.

8. Mountjoy, M., Sundgot-Borgen, J. K., Burke, L. M., Ackerman, K. E., Blauwet, C., Constantini, N., ... & Sherman, R. T. (2018). IOC consensus statement on relative energy deficiency in sport (RED-S): 2018 update. *British Journal of Sports Medicine*.

9. Genin, J., Mann, R., & Theisen, D. (2011). Determining the running-related injury risk factors in long distance runners. *British Journal of Sports Medicine*, *45*(4), 349-349.

10. Tan, D. W., Yap, S. H., Wang, M., Fan, P. W., Teo, Y. S., Krishnasamy, P., ... & Lee, J. K. W. (2016). Body mass changes across a variety of running race distances in the tropics. *Sports Medicine-Open*, *2*(1), 26.

11. Giampiccoli, A., Lee, S. S., & Nauright, J. (2015). Destination South Africa: Comparing global sports mega-events and recurring localised sports events in South Africa for tourism and economic development. *Current Issues in Tourism*, *18*(3), 229-248.

12. Scheer, V. (2019). Participation trends of ultra endurance events. *Sports Medicine and Arthroscopy Review*, *27*(1), 3-7.

13. Zach, S., Xia, Y., Zeev, A., Arnon, M., Choresh, N., & Tenenbaum, G. (2017). Motivation dimensions for running a marathon: A new model emerging from the Motivation of Marathon Scale (MOMS). *Journal of Sport and Health Science*, *6*(3), 302-310.

14. Lepers, R., & Stapley, P. J. (2016). Master athletes are extending the limits of human endurance. *Frontiers in Physiology*, *7*, 613.

15. Zingg, M., Rüst, C. A., Lepers, R., Rosemann, T., & Knechtle, B. (2013). Master runners dominate 24-h ultramarathons worldwide—a retrospective data analysis from 1998 to 2011. *Extreme Physiology & Medicine*, *2*(1), 21.

16. Karlstedt, E., Chelvanathan, A., Da Silva, M., Cleverley, K., Kumar, K., Bhullar, N., ... & Du, X. (2012). The impact of repeated marathon running on cardiovascular function in the aging population. *Journal of Cardiovascular Magnetic Resonance*, *14*(1), 58.

17. Lee, D. C., Brellenthin, A. G., Thompson, P. D., Sui, X., Lee, I. M., & Lavie, C. J. (2017). Running as a key lifestyle medicine for longevity. *Progress in Cardiovascular Diseases*, *60*(1), 45-55.

18. DeVita, P., Seay, J. F., Fellin, R. E., Ip, E., Stavro, N., & Messier, S. (2015). The Relationships Between Age and Running Biomechanics: 2636 Board# 2 May 29, 100 PM-300 PM. *Medicine & Science in Sports & Exercise*, *47*(5S), 709.

19. Jones, A. M., & Carter, H. (2000). The effect of endurance training on parameters of aerobic fitness. *Sports Medicine*, *29*(6), 373-386.

20. Junior, L. C. H., Pillay, J. D., van Mechelen, W., & Verhagen, E. (2015). Meta-analyses of the effects of habitual running on indices of health in physically inactive adults. *Sports Medicine*, *45*(10), 1455-1468.

21. Couppé, C., Svensson, R. B., Grosset, J. F., Kovanen, V., Nielsen, R. H., Olsen, M. R., ... & Aagaard, P. (2014). Life-long endurance running is associated with reduced glycation and mechanical stress in connective tissue. *Age*, *36*(4), 9665.

22. Bogdanis, G. C. (2012). Effects of physical activity and inactivity on muscle fatigue. *Frontiers in Physiology*, *3*, 142.

23. Zlotnicki, J. P., Mares, A., & Musahl, V. (2016). Exercise and osteoarthritis: the effect of running with aging in the masters-level athlete. In *Endurance Sports Medicine* (pp. 183-197). Springer, Cham.

24. Trappe, S., Hayes, E., Galpin, A., Kaminsky, L., Jemiolo, B., Fink, W., ... & Tesch, P. (2013). New records in aerobic power among octogenarian lifelong endurance athletes. *Journal of Applied Physiology*, *114*(1), 3-10.

25. Witham, B. R., & Babbitt, K. (2017). Cardiovascular Risks in Long Distance Runners. *Journal of Christian Nursing*, *34*(2), 97-101.

26. Schwabe, K., Schwellnus, M. P., Derman, W., Swanevelder, S., & Jordaan, E. (2014). Less experience and running pace are potential risk factors for medical complications during a 56 km road running race: a prospective study in 26 354 race starters—SAFER study II. *British Journal of Sports Medicine*, *48*(11), 905-911.

27. Rae, D. E., Bosch, A. N., Collins, M., & Lambert, M. I. (2005). The interaction of aging and 10 years of racing on ultraendurance running performance. *Journal of Aging and Physical Activity*, *13*(2), 210-222.

28. Knechtle, B., Rosemann, T., Knechtle, P., & Lepers, R. (2010). Predictor variables for a 100-km race time in male ultra-marathoners. *Perceptual and Motor Skills*, *111*(3), 681-693.

29. Zaryski, C., & Smith, D. J. (2005). Training principles and issues for ultra-endurance athletes. *Current Sports Medicine Reports*, *4*(3), 165-170.

30. Galetta, F., Franzoni, F., Femia, F. R., & Roccella, N. (2005). Lifelong physical training prevents the age-related impairment of heart rate variability and exercise capacity in elderly people. *Journal of Sports Medicine and Physical Fitness*, *45*(2), 217-221.

31. Kruger, M., & Saayman, M. (2013). Who are the comrades of the Comrades Marathon?. *South African Journal for Research in Sport, Physical Education and Recreation*, *35*(1), 71-92.

32. Roebuck, G. S., Fitzgerald, P. B., Urquhart, D. M., Ng, S. K., Cicuttini, F. M., & Fitzgibbon, B. M. (2018). The psychology of ultra-marathon runners: A systematic review. *Psychology of Sport and Exercise*, *37*, 43-58.

33. Holt, N. L., Lee, H., Kim, Y., & Klein, K. (2014). Exploring experiences of running an ultramarathon. *The Sport Psychologist*, *28*(1), 22-35.

34. Knechtle, B., Rüst, C. A., Rosemann, T., & Lepers, R. (2012). Age-related changes in 100-km ultra-marathon running performance. *Age*, *34*(4), 1033-1045.

35. Hoffman, M. D., Ong, J. C., & Wang, G. (2010). Historical analysis of participation in 161 km ultramarathons in North America. *The International Journal of the History of Sport*, *27*(11), 1877-1891.

36. Cejka, N., Rüst, C. A., Lepers, R., Onywera, V., Rosemann, T., & Knechtle, B. (2014). Participation and performance trends in 100-km ultra-marathons worldwide. *Journal of Sports Sciences*, *32*(4), 354-366.

37. Agnew, J. W., Hammer, S. B., Roy, A. L., & Rahmoune, A. (2018). Central and peripheral pain sensitization during an ultra-marathon competition. *Scandinavian Journal of Pain*, *18*(4), 703-709.

38. Simpson, D., Post, P. G., Young, G., & Jensen, P. R. (2014). "It's not about taking the easy road": The experiences of ultramarathon runners. *The Sport Psychologist*, *28*(2), 176-185.

39. Kotze, N., 2006, July. Cape Town and the Two Oceans Marathon: The impact of sport tourism. In *Urban Forum* (Vol. 17, No. 3, pp. 282-293). Springer Netherlands.

40. Zhang, X., Bob, U., & Swart, K. (2008). A comparison of spectators' and participants' profiles and perceptions of the 2006 Old Mutual Two Oceans Marathon. *Africa Insight*, *38*(3), 135-146.

41. Baba, S. R. (2014). *Psychological correlates of performance, injury and illness in Two Oceans Ultramarathon athletes* (Doctoral dissertation, University of Cape Town).

42. Otter, R. T., Brink, M. S., Diercks, R. L., & Lemmink, K. A. (2016). A negative life event impairs psychosocial stress, recovery and running economy of runners. *International Journal of Sports Medicine*, *37*(03), 224-229.

43. Lee DC, Lavie CJ, Vedanthan R. (2015). Optimal dose of running for longevity: is more better or worse? *Journal of the American College of Cardiology*, 65, 420–2

44. Young, B. W., Medic, N., Weir, P. L., & Starkes, J. L. (2008). Explaining performance in elite middle-aged runners: Contributions from age and from ongoing and past training factors. *Journal of Sport and Exercise Psychology*, *30*(6), 737-754.

45. Bertelsen, M. L., Hulme, A., Petersen, J., Brund, R. K., Sørensen, H., Finch, C. F., ... & Nielsen, R. O. (2017). A framework for the etiology of running-related injuries. *Scandinavian Journal of Medicine & Science in Sports*, *27*(11), 1170-1180.

46. Hamstra-Wright, K. L., Coumbe-Lilley, J. E., Kim, H., McFarland, J. A., & Bliven, K. C. H. (2013). The influence of training and mental skills preparation on injury incidence and performance in marathon runners. *The Journal of Strength & Conditioning Research*, *27*(10), 2828-2835.

47. Nippert, A. H., & Smith, A. M. (2008). Psychologic stress related to injury and impact on sport performance. *Physical Medicine and Rehabilitation Clinics of North America*, *19*(2), 399-418.

48. Morgan, W. P. (2000). Psychological factors associated with distance running and the marathon. *Marathon Medicine*, 293-310.

49. Burr, J. F., Drury, C. T., Phillips, A. A., Ivey, A., Ku, J., & Warburton, D. E. (2014). Long-term ultra-marathon running and arterial compliance. *Journal of Science and Medicine in Sport*, *17*(3), 322-325.

50. Van Gent, R. N., Siem, D., van Middelkoop, M., Van Os, A. G., Bierma-Zeinstra, S. M. A., & Koes, B. W. (2007). Incidence and determinants of lower extremity running injuries in long distance runners: a systematic review. *British Journal of Sports Medicine*, *41*(8), 469-480.

51. Szabo, A., & Ábrahám, J. (2013). The psychological benefits of recreational running: A field study. *Psychology, Health & Medicine*, *18*(3), 251-261.

52. Kenney, W. L., Wilmore, J. H., & Costill, D. L. (2015). *Physiology of Sport and Exercise*. Human Kinetics.

53. Brisswalter, J., & Nosaka, K. (2013). Neuromuscular factors associated with decline in long-distance running performance in master athletes. *Sports Medicine*, *43*(1), 51-63.

54. Ryan, A. S., Katzel, L. I., Prior, S. J., McLenithan, J. C., Goldberg, A. P., & Ortmeyer, H. K. (2014). Aerobic exercise plus weight loss improves insulin sensitivity and increases skeletal muscle glycogen synthase activity in older men. *Journals of Gerontology Series A: Biomedical Sciences and Medical Sciences*, *69*(7), 790-798.

55. Stanford, K. I., Middelbeek, R. J., & Goodyear, L. J. (2015). Exercise effects on white adipose tissue: beiging and metabolic adaptations. *Diabetes*, *64*(7), 2361-2368.

56. Brenmoehl, J., Ohde, D., Albrecht, E., Walz, C., Tuchscherer, A., & Hoeflich, A. (2017). Browning of subcutaneous fat and higher surface temperature in response to phenotype selection for advanced endurance exercise performance in male DUhTP mice. *Journal of Comparative Physiology B,* 187(2), 361-373.

57. Fan, W., Waizenegger, W., Lin, C. S., Sorrentino, V., He, M. X., Wall, C. E., ... & Auwerx, J. (2017). PPARδ promotes running endurance by preserving glucose. *Cell Metabolism*, *25*(5), 1186-1193.

58. McArdle, W. D., Katch, F. I., & Katch, V. L. (2010). *Exercise physiology: nutrition, energy, and human performance*. Lippincott Williams & Wilkins.

59. Rae, D. E., Vignaud, A., Butler-Browne, G. S., Thornell, L. E., Sinclair-Smith, C., Derman, E. W., ... & Collins, M. (2010). Skeletal muscle telomere length in healthy, experienced, endurance runners. *European Journal of Applied Physiology*, *109*(2), 323-330.

60. Wasfy, M. M., Weiner, R. B., Wang, F., Berkstresser, B., Lewis, G. D., DeLuca, J. R., ... & Baggish, A. L. (2015). Endurance exercise-induced cardiac remodeling: not all sports are created equal. *Journal of the American Society of Echocardiography*, *28*(12), 1434-1440.

61. Scofield, K. L., & Hecht, S. (2012). Bone health in endurance athletes: runners, cyclists, and swimmers. *Current Sports Medicine Reports*, *11*(6), 328-334.

62. Sato, M., Jordan, J. S., & Funk, D. C. (2015). Distance running events and life satisfaction: A longitudinal study. *Journal of Sport Management*, *29*(4), 347-361.

63. Boecker, H., Sprenger, T., Spilker, M. E., Henriksen, G., Koppenhoefer, M., Wagner, K. J., ... & Tolle, T. R. (2008). The runner's high: opioidergic mechanisms in the human brain. *Cerebral Cortex*, *18*(11), 2523-2531.

64. Evans, M. B., Hoar, S. D., Gebotys, R. J., & Marchesin, C. A. (2014). Endurance athletes' coping function use during competitive suffering episodes. *European Journal of Sport Science*, *14*(4), 368-375.

65. Smith, D. J. (2003). A framework for understanding the training process leading to elite performance. *Sports Medicine*, *33*(15), 1103-1126.

66. Masters, K. S., Ogles, B. M., & Jolton, J. A. (1993). The development of an instrument to measure motivation for marathon running: The Motivations of Marathoners Scales (MOMS). *Research Quarterly for Exercise and Sport*, *64*(2), 134-143.

67. DiLorenzo, T. M., Bargman, E. P., Stucky-Ropp, R., Brassington, G. S., Frensch, P. A., & LaFontaine, T. (1999). Long-term effects of aerobic exercise on psychological outcomes. *Preventive Medicine*, *28*(1), 75-85.

68. Perrey, S., & Mandrick, K. (2012). Evidence from neuroimaging to explore brain plasticity in humans during an ultra-endurance burden. *BMC Medicine*, *10*(1), 171.

69. Freund, W., Faust, S., Birklein, F., Gaser, C., Wunderlich, A. P., Müller, M., ... & Schütz, U. H. (2012). Substantial and reversible brain gray matter reduction but no acute brain lesions in ultramarathon runners: experience from the TransEurope-FootRace Project. *BMC Medicine*, *10*(1), 170.

70. Bogdanis, G. C. (2012). Effects of physical activity and inactivity on muscle fatigue. *Frontiers in Physiology*, *3*, 142.

71. Hulme, A., Nielsen, R. O., Timpka, T., Verhagen, E., & Finch, C. (2017). Risk and protective factors for middle-and long-distance running-related injury. *Sports Medicine*, *47*(5), 869-886.

72. Knobloch, K., Yoon, U., & Vogt, P. M. (2008). Acute and overuse injuries correlated to hours of training in master running athletes. *Foot & Ankle International*, *29*(7), 671-676.

73. McKean, K. A., Manson, N. A., & Stanish, W. D. (2006). Musculoskeletal injury in the masters runners. *Clinical Journal of Sport Medicine*, *16*(2), 149-154.

74. Connolly, D. A., Sayers, S. P., & McHugh, M. P. (2003). Treatment and prevention of delayed onset muscle soreness. *Journal of Strength and Conditioning Research*, *17*(1), 197-208.

75. Stand, P. (2007). The female athlete triad. *Medicine & Science in Sports & Exercise*, *39*(10), 1867-82.

76. Jassal, D. S., Moffat, D., Krahn, J., Ahmadie, R., Fang, T., Eschun, G., & Sharma, S. (2009). Cardiac injury markers in non-elite marathon runners. *International Journal of Sports Medicine*, *30*(02), 75-79.

77. Mont, L., Elosua, R., & Brugada, J. (2009). Endurance sport practice as a risk factor for atrial fibrillation and atrial flutter. *Europace*, *11*(1), 11-17.

78. Trachsel, L. D., Carlen, F., Brugger, N., Seiler, C., & Wilhelm, M. (2015). Masked hypertension and cardiac remodeling in middle-aged endurance athletes. *Journal of Hypertension*, *33*(6), 1276-1283.

79. Trivax, J. E., Franklin, B. A., Goldstein, J. A., Chinnaiyan, K. M., Gallagher, M. J., deJong, A. T., ... & McCullough, P. A. (2010). Acute cardiac effects of marathon running. *Journal of Applied Physiology*, *108*(5), 1148-1153.

80. Ford, S. J., Rehman, A., & Bradbury, A. W. (2003). External iliac endofibrosis in endurance athletes: a novel case in an endurance runner and a review of the literature. *European Journal of Vascular and Endovascular Surgery*, *26*(6), 629-634.

81. Hazelwood, S. J., & Castillo, A. B. (2007). Simulated effects of marathon training on bone density, remodeling, and microdamage accumulation of the femur. *International Journal of Fatigue*, *29*(6), 1057-1064.

82. Zanker, C. L., & Swaine, I. L. (2000). Responses of bone turnover markers to repeated endurance running in humans under conditions of energy balance or energy restriction. *European Journal of Applied Physiology*, *83*(4-5), 434-440.

83. Willick, S. E., & Hansen, P. A. (2010). Running and osteoarthritis. *Clinics in Sports Medicine*, *29*(3), 417-428.

84. Mountjoy, M., Sundgot-Borgen, J. K., Burke, L. M., Ackerman, K. E., Blauwet, C., Constantini, N., ... & Sherman, R. T. (2018). IOC consensus statement on relative energy deficiency in sport (RED-S): 2018 update. *British Journal of Sports Medicine*.

85. Gibbs, J. C., Williams, N. I., & De Souza, M. J. (2013). Prevalence of individual and combined components of the female athlete triad. *Medicine & Science in Sports & Exercise*, *45*(5), 985-996.

86. Wigernæs, I., Høstmark, A. T., Strømme, S. B., Kierulf, P., & Birkeland, K. (2001). Active recovery and post-exercise white blood cell count, free fatty acids, and hormones in endurance athletes. *European Journal of Applied Physiology*, *84*(4), 358-366.

87. Pacque, P. F. J., Booth, C. K., Ball, M. J., & Dwyer, D. B. (2007). The effect of an ultra-endurance running race on mucosal and humoral immune function. *Journal of Sports Medicine and Physical Fitness*, *47*(4), 496.

88. Ihalainen, J. K., Schumann, M., Häkkinen, K., & Mero, A. A. (2016). Mucosal immunity and upper respiratory tract symptoms in recreational endurance runners. *Applied Physiology, Nutrition, and Metabolism*, *41*(1), 96-102.

89. Kakanis, M., Peake, J., Hooper, S., Gray, B., & Marshall-Gradisnik, S. (2010). The open window of susceptibility to infection after acute exercise in healthy young male elite athletes. *Journal of Science and Medicine in Sport*, *13*, e85-e86.

90. Marcora, S. M., & Bosio, A. (2007). Effect of exercise-induced muscle damage on endurance running performance in humans. *Scandinavian Journal of Medicine & Science in Sports*, *17*(6), 662-671.

91. Meeusen, R., Watson, P., Hasegawa, H., Roelands, B., & Piacentini, M. F. (2006). Central fatigue. *Sports Medicine*, *36*(10), 881-909.

92. He, C.S., Bishop, N.C., Handzlik, M.K., Muhamad, A.S., & Gleeson, M. (2014). Sex differences in upper respiratory symptoms prevalence and oral-respiratory mucosal immunity in endurance athletes. *Exercise Immunology Review*. 20. p. 8-22.

93. Hausswirth, C., Louis, J., Aubry, A., Bonnet, G., Duffield, R., & Le Meur, Y. (2014). Evidence of disturbed sleep and increased illness in overreached endurance athletes. *Medicine and Science in Sports and Exercise*.

94. Derman, W., Schwellnus, M. P., Lambert, M. I., Emms, M., Sinclair-Smith, C., Kirby, P., & Noakes, T. D. (1997). The 'worn-out athlete': a clinical approach to chronic fatigue in athletes. *Journal of Sports Sciences*, *15*(3), 341-351.

95. Symonds, G. (1995). *Psychological aspects of long-distance running among South African marathon runners*. (Masters dissertation, UNISA)

96. Devita, P., Fellin, R. E., Seay, J. F., Ip, E., Stavro, N., & Messier, S. P. (2016). The relationships between age and running biomechanics. *Medicine and Science in Sports and Exercise*, *48*(1), 98-106.

97. Ronkainen, N. J., & Ryba, T. V. (2017). Rethinking age in athletic retirement: An existential-narrative perspective. *International Journal of Sport and Exercise Psychology*, *15*(2), 146-159.

98. Ronkainen, N. J., Ryba, T. V., & Nesti, M. S. (2013). 'The engine just started coughing!'—Limits of physical performance, aging and career continuity in elite endurance sports. *Journal of Aging Studies*, *27*(4), 387-397.

99. Knechtle, B., Rosemann, T., & Nikolaidis, P. T. (2018). Pacing and changes in body composition in 48 h ultra-endurance Running—A Case Study. *Sports*, *6*(4), 136.

100. Millet, G. Y. (2011). Can neuromuscular fatigue explain running strategies and performance in ultra-marathons?. *Sports Medicine*, *41*(6), 489-506.

101. Breen, D., Norris, M., Healy, R., & Anderson, R. (2018). Marathon pace control in masters athletes. *International Journal of Sports Physiology and Performance*, *13*(3), 332-338.

102. Tan, P. L., Tan, F. H., & Bosch, A. N. (2016). Similarities and differences in pacing patterns in a 161-km and 101-km ultra-distance road race. *Journal of Strength and Conditioning Research*, *30*(8), 2145-2155.

103. Knechtle, B., Rosemann, T., Zingg, M.A., Stiefel, M. and Rüst, C.A., 2015. Pacing strategy in male elite and age group 100 km ultra-marathoners. *Open Access Journal of Sports Medicine*, *6*, p.71.

104. Zingg, M. A., Rüst, C. A., Rosemann, T., Lepers, R., & Knechtle, B. (2014). Runners in their forties dominate ultra-marathons from 50 to 3,100 miles. *Clinics*, *69*(3), 203-211.

105. Lazarus, N. R., & Harridge, S. D. (2017). Declining performance of master athletes: silhouettes of the trajectory of healthy human ageing?. *The Journal of Physiology*, *595*(9), 2941-2948.

106. Lepers, R., Rüst, C. A., Stapley, P. J., & Knechtle, B. (2013). Relative improvements in endurance performance with age: evidence from 25 years of Hawaii Ironman racing. *Age*, *35*(3), 953-962.

107. Tanaka, H., & Seals, D. R. (2008). Endurance exercise performance in Masters athletes: age-associated changes and underlying physiological mechanisms. *The Journal of Physiology*, *586*(1), 55-63.

108. Millet, G. P., & Millet, G. Y. (2012). Ultramarathon is an outstanding model for the study of adaptive responses to extreme load and stress. *BMC Medicine*, *10*(1), 77.

109. Leyk, D., Erley, O., Gorges, W., Ridder, D., Rüther, T., Wunderlich, M., ... & Erren, T. (2009). Performance, training and lifestyle parameters of marathon runners aged 20–80 years: results of the PACE-study. *International Journal of Sports Medicine*, *30*(05), 360-365.

110. Kallinen, M., & Markku, A. (1995). Aging, physical activity and sports injuries. *Sports Medicine*, *20*(1), 41-52.

111. Karamanidis, K., & Arampatzis, A. (2005). Mechanical and morphological properties of different muscle–tendon units in the lower extremity and running mechanics: effect of aging and physical activity. *Journal of Experimental Biology*, *208*(20), 3907-3923.

112. Karamanidis, K., & Arampatzis, A. (2007). Age-related degeneration in leg-extensor muscle–tendon units decreases recovery performance after a forward fall: compensation with running experience. *European Journal of Applied Physiology*, *99*(1), 73-85.

113. Couppé, C., Svensson, R. B., Grosset, J. F., Kovanen, V., Nielsen, R. H., Olsen, M. R., ... & Aagaard, P. (2014). Life-long endurance running is associated with reduced glycation and mechanical stress in connective tissue. *Age*, *36*(4), 9665.

114. Trappe, S. (2007). Marathon runners. *Sports Medicine*, *37*(4-5), 302-305.

115. Bonacci, J., Chapman, A., Blanch, P., & Vicenzino, B. (2009). Neuromuscular adaptations to training, injury and passive interventions. *Sports Medicine*, *39*(11), 903-921.

116. Lepers, R., & Cattagni, T. (2012). Do older athletes reach limits in their performance during marathon running?. *Age*, *34*(3), 773-781.

117. Lambert, M. I., Bryer, L., Hampson, D. B., Nobbs, L., Rapolthy, A. M., Taliep, M. S., & Viljoen, L. W. (2002). Accelerated decline in running performance in a master runner with a history of a large volume of training and racing. *Journal of Aging and Physical Activity*, *10*(3), 314-321.

118. Jampen, S. C., Knechtle, B., Rüst, C. A., Lepers, R., & Rosemann, T. (2013). Increase in finishers and improvement of performance of masters runners in the Marathon des Sables. *International Journal of General Medicine*, *6*, 427.

119. Cheuvront, S. N., Carter, R., DeRuisseau, K. C., & Moffatt, R. J. (2005). Running performance differences between men and women. *Sports Medicine*, *35*(12), 1017-1024.

120. Eichenberger, E., Knechtle, B., Rüst, C. A., Rosemann, T., & Lepers, R. (2012). Age and sex interactions in mountain ultramarathon running–the Swiss Alpine Marathon. *Open Access Journal of Sports Medicine*, *3*, 73.

121. Knechtle, B., & Nikolaidis, P. T. (2017). The age of the best ultramarathon performance–the case of the "Comrades Marathon". *Research in Sports Medicine*, *25*(2), 132-143.

122. Birkenhead, K., Lovell, G., Barr, S. I., & Solomon, C. (2018). Changes in physical activity across the lifetime of current ultra-endurance exercisers. *Journal of Physical Activity Research*, *3*(1), 11-19.

123. Hunter, S. K., & Stevens, A. A. (2013). Sex differences in marathon running with advanced age: physiology or participation?. *Medicine and Science in Sports and Exercise*, *45*(1), 148-156.

124. Senefeld, J., Smith, C., & Hunter, S. K. (2016). Sex differences in participation, performance, and age of ultramarathon runners. *International Journal of Sports Physiology and Performance*, *11*(5), 635-642.

125. Nikolaidis, P. T., Rosemann, T., & Knechtle, B. (2018). Sex differences in the age of peak marathon race time. *Chinese Journal of Physiology*, *61*, 85-91.

126. McGannon, K. R., McMahon, J., & Gonsalves, C. A. (2018). Juggling motherhood and sport: A qualitative study of the negotiation of competitive recreational athlete mother identities. *Psychology of Sport and Exercise*, *36*, 41-49.

127. Belforth, E. (2013). *The elite endurance athlete as a mother – a case study of four elite endurance sporting women* (Masters dissertation - Goteborgs University, Sweden).

128. Darroch, F., & Hillsburg, H. (2017, May). Keeping pace: Mother versus athlete identity among elite long distance runners. In *Women's Studies International Forum* (Vol. 62, pp. 61-68). Pergamon.

129. De Souza, M. J., Williams, N. I., Nattiv, A., Joy, E., Misra, M., Loucks, A. B., ... & Gibbs, J. C. (2014). Misunderstanding the female athlete triad: refuting the IOC consensus statement on Relative Energy Deficiency in Sport (RED-S). *British Journal of Sports Medicine*. 48(20):1461-1465.

130. Waldvogel, K. J., Nikolaidis, P. T., Di Gangi, S., Rosemann, T., & Knechtle, B. (2019). Women reduce the performance difference to men with increasing age in ultra-marathon running. *International Journal of Environmental Research and Public Health*, *16*(13), 2377.

131. Knechtle, B., and Nikolaidis, P. (2015). Ultra-marathon running. *Dansk Sportsmedicin*, *19*(4), 6-10.

132. Nikolaidis, P. T., & Knechtle, B. (2019). Do fast older runners pace differently from fast younger runners in the "New York city marathon"?. *The Journal of Strength & Conditioning Research*, *33*(12), 3423-3430.

133. Hoffman, M. D., & Wegelin, J. A. (2009). The Western States 100-mile endurance run: participation and performance trends. *Medicine and Science in Sports and Exercise*, *41*(12), 2191.

134. Ronkainen, N. J., Watkins, I., & Ryba, T. V. (2016). What can gender tell us about the pre-retirement experiences of elite distance runners in Finland?: A thematic narrative analysis. *Psychology of Sport and Exercise*, *22*, 37-45.

135. Frick, B. (2011). Gender differences in competitive orientations: Empirical evidence from ultramarathon running. *Journal of Sports Economics*, *12*(3), 317-340.

136. Schneider, A. L., Nikolaidis, P. T., & Knechtle, B. (2019). Improved performance in master runners competing in the European championships between 1978 and 2014. *The Journal of Strength & Conditioning Research*, *33*(9), 2559-2569.

137. Knechtle, B., Nikolaidis, P. T., Zingg, M. A., Rosemann, T., & Rüst, C. A. (2017). Differences in age of peak marathon performance between mountain and city marathon running—The 'Jungfrau Marathon'in Switzerland. *Chinese Journal of Physiology*, *60*, 11-22.

138. Haney, T. A. (2010). *Variability of pacing in marathon distance running.* (Masters Dissertation, University of Nevada, Las Vegas).

139. Nikolaidis, P. T., & Knechtle, B. (2019). Do fast older runners pace differently from fast younger runners in the "New York city marathon"?. *The Journal of Strength & Conditioning Research*, *33*(12), 3423-3430.

APPENDICES

Appendix A: Data Extraction Sheet

	Runner 1	Runner 2	Runner 3	…	Runner 625
Name					
Sex Code					
Sex					
Nationality					
Year of first Two Oceans Ultramarathon					
Year of last Two Oceans Ultramarathon					
Age of first Two Oceans Ultramarathon					
Age Category Code					
Years taken for first 20 Two Oceans Ultramarathons					
First 5 Two Oceans Ultramarathons (years)					
Second 5 Two Oceans Ultramarathons (years)					
Third 5 Two Oceans Ultramarathons (years)					
Fourth 5 Two Oceans Ultramarathons (years)					
Number of Two Oceans Ultramarathons thereafter					
Years taken for 20+ Two Oceans Ultramarathons					
Total years Two Oceans Ultramarathon running					
Total number of Two Oceans Ultramarathon Medals					
Two Oceans Ultramarathon peak performance time					
Two Oceans Ultramarathon peak performance year					

peak performance number of Two Oceans Ultramarathon race					
Two Oceans Ultramarathon peak performance Medal Category					
Slowest Two Oceans Ultramarathon time					
Slowest Two Oceans Ultramarathon year					
Number of Two Oceans Ultramarathon slowest race					
Two Oceans Ultramarathon 1 finishing time					
Two Oceans Ultramarathon 2 finishing time					
Two Oceans Ultramarathon 3 finishing time					
Continue for all TOM completed					
Average Two Oceans Ultramarathon finishing time					
Average Two Oceans Ultramarathons 1-5 finishing time					
Average Two Oceans Ultramarathons 6-10 finishing time					
Average Two Oceans Ultramarathons 11-15 finishing time					
Average Two Oceans Ultramarathons 16-20 finishing time					
Average Two Oceans Ultramarathons 20+ finishing time					
Two Oceans Ultramarathon 1 pace m.s-1					
Two Oceans Ultramarathon 2 pace m.s-1					
Two Oceans Ultramarathon 3 pace m.s-1					
Continue for all Two Oceans Ultramarathon completed					
Average Two Oceans Ultramarathon pace m.s-1					
Average Two Oceans Ultramarathon 1-5 pace m.s-1					

Average Two Oceans Ultramarathon 6-10 pace m.s-1					
Average Two Oceans Ultramarathon 11-15 pace m.s-1					
Average Two Oceans Ultramarathon 16-20 pace m.s-1					
Average Two Oceans Ultramarathon 20+ pace m.s-1					
Two Oceans Ultramarathon 1 pace min/km					
Two Oceans Ultramarathon 2 pace min/km					
Two Oceans Ultramarathon 3 pace min/km					
Continue for all Two Oceans Ultramarathons completed					
Average Two Oceans Ultramarathon pace min/km					
Average Two Oceans Ultramarathon 1-5 pace min/km					
Average Two Oceans Ultramarathon 6-10 pace min/km					
Average Two Oceans Ultramarathon 11-15 pace min/km					
Average Two Oceans Ultramarathon 16-20 pace min/km					
Average Two Oceans Ultramarathon 20+ pace min/km					
SD for Two Oceans Ultramarathon 1					
SD for Two Oceans Ultramarathon 2					
SD for Two Oceans Ultramarathon 3					
Continue for first 20 Two Oceans Ultramarathons					
Marathon split 1					
Marathon split 2					
Marathon split 3					
Continue for all marathon splits					

Average for all Marathon splits					
Marathon 1 average pace m.s-1					
Marathon 2 average pace m.s-1					
Marathon 3 average pace m.s-1					
Continue for all marathon splits					
Average marathon pace m.s-1					
Marathon 1 average pace min/km					
Marathon 2 average pace min/km					
Marathon 3 average pace min/km					
Continue for all marathon splits					
Average marathon pace min/km					
SD for marathon 1					
SD for marathon 2					
SD for marathon 3					
Continue for marathon splits in first 20 Two Oceans Ultramarathon					

Appendix B: Ethics Approval Letter

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

26 May 2017

HREC REF: 309/2017

Dr Theresa Burgess
Physiotherapy
F-floor, OMB

Dear Dr Burgess

PROJECT TITLE: FACTORS INFLUENCING THE LONGEVITY OF RUNNING CAREERS OF SEASONED ULTRAMARATHON RUNNERS (MPhil-candidate-H Noll)

Thank you for submitting your study to the Faculty of Health Sciences Human Research Ethics Committee.

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, Helena Noll 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

HREC 309/2017

Research Council (MRC-SA), Food and Drug Administration (FDA-USA), International Convention on Harmonisation Good Clinical Practice (ICH GCP), South African Good Clinical Practice Guidelines (DoH 2006), based on the Association of the British Pharmaceutical Industry Guidelines (ABPI),and Declaration of Helsinki (2013) guidelines.
The Human Research Ethics Committee granting this approval is in compliance with the ICH Harmonised Tripartite Guidelines E6: Note for Guidance on Good Clinical Practice (CPMP/ICH/135/95) and FDA Code Federal Regulation Part 50, 56 and 312.

HREC 309/2017

Appendix C: Annual Progress Report

UNIVERSITY OF CAPE TOWN

FACULTY OF HEALTH SCIENCES
Human Research Ethics Committee

FHS016: Annual Progress Report / Renewal

HREC office use only (FWA00001637; IRB00001938)
This serves as notification of annual approval, including any documentation described below.

☑ Approved	Annual progress report	Approved until/next renewal date	30/05/2020
☐ Not approved	See attached comments		
Signature Chairperson of the HREC		Date Signed	7/2/2020

Comments to PI from the HREC

Thank you for the deviation document

Principal Investigator to complete the following:

1. Protocol information

Date (when submitting this form)	07/02/2020		
HREC REF Number	309/2017	Current Ethics Approval was granted until	30th May 2019
Protocol title			
Protocol number (if applicable)			
Are there any sub-studies linked to this study?	☐ Yes ✓ No		
If yes, could you please provide the HREC Ref's for all sub-studies? **Note:** A separate FHS016 must be submitted for each sub-study.			
Principal Investigator	Dr. Theresa Burgess		
Department / Office Internal Mail Address	Division of Physiotherapy, F45 OMB, GSH		

1.1 Does this protocol receive US Federal funding?	☐ Yes	✓ No

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(Note: Please complete the Closure form (FHS010) if the study is completed within the approval period)