UNIVERSITY OF CAPE TOWN

DEPARTMENT OF HEALTH AND REHABILITATION SCIENCES

DIVISION OF PHYSIOTHERAPY

"A comparison of pacing strategies adopted by elite versus non-elite female Two Oceans Ultramarathon runners".

A dissertation by Chanel Mouton (MTNCHA010) in partial fulfilment of the requirements for the degree Master of Science in Exercise and Sports Physiotherapy.

STUDENT : CHANEL MOUTON

SUPERVISOR : PROFESSOR ANDREW BOSCH

DECLARATION

I, Chanel Mouton (MTNCHA010), hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree at this or any other university.

Signed by student: Signed by candidate

C. Mouton

Date: 05/02/2024

ACKNOWLEDGEMENTS

This research project would not have been possible without the continued support and guidance from several key individuals. I would hereby like to extend my sincerest gratitude to all those who played such a vital role in the completion of this study:

My supervisor **Andrew Bosch**, thank you for your insights and guidance.

To **Brian Gibbon**, thank you for your expert knowledge on practical applications of the results in this study.

To **Taahira Goolam Hoosen** from the Faculty of Health Sciences Writing Lab, thank you for your added support in my writing process.

My business partners, **Nicola Clark,** and **Franci du Plessis**, thank you for encouraging me to take the time to complete this project. Your continued support in creating a flexible working environment was remarkable.

To all my patients, friends, and family, thank you for your unwavering support and encouragement over the past three years.

My deepest gratitude to all of you.

Sincerely,
Chanel

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS:

ATP	Adenosine Triphosphate
HREC	Human Research Ethics Council
HTW	Hitting the Wall
IAAF	International Amateur Athletics Federation
IAU	International Association of Ultrarunners
km	Kilometres
km/h	Kilometres per hour
min/s	Minutes per second
MRP	Mean Race Pace
RPE	Rate of Perceived Exertion
TOM	Two Oceans Marathon
UCT	University of Cape Town
WMM	World Marathon Majors

GLOSSARY OF TERMS

Pacing	A self-selected strategy in which an athlete distributes their energy expenditure or muscle work during a bout of exercise. The three pacing profiles applicable to marathon running are: - Positive pacing (slowing of running speed throughout the competition). - Negative pacing (increasing running speed throughout the competition). - Even pacing (maintain a stable, steady running speed throughout the competition) (Abbiss & Laursen, 2008).
Marathon	A footrace covering 42.195 kilometres is considered a classic marathon (Nikolaides & Knechtle, 2018). The first organised marathon was run in 1896 during the first modern Olympic Games. The race was created to pay homage to the legend of Pheidippides, a man who ran 42 kilometres from Marathon to Athens to carry news of the Greeks defeating the Persians in battle (Feldman, 2018).
Ultramarathon	Any running event that is longer than the traditional 42.2-kilometre marathon distance (Zingg et al., 2014). The shortest ultramarathon distance is 50 kilometres (Knechtle & Nikolaides, 2015).
Major Marathons	Six major marathons are held annually that collectively make up the World Marathon Majors (WMM). These are: - The **Tokyo** Marathon (since 2007) which has a capacity of 38 000 entrants. - The **Boston** Marathon (since 1897) which is the world's oldest annual marathon. - The **London** Marathon (since 1981) which has seen over one million finishers since its inception. - The **Berlin** Marathon (since 1974) where Eliud Kipchoge set the previous men's world record with a time of 2:01:09 in 2022. In September 2023, Tigst Assefa, set the new women's world record on this course at 02:11:53.

	- The **Chicago** Marathon (since 1977) where Brigid Kosgei set the previous women's world record with a time of 2:14:04 in 2019. More recently (October 2023) Kelvin Kiptum set the new men's world record at 2:00:35. - The **New York City** Marathon (since 1970) which is considered as the world's largest mass participation marathon (www.worlmarathonmajors.com).
Hitting the Wall	A multidimensional experience thought to be caused by a combination of motivational, cognitive, physiological, and affective factors. This phenomenon is characterised by the discreet and distressing onset of extreme fatigue and drastic slowing in a race, most typically between 28 to 33km of the marathon (Buman et al., 2009).
Elite Marathon Runners	In athletic performance the term "elite" is ill-defined. For the purpose of this study, we will therefore use the time categories stipulated below to classify our top finishers as elite, since their 42km splits are closest to "high-level" marathon finishing times. "High-level" male marathon runners have finishing times between 2:12:00 to 2:16:00 and females between 2:31:00 to 2:38:00. "Top-class" male marathon runners have finishing times between 2:06:00 (hr:min:sec) to 2:11:00 and females between 2:25:00 to 2:30:00 (Billat, 2001). These times are still in line with the current Olympic marathon qualifying time for females set at 2:29:30.
Mean Race Pace	The average running speed, calculated in minutes per kilometre, that a runner maintains from the start to the finish of a race (Smyth, 2018).
Neuromuscular fatigue	Exercise-induced neuromuscular fatigue is characterised by a decrease in the ability of the neuromuscular system to generate force. This phenomenon is associated with difficulty in activating the required motor units to produce adequate

	muscular power to complete a particular exercise activity (Millet, Martin & Temesi, 2018).

ABSTRACT

Background: Ultramarathon running is becoming an increasingly popular sport with millions of runners participating annually in events hosted all around the world. Pacing is considered as one of the key determinants of ultramarathon running success. Optimal pacing allows a runner to selectively manage their running speed throughout the race, to prevent premature fatigue, as they aim to achieve their desired outcomes. Although previous pacing studies provide a strong scientific foundation for research on Olympic and Championship endurance running, less is known about pacing patterns during mass-participation events – especially when focusing on female running performance. Previous research found that faster, older, and female runners achieve superior outcomes in marathon running due to their ability to maintain even pacing during competition. In a race with a challenging geographical profile, such as the Two Oceans Ultramarathon, it is unrealistic to adopt an even pacing profile throughout the entire race. This prompted us to investigate the effect of elevation on the pacing patterns adopted by elite and progressively slower female runners who successfully completed the 56-kilometre road race.

Aim: The aim of this study was to determine, analyse and compare the pacing profiles adopted by elite and non-elite female runners during the Two Oceans Ultramarathon from 2007 to 2018.

Specific objectives: 1) To describe the pacing profiles displayed by the elite female runners. 2) To describe the pacing profiles displayed by the successively slower categories of female runners. 3) To compare how pacing profiles might differ between the elite and slower category female runners. 4) To establish how the different categories of female runners adapted their pace in response to the flat and hilly sections of the race and compare how it varied between runners of different ability.

Methods: A retrospective, descriptive study was conducted to investigate the pacing patterns of female runners who successfully completed the Two Oceans Ultramarathon from 2007 to 2018. Race results from 9 682 eligible runners were obtained from a publicly accessible archive (www.twooceansmarathon.org). Participants were categorised into seven distinct groups based on their overall finish time. Split times recorded at 28km, 42km, 50km and at the finish (56km) were used to calculate the segmental splits and overall mean race pace for each runner included in the study. The segmental race pace for progressively slower groups were analysed to establish how each group a) paced over the first half of the race; b) changed their pace in response to the elevation over the second half of the race; c) might differ in their pacing profile depending on their running ability.

Results: All seven groups of runners slowed down during the race before speeding up toward the finish, thereby adopting an initial positive pacing pattern followed by negative pacing towards the end of the race. The analysis of segmental split and overall finish times showed that the fastest finishers started the race within 4% of their overall mean race pace (103.97%; 95% confidence interval = 102.74 lower level, 105.20 upper level) whereas the slowest finishers had the fastest start, running 8% faster than their mean race pace (107.98%; 95% CI = 107.83 - 108.14). This unrealistic early race pace forced the lesser runners to slow down, resulting in finishing speeds of 8% slower than their starting speed (92.42%; 95% CI = 92.22 - 92.62). In contrast, the strongest group finished within 4% of their starting speed (96.11; 95% CI = 94.52 - 97.71) by adopting a more sustainable early race pace.

The fastest finishers were the youngest (33.6 ± 5.1; years ± SD) and the slowest finishers were the oldest (39.5 ± 8.7). The average finishing time was 06:04:52 ± 00:38:11 (hr:min:sec ± SD). Only 0.5% of runners finished in less than four hours (49 of 9 682 participants), whereas 56.4% of the runners (5 406 of 9 682 participants) required six hours or more to finish the race.

Conclusion: The results of this study suggest that runners should adopt a patient, sustainable starting speed. Elite runners with a specific time-objective may benefit from a faster pace over the flat first half of the race, making up for time lost over the challenging second half of the race. Slower runners, whose primary goal is to finish the event, should aim for a more conservative approach, equal to their running ability. These recommendations allow for the even distribution of energy resources throughout the race, preventing premature fatigue and improving race outcomes. The findings in this study provide valuable insights into effective pacing strategies for ultrarunners, contributing to our understanding of optimising performance in endurance running events.

Key words: Pacing strategy, ultramarathon.

CHAPTER 1: INTRODUCTION AND SCOPE OF DISSERTATION

1.1 INTRODUCTION

The Two Oceans Ultramarathon is an esteemed 56-kilometre road running race held annually in Cape Town, South Africa. Since its inception in 1970, the event has gained global recognition, attracting approximately 11 000 runners each year (www.twooceansmarathon.org.za). The race is considered as one of the most scenic road races in the world, characterised by a challenging geographical profile. With a relatively circular route that includes significant climbs at Chapman's Peak (elevation 180m) and Constantia Nek (elevation 215m), participants face the task of maintaining an average pace of 7 minutes and 30 seconds per kilometre or faster to complete the race within the strict seven-hour time limit. Pacing strategy therefore plays a crucial role in successfully finishing the Two Oceans Ultramarathon.

Marathon pacing involves continuous decision making throughout the race (Renfree et al., 2014). It is considered a self-selected strategic and tactical approach that athletes adopt from the start of an event (Kais et al., 2019). Strategic decisions are made in preparation for the race where the athlete decides what their overall approach to the competition will be. Tactical decisions are made during the race in response the athlete's reaction to physical exertion and the behaviour of fellow competitors (Renfree & Casado, 2018). Pacing strategy is further influenced by the duration of the event as well as the athlete's fitness, experience, and knowledge at the time of competition (Gibson et al., 2006). Knowledge regarding the race profile is essential to effectively distribute energy resources throughout the race, using all available resources, but not so early as to fatigue before the finish (Casado et al., 2020).

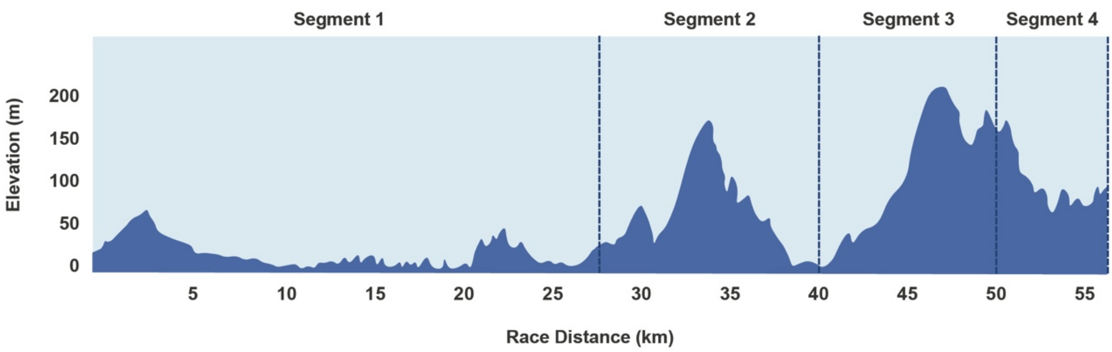

Figure 1: The Two Oceans Ultramarathon 56-kilometre race profile. Segment 1, 2, 3 and 4 indicates the 28km, 42km, 50km and 56km marks where split times were recorded.

While numerous studies have examined marathon pacing, there is limited information about how individual race characteristics or profiles can influence pacing. Haney and Mercer (2011) first investigated how elevation changes can affect running speed. They found that a comprehensive understanding of how these factors impact race pace, could prove beneficial for coaches and athletes, aiding in the effective management of pacing during endurance events. Adopting incorrect running speeds, such as starting too fast, may result in premature fatigue, suboptimal performance, or even failure to complete the race.

Doherty et al. (2020) found that the rate of non-completion in the marathon was 7.27%. Their research provides the first comprehensive analysis of non-completion statistics based on data collected from various marathons worldwide. The study revealed that non-completion rates in the 2015 Major Marathons were: 2.1% in the Boston marathon, 3.6% in Tokyo, 14.1% in London, 18.7% in Chicago and 22.6% in the Berlin marathon. These statistics highlight the need for further research on pacing strategies to potentially improve completion rates in marathon events.

With previous research revealing sex differences in marathon pacing in both elite and non-elite runners (Deaner et al., 2015; Diaz et al., 2019; Hanley et al., 2016; Hettinga et al., 2019; March et al., 2011; Santos-Lozano et al., 2014), it is important to further understand how female athletes approach endurance running. Since female participants are generally underrepresented in scientific research (Costello et al., 2014), this study provides a valuable opportunity to investigate female ultramarathon pacing. The results will provide coaches working with female runners with the necessary information to design individualised race strategies for their athletes.

The findings above prompted our investigation of pacing strategies from elite to non-elite female runners who participated in the Two Oceans Ultramarathon. It was hypothesised that all runners would slow down during the second half of the race, but that stronger runners would show less variability in pacing compared to slower runners. In addition, the study explored whether more successful runners were able increase their running speed during the flat first half to compensate for time anticipated to be lost during the more challenging second half of the race. To answer these questions, the running speeds of progressively slower groups of runners over four distinct segments in the race were analysed. The pacing profiles were then compared within and between each group to determine any similarities and/ or differences in their approach to the race.

1.2 AIM AND OBJECTIVES

1.2.1 Aim

The aim of this study was to calculate, analyse and compare the pacing profiles adopted by elite and non-elite female runners during the Two Oceans Ultramarathon from 2007 until 2018.

1.2.2 Specific Objectives

In this study our objectives were to:

1. Describe the pacing profiles adopted by the elite female runners.
2. Describe the pacing profiles adopted by successively slower categories of female runners.
3. Compare how pacing profiles differ between the elite female runners and the slower category female runners.
4. Establish how the different categories of female runners change their pace in response to the elevation of the race profile and compare how it might differ between runners of different ability.

1.2.3 Significance of the study

Physiotherapists working with endurances athletes are often challenged with the management of running-related musculoskeletal injuries. The holistic treatment of runners should include adequate race planning, preparation, and execution to prevent re-injury or worsening of an existing injury to occur. Optimal pacing strategies could therefore play an integral part in injury prevention and/or management in endurance athletes. Although an abundance of literature is available on pacing strategies employed during marathon and ultramarathon running, a consensus on the ideal pacing strategy has not been reached.

This study will add to the knowledge currently available on pacing strategies in ultramarathon running. The findings will provide therapists working with female ultramarathon runners with the necessary information to advise their patients on optimal pacing during a race such as the Two Oceans Ultramarathon.

1.3 PLAN OF DEVELOPMENT

A brief review of the most recent relevant literature related to endurance running, performance trends found in endurance running, sex differences in endurance running performance, psychological and physiological determinants of endurance performance and additional factors that may influence pacing profiles will be presented (Chapter 2). A retrospective observational study will follow that was designed to investigate the pacing strategies of elite and progressively slower female Two Oceans Ultramarathon runners (Chapter 3). This will be followed by discussion (Chapter 4). Finally, the summary, conclusion and recommendations for future research will be presented (Chapter 5).

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

The ultramarathon is a popular endurance event where pacing strategy is essential for optimal performance (Hanley, 2016). Pacing strategy is described as the way an athlete manages their effort during athletic competition (Casado et al., 2020). Runners must decide how and when to invest their energy, as this ability to regulate energy expenditure effectively, enables the runner to sustain sufficient neuromuscular function to successfully complete the race (Millet, 2011). Although optimal pacing is predominantly influenced by physiological limitations, psychological influences such as motivation and decision-making may prove to be equally important (Renfree & Casado, 2018).

Whilst earlier pacing studies focused on small samples of elite and top-class runners (Hanley, 2016; Hettinga et al., 2019; Renfree & Gibson, 2013), more recently large databases with results from mass-participation events - such as the Two Oceans Ultramarathon - allow researchers to investigate a much wider range of ability and outcomes in endurance running. Therefore, this narrative review will briefly explore marathon and ultramarathon running. The concept of pacing will be introduced. The focus will be pacing trends in elite and non-elite male and female endurance running. In addition, the physiological and psychological factors that influence pacing will briefly be presented.

The databases and online search engines searched were Pubmed, EBSCOhost, Google Scholar and UCT Primo to find the most recent relevant literature on topics relating to this study. Where additional information was required, manual searches and cross-referencing were performed. More recent articles were prioritised over older ones, unless pertinent information was not available in the latest research or if important information was only available in older papers. A combination of the following key search terms was used: *"marathon running", "ultramarathon running", "endurance running", "ultradistance running", "pacing", "pacing profile", "pacing strategy", "pacing tactics", "pacing variability", "running physiology", "Two Oceans Marathon".*

2.2 THE MARATHON

The marathon is a footrace of 42.2 kilometres. The original marathon distance was 40km as hosted in the 1896 Olympic Games. However, this distance was extended to 42.2km to accommodate a race start at Windsor Castle in the 1908 London Olympics. This race distance then became the standard in the early 1920s (Joyner, 2017). In 1976 the first ‘urban tour’ marathon was introduced. The New York City Marathon pioneered mass-participation endurance running and soon hundreds of major cities around the world began to host annual urban marathons. This allowed marathon running to evolve from Olympic exclusivity to a worldwide social and fitness phenomenon (Burfoot, 2007).

The marathon saw several milestones throughout its history that would have a significant impact on its growth in popularity. In 1972 women were officially allowed to compete in the Boston Marathon for the first time (Chauvront, 2005). This led to a gradual but substantial increase in the number of female participants in running events over the past five decades. Another transformation came in 1982 when the International Amateur Athletics Federation (IAAF) (now World Athletics) legalised payment for participation (Billat, 2005). This gave rise to the emergence, and subsequent dominance, of East-African runners in marathon running – most notably the Kenyans and Ethiopians (Aschmann et al., 2018). In fact, by 2020, Kenyan and Ethiopian runners had achieved 43% and 10%, respectively of the world’s best marathon performances (Billat, 2020). These elite runners now earn a living by participating in a few of the lucrative major marathons each year. In doing so, they can make a career out of long-distance running through prize money and endorsements (Billat, 2005).

The World Marathon Majors (WMM) was started in 2006 as an annual championship-style competition in marathon running. The series consists of six existing marathon events: New York, Chicago, Boston, Berlin, London, and Tokyo (since 2007). The top athlete in each gender category with the best overall performance – based on a points system calculated after a full year of competition – receives a $500 000 purse (worldmarathonmajors.com). It is believed that this ultimate prize, along with substantial prize money in each of the individual marathons, helps to attract top-class runners to these races (Maffetone et al., 2017). Considering what is at stake for these elite athletes, even the slightest improvement in performance can be crucial to achieve success.

2.3 THE ULTRAMARATHON

The ultramarathon is any running event further than the standard 42.2-kilometre marathon distance. The oldest known ultramarathon was an 89km race from London to Brighton that was held in 1837, as described in the German Society for Ultramarathons (Waldvogel et al., 2019).

An ultramarathon event can be classified either by distance, often ranging from 50 kilometres to 100 miles (Knechtle, 2012); or by time, ranging from six to 24 hours (Scheer, 2019). In South Africa, the world-renowned 90km Comrades Marathon (www.comrades.com) is the world's oldest and largest ultramarathon (Kruger & Saayman, 2013). The race was first hosted in 1921 by World War I veteran, Vic Clapham, to commemorate fallen South African soldiers. One of the key motivations behind the race was to "celebrate mankind's spirit over adversity" (Scheer, 2019).

In 2020, the largest study to date was conducted on ultramarathon running race results. In this article, The State of Ultrarunning, race results from over 15 000 ultramarathons held between 1996 and 2018 were analysed (Ronto, 2023). Although this study was a non-academic online publication, it provided some interesting findings through large-scale data analysis:

- From 1996 to 2018, the performance gap in ultramarathon running reduced with an increase in race distance. In 5km races, males were 17.9% faster than females, in marathon races there was an 11.1% performance difference, in 100-mile races males were 0.25% faster than females and in distances beyond 195 miles, female runners outperformed males by 0.6%.

- When considering the entire field of female participants, on average, the fastest female ultrarunners were from South Africa (average pace of 8.6km/h). They are followed by Sweden (7.8km/h) and Germany (7.7km/h). Based on this average running speed, it was found that female runners from South Africa outperformed men from all other countries, except South Africa, when considering the entire population of ultrarunners included in the study.

- South Africa had the third highest rate of participation, making up 6.7% of the world's ultramarathon participants that were studied. They were surpassed only by the United States of America (12.1%) and France (12.4%).

- Overall, there has been 1676% increase in ultrarunning participation since 1996, a decrease in participation in 5km races, and a plateau in marathon participation. These findings might suggest that traditional marathon running is no longer considered to be as extreme, but rather becoming more mainstream. It seems ultradistance running is now becoming more popular as athletes may be seeking greater challenges. Interestingly, participation in races less than 50 miles (such as the Two Oceans Ultramarathon) increased 33 times, as opposed to longer races (9.5 times).

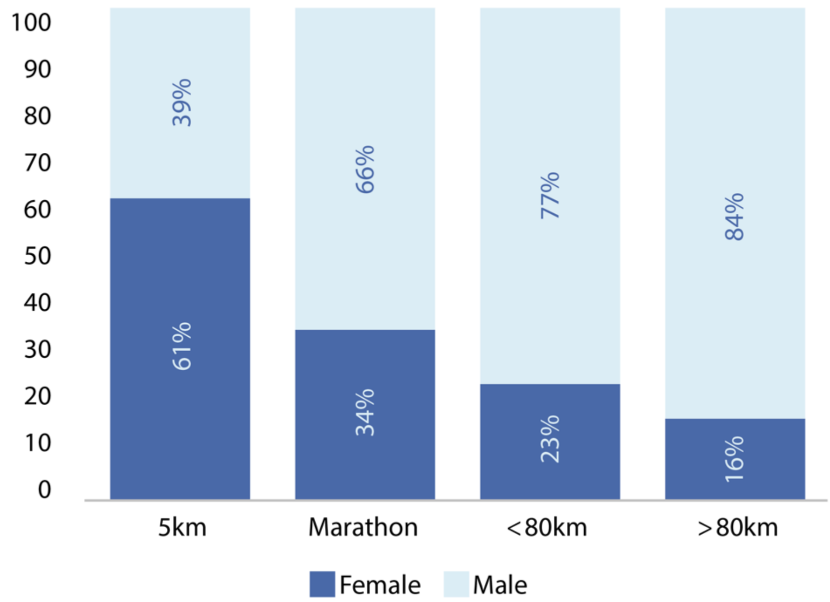

Figure 2: Gender distribution (%) of participation in running – 5km, marathon, less than 80km, and more than 80km race distances (Ronto, 2023).

According to the State of Ultrarunning, over the last 23 years, the participation rate of females has increased by 64%, yet the overall field of female ultrarunners still remains relatively small. The following section will explore this finding in greater detail.

2.4 FEMALE ENDURANCE RUNNING

In 1966, Roberta Gibb became the first ever female to run the Boston marathon. Gibb clocked a time of 3:21:04 – finishing ahead of two-thirds of all male participants (Knechtle et al., 2020). The following year, in 1967, Kathrine Switzer became the first female to participate in a marathon with an official race entry. She pretended to be a man to compete in the Boston Marathon, finishing in a time of 4:20:00. Despite her admirable performance, race organisers tried to remove Switzer from the event. Since then, there has been a global rise in marathon popularity amongst female runners.

2.4.1 The Evolution of Female Marathon Running

Female marathon running reached a milestone in 1984 when the Women's Marathon was first introduced at the Olympic Games. In that year, only 1% of marathon finishers were female. By 2003, this had increased to 15% (Billat, 2005).

This “universalisation” of the marathon contributed to its popularity amongst runners and researchers alike. Once females were included in marathon running, the event gained more scientific interest (Billat, 2005). Researchers took note when female performance rapidly improved and it appeared that they might overtake male running results (Whip & Ward, 1992). For instance, Paula Radcliffe’s world record of 2:15:25 in 2003 was a mere nine seconds slower than Abebe Bikila’s Olympic Gold medal time in 1960. This rapid improvement could be attributed to the official recognition of females in endurance running leading to more opportunities to receive coaching and to partake in competition (Sparling et al., 1993). The fact that female runners only started competing in the marathon seriously by the late sixties and that elite female marathon running was only acknowledged from 1984, may explain the faster rate of improvement in female marathon running records compared to male’s (see Figure 2). What Whip and Ward (1992) failed to take into consideration was the late start of females in elite marathon running.

Although female marathon performances have rapidly improved over the past 20 years, it seemed to have plateaued in recent years. Even Tigst Assefa’s record-breaking performance of 2:11:53 (September 2023) remains approximately 10% slower than the current male world marathon record (2:00:35), which is the gap for most distances, such as 5000m, 10 000m and the half marathon (www.worldathletics.org).

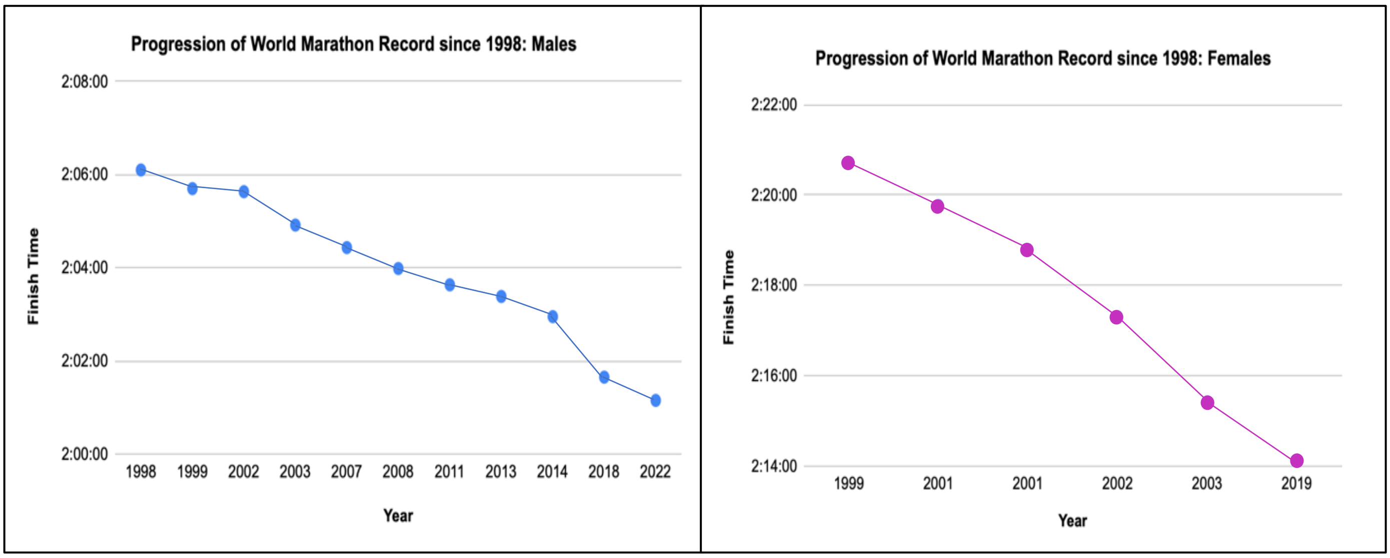

Figure 3: Comparison of improvement in World Marathon Records between male and female champions, from 1998 until 2022.

Regardless of the existing performance gap, these statistics highlight the rapid growth and improvement in female marathon and ultramarathon racing, justifying more research on female endurance running.

2.4.2 South African Female Running Performance

Locally, South African female runners have also produced exceptional results. Below are highlights throughout the history of the Two Oceans Ultramarathon (www.twooceansmarathon.org.za).

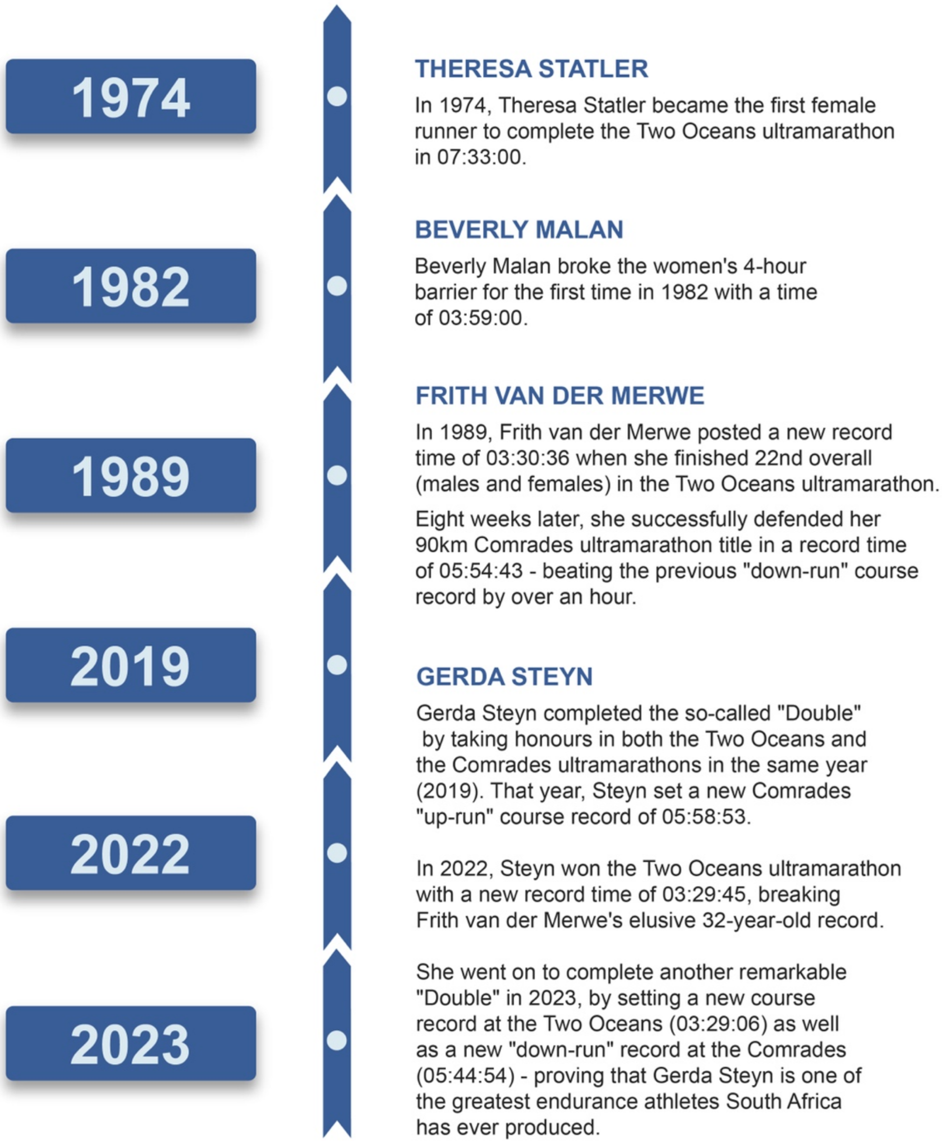

Figure 4: South African female running performance throughout the history of the Two Oceans Ultramarathon.

2.5 THE CONCEPT OF PACING

Pacing in endurance running is essential for elite athletes who aim to achieve record-breaking performances or for the lesser athlete who aims to run a personal best by improving their individual performance (Santos-Lozano et al., 2014). Appropriate pacing strategies help prevent premature fatigue (Tucker & Noakes, 2009), reduces the risk of sustaining musculoskeletal injuries (De Koning et al., 2011), and enhances the overall enjoyment of the race (Cuk et al., 2019).

Abbiss and Laursen (2008) describe three main pacing profiles applicable to marathon running:

a) *Positive pacing* refers to a speed profile where the runner will start the race at a fast pace and then slow down in the second half of the race.
b) *Negative pacing* refers to a slower start, followed by an increase in running speed in the second half of the competition. The rationale behind negative pacing is to prevent premature glycogen depletion, to reduce oxygen demands to the working muscles, and to reduce the concentration of blood lactate, thereby delaying physiological fatigue and preventing a subsequent decrease in running performance (Hanley, 2016).
c) *Even pacing* is characterised by maintaining a steady speed throughout a race and is considered an ideal component of pacing strategy in long-distance events (Renfree & Gibson, 2013).

The concept of pacing has been a topic of great interest in running performance research in recent years, with several pacing patterns emerging. The next section will explore pacing patterns as seen in elite running as well as mass-participation events.

2.5.1 Pacing Strategies in Elite Marathon Running

Although positive pacing was previously the most common strategy among runners (Hanley, 2016), in the last 50 years a tendency toward negative pacing was noted among the best marathon runners in the world. A study investigating the pacing profiles of male World Marathon runners from 1967 to 2018, classified runners from 1967 to 1988 as “classic” athletes - finding that these runners typically displayed positive pacing profiles (Diaz et al., 2018). The more modern approach by “contemporaneous” athletes - from 1988 to 2018 - was to adopt negative pacing patterns. The best classic runners started a race faster than the ideal speed needed to break the world record. Due to these unsustainable initial speeds, runners displayed a significant decrease in pace during the last kilometres of the race. Contemporary athletes, on the other hand, completed the first 21 to 25km of the race at a slower, more even pace and then increased their speed from 25km to the finish line.

In a similar study conducted on elite female runners, Renfree and Gibson (2013) investigated the pacing strategies of World Championship marathoners. They found that the fastest competitors ran at a lower percentage of their personal best times for the first and second 5km segments of the race after which they increased their running speed. These runners were able to maintain a faster running speed throughout the race and showed less segment-to-segment speed variability than the slower runners. The strategies employed by the fastest athletes lead to better performances than the slower athletes, achieving marathon finishing times closer to their personal best times. The relative under-performance of the slower runners could be attributed to the selection of an initial speed that was unsustainable for the duration of the race. This led to considerable speed reductions later in the race (positive pacing) as the runners became fatigued. The authors believe that selecting inappropriate initial work rates compromises a runner's ability to fully realise physiological performance potential (Renfree & Gibson, 2013).

In a more recent study on world champions and Olympic medallists (Hettinga et al., 2019), it was shown that male athletes showed greater pacing variability compared to female athletes who paced more evenly throughout the race. All male athletes and eight out of nine female champions ran negative splits. Interestingly, all male athletes started the race off slower than all female athletes relative to their best marathon times; they ran the middle section of the race faster, but then showed greater speed reductions in the final segments of the race compared to the female athletes. These results differ from the findings by Diaz et al. (2019). In their study, female runners paced less evenly than males, and male runners were able to increase their running speed in the latter stages of the race as opposed to slowing down. It can be argued that the pacemakers in the study by Diaz et al. helped the best athletes to achieve even or negative pacing. These findings highlight the differences between championship and non-championship running which should be considered during preparation for elite competition.

2.5.2 Pacing Strategies in Mass-participation Events

The studies above are examples of how previous research focused more on smaller samples of elite and top-class runners or those achieving world record performances. More recently, the availability of data from mass-participation events has enabled researchers to broaden their scope of interest to include a wider range of athletes, including non-elite or recreational runners. This allows for large-scale comparison of pacing profiles adopted by runners in a variety of different races and environments. Several pacing differences have emerged, most notably that male runners are more likely to slow down in a marathon than female runners (Deaner et al., 2015; Kais et al., 2019) and that faster, female, and older runners pace more evenly in the marathon (Cuk et al., 2019; March et al., 2011).

The pacing profiles of female participants in the Tokyo, Osaka and Nagoya marathons was first investigated by Ely et al. (2008). All three races have a similar profile (flat and excellent quality running surface) and are located at or near sea level, allowing for comparison of results between these three popular Japanese marathons. Participants were of a more advanced level of ability, as qualifying is needed to partake in each of the events. It was found that race winners maintained an even pace throughout the race, whilst slower runners started off relatively fast compared to their mean race pace over the first 5km then settle into a running speed that they could maintain for 20-25km before slowing down for the rest of the race until the end spurt at 40km. Similar to Renfree and Gibson (2013), the authors recommend adopting an even pacing strategy for optimal performance, as variability in pacing is associated with greater physiological load and slower performance (Staab et al., 1992).

In the United States, March et al. (2011) compared pacing strategies according to age and sex. More recently, Kais et al. (2019) followed suit. Both studies found that older, female, and faster runners were better pacers than their younger, male, and slower counterparts. The authors believe that older runners potentially pace better due to their experience. Older runners are more aware of their own abilities and limitations making them more skilled in effectively distributing their running speed.

When considering sex-differences in pacing, it is believed that female and male runners are motivated differently when competing in long distance running. Female endurance runners, as interviewed by Boudreau and Giorgi (2010), are generally less competitive and their aim is to socialise, enjoy the race and finally – to cross the finish line. In contrast, male runners are more success-driven, leading them to speed up during the race to try to outrun their opponents (Casado et al., 2020). In addition, Deaner et al. (2015) found that faster male runners (3:00:00 finishing time) slowed approximately 25% more than female runners (3:26:00 finishing time). In the slower categories (5:00:00 finishing time for males vs 5:36:00 for females) the male runners slowed approximately 30% more than female runners during the second half of the race, suggesting that female runners might pace more effectively than males.

Similar findings by Hubble and Zhao (2016) showed that female athletes slowed 8%, compared to 11% by male athletes as the race progressed. In their novel study, the authors had runners predict their finishing time ahead of the race. In male runners their pre-race predictions did not meet their actual finishing times. The overall finding was that male runners under-performed compared to the females, indicating that over-confidence is a possible explanation for poor outcomes. The pacing variability shown amongst male runners lead to poorer performances possibly due to over-optimism regarding their finishing times. An alternative explanation for the shortfall in forecasted finishing time might be that females differ in their risk preferences. Female runners are more likely to set conservative goals, which might reflect a higher general aversion to risk (Boudreau & Giorgi, 2010; Krouse et al., 2011). These findings agree with Cuk et al. (2019) who compared sex-differences in pacing during the half-marathon and marathon. They found that male runners were more likely to accelerate during the start of the marathon, thereby adopting a “riskier” inappropriately fast start to the race, which causes them to slow down later. In contrast, during the half-marathon, male and female runners adopted similar pacing profiles. The authors argue that *physiological* rather than *psychological* factors influence pacing in male runners leading to progressive slowing in the marathon event and not in the half-marathon.

2.5.3 Pacing strategies in Ultramarathon Running

The heterogeneity of ultramarathon race formats in terms of terrain, distance and duration provides a challenge when comparing the results of ultramarathon pacing studies. Nonetheless, several pacing studies have investigated ultradistance running (Hofmann, 2014; Knechtle et al., 2015; Lambert et al., 2004; Parise & Hoffman, 2011; Renfree et al., 2015; Tan et al., 2016).

In the 100km IAU World Challenge (Lambert et al., 2004) it was found that faster runners showed fewer fluctuations in running speed throughout the race, maintaining their starting speed for the first 50km of the race, unlike the slower runners who slowed down earlier in the race. The fastest runners finished the race at a running speed that was within 15% of their starting speed, whereas slower runners displayed a much larger speed loss from start to finish. This indicates an overly ambitious initial running speed, that the lesser runners were unable to maintain throughout the race. Similar findings emerged in studies of the 161km Western States Endurance trail run (Hoffman, 2014; Parise & Hoffman, 2011). The fastest finishing times were achieved when runners were able to limit fluctuations in running speed, despite changes in course elevation. Race winners also displayed a more conservative start, potentially saving their energy resources for the latter stages of the race, thereby preventing them from having to slow down as the race progressed.

Female runners were more efficient at pacing during the 100km World Masters Championships (Renfree et al., 2015). Although various pacing profiles emerged in this study, it was found that female runners were able to maintain a more even pacing profile which was deemed to be the ideal approach as suggested in marathon running research (Cuk et al., 2019; Deaner et al., 2015; Ely et al., 2008; March et al., 2011). Several editions of the 100km Lauf Biel Ultramarathon (Knechtle et al., 2015) revealed that older runners (40 to 44 years) showed less pacing variability than younger runners (18 to 24 years) who showed a marked decrease in running speed as the race progressed (positive pacing). This finding was surprising as the authors hypothesised that running speed would decrease more rapidly with increasing age. Similar findings, however, emerged in another large-scale study of all 100km finishes between 1960 and 2012 (Cejka et al., 2015). The age of the fastest males increased from 29 to 40 years, whereas the age of the fastest females remained unchanged at 35.0 ± 9.7 years. It is believed that older runners have more years of training and extensive endurance running experience, which seem to be a requirement in successful ultramarathon running (Knechtle & Nikolaides, 2015). Interestingly, a marked reduction in the performance gap was noted between male and female runners. The average running speed in female runners improved from 8.06km/h to 13.22km/h, which reduced the sex difference in performance from 56.1% to 16.3% for the fastest female finishers compared to males. This finding could be explained by the nearly five-fold increase in female participation in 100km ultramarathons: from only 3.8% in 1969 to 15.0% in 2012 (Cejka et al., 2015).

2.5.4 The Ideal Pacing Strategy

From the research reviewed above, the ideal pacing profile still eludes researchers, although it seems that even pacing is most frequently suggested as the optimal approach in both marathon running (Deaner et al., 2015; Ely et al., 2008; March et al., 2011; Refree & Gibson, 2013) and ultramarathon running (Hoffman, 2010; Lambert et al., 2004; Renfree et al., 2015). This should be interpreted with caution, however, as an evenly paced race does not necessarily imply a successfully paced race. The athlete may have been overly cautious in their approach to the race when considering their training and ability. On the other hand, even though drastic slowing during the marathon will most certainly lead to a poor result, a riskier start may be effective when considering the desired end-result. An example might be a runner who wants to achieve a personal best or a podium position at least once in a season and the best way for them to achieve that goal might be to start the race at a faster, riskier pace (Deaner et al., 2015).

The norm of even pacing is further supported by marathon event organisers who provide "pace-group leaders" to assist runners in maintaining their target speed to achieve their desired result. Billat et al. (2019), however, found that athletes competing in these mass-participation events unsuccessfully try to maintain a constant running speed – regardless of sex, performance level or race profile. The authors disagree with Ely's (2008) suggestion that more successful runners show fewer changes in pace (i.e. low pacing variability) during a race. Considering that performance is limited by physiological ability, runners must consciously select a realistic running speed that will allow them to perform optimally. They must continuously adapt their pace in response to perceived effort, thereby making fluctuations in running speed inevitable (Billat et al., 2019).

In one of the largest pacing studies to date, Smyth (2018) analysed the pacing profiles of 1.7 million recreational marathon runners. Race results from 64 different races around the world over a period of 12 years were analysed. The study focused on the starting and finishing speeds of the runners and the influence it had on their overall marathon finishing times. The author found that fast starting *or* finishing speeds can both be an indication of poor pacing strategy. Adopting a faster running speed at the start of the race leads to early onset of fatigue, causing the runner to slow down and adds minutes to their finishing time. A faster finishing speed suggests overly conservative pacing earlier in the race which also leads to slower finishing times. Although female runners paced their race more effectively than males, their overly cautious approach may have cost them overall time.

Furthermore, Smyth (2018) showed that runners who ran the first 5km segment at, or very close to their mean race pace (MRP) had the best finishing times (233 minutes). Runners who started their race much faster or slower than their mean race pace had slower finishing times. A 10% faster running speed during the first 5km segment added 37 minutes to the average finishing time and a 10% slower running speed added about 29 minutes. The authors also compared individual marathon performances to each runner's personal best marathon time of the season. A significant finding was that 77% of all personal best times (across runners of all ability) during this 12-year period were achieved when runners would start within ± 5% of their MRP.

2.5.5 Pacing and Elevation

A runner's pacing strategy is chosen based on several factors such as altitude, ambient temperature, terrain, or gradient of the race profile (Breen et al., 2018). Insights on how elevation in a race influences pacing, is therefore especially relevant when attempting the Two Oceans Ultramarathon or a race with a similar course profile.

The Athens Classic Marathon is one of the most challenging marathons in the world as it is characterised by numerous hills and boasts the most strenuous uphill climb of all the major city marathons. A total of 51.2% of the race route is uphill with a total elevation of 317m and decent of 262m, making 40.5% of the route downhill (Myrkos et al., 2020). The increase in elevation from 21.1km to 30km is nearly 122m of uninterrupted uphill. Nikolaides and Knechtle (2018) investigated the pacing profiles of runners during the Athens Marathon. All runners displayed positive pacing, with female, older and faster runners pacing more evenly. The slowest finishers ran slower than medium to fast finishers during the inclines of the race (Myrkos et al., 2020). During the last segments of the race, which is mostly downhill, slower runners were unable to increase their speed. One could argue that downhill running places an increased eccentric load on the already fatigued musculoskeletal system, preventing the runner from increasing their running speed.

The New York Marathon is the perfect example that time lost on the uphill segments cannot be caught up by accelerating downhill. This race profile starts with a steep hill, has several hills throughout the race and ends with another hilly segment. Although the New York Marathon allows for a fast finish, it never compensates for the slow pace at the start (Diaz et al., 2019). In the following section, current knowledge on physiological factors associated with fatigue and how it influences performance during graded running (uphill, level and downhill), will briefly be presented.

2.6 THE PHYSIOLOGY OF ENDURANCE RUNNING

Although the physiology of running is beyond the scope of this dissertation, it adds valuable insight to understand the mechanisms that underpin fatigue and how it influences pacing during endurance events.

2.6.1 Proposed models of fatigue

Several different models have been proposed to explain how the human body responds to fatigue during prolonged exercise. The cardiovascular/ anaerobic model, as discussed by

Green (1997) and Noakes (2000), postulates that fatigue sets in when the cardiovascular system can no longer meet the oxygen demands of or remove waste products from the active muscles. A similar model is the supply/ energy depletion model (Shulman & Rothman, 2001). The basis of this model is that fatigue occurs due to two factors:

a) the inability to supply adenosine triphosphate (ATP) to the active muscles via the energy production cycle of glycogen metabolism.
b) a lack of fuel due to the depletion of energy resources which include blood glucose, muscle and liver glycogen, and phosphocreatine (Bosch et al., 1993).

In the central governor model, Noakes et al. (2004) state that prolonged exercise is regulated by a governor located in the central nervous system. It uses signals and feedback provided by muscles and organs to control exercise output, preventing damage or injury to physiological systems. Similarly, the theory of teleoanticipation proposes that the brain continuously regulates and modifies effort according to feedback information from a range of peripheral and central signals, thereby controlling pace in a feedforward manner (Ulmer, 1996). The pacing process that the brain uses for a specific event (with a known endpoint) is based on previous experience of distance, duration, and pacing strategies to optimise performance (Mauger et al., 2009).

2.6.2 Neuromuscular fatigue

Millet (2011) believes that all these proposed models of fatigue are interrelated and potentially contribute to the development of "neuromuscular fatigue". The term neuromuscular fatigue is used to describe the progressive deterioration of force generation during voluntary or simulated muscle contraction, caused by exercise-induced changes that occur within muscles and/ or the central nervous system (MacIntosh & Rassier, 2002).

Central fatigue involves changes or limitations within the central nervous system (brain and spinal cord) due to various factors such as alterations in neurotransmitter function, impaired neural drive, and changes in the excitability of motor neurons (Gandevia, 2001). During

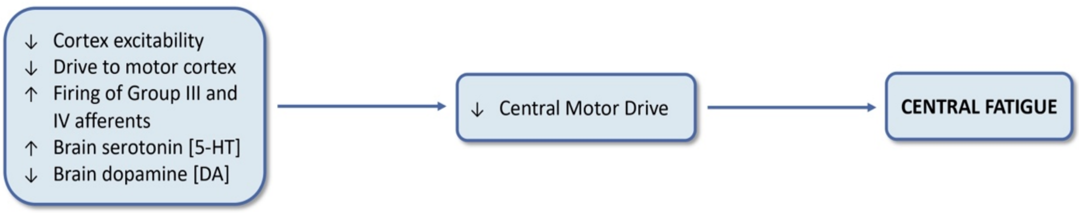

Figure 5: Central factors that contribute to neuromuscular fatigue (Shei & Mickleborough, 2013).

intense or prolonged exercise, alterations in the concentration or activity of neurotransmitters, such as serotonin and dopamine, in the brain may occur. Increased serotonin levels, for example, are associated with increased levels of perceived exertion and can affect motor neuron activity (Meeusen et al., 2006). The ability of the motor cortex to recruit and activate motor neurons can be compromised, resulting in a reduced force-generating capacity of the working muscles (Taylor et al., 2006). Psychological factors such as motivation, perception of effort, and mental fatigue can also contribute to central fatigue, which may influence the athlete's willingness or ability to continue exerting effort (Meeusen et al., 2006).

Peripheral fatigue involves changes or limitations at the muscular level, away from the central nervous system. Factors such as depletion of energy substrates, accumulation of metabolic by-products, and impaired excitation-contraction coupling can contribute to peripheral fatigue (Shei & Mickleborough, 2013). During sustained or intense muscle activity, depletion of energy substrates, particularly adenosine triphosphate (ATP) and phosphocreatine (PCr) occurs (see Chapter 2.6.1), which are essential for muscle contraction (Bosch et al., 1993). The accumulation of metabolites, such as inorganic phosphate, lactate, ammonium, and hydrogen ions increase the acidity in the muscle milieu and may impair muscle function by reducing adequate force production (Cooke & Pate, 1985). Impairments in the processes that link neural excitation to muscle contraction, known as excitation-contraction coupling, can also contribute to peripheral fatigue. This may lead to disruptions in the release and sensitivity of calcium ions, which are crucial for muscle contraction (MacIntosh et al., 2012).

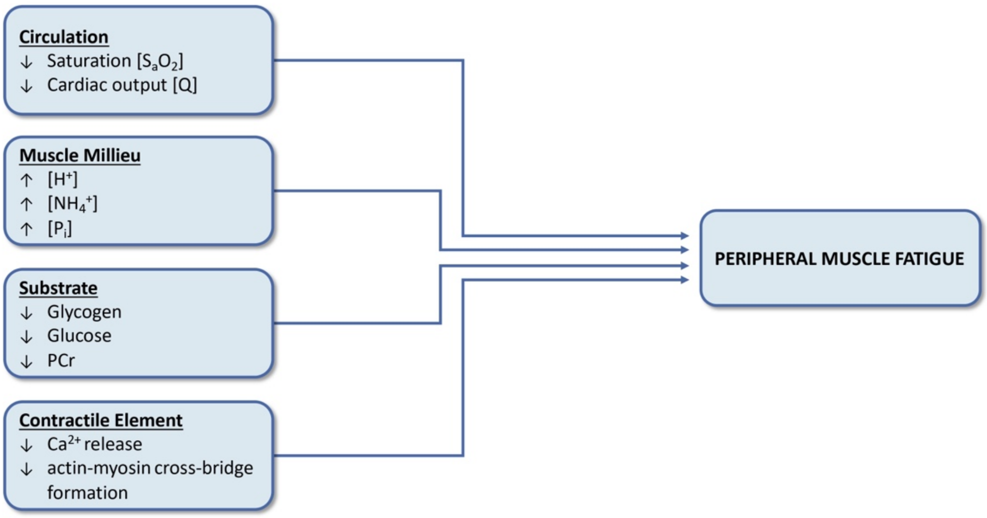

Figure 6: Peripheral factors that contribute to muscle fatigue (Shei & Mickleborough, 2013). S_aO_2: Saturation of arterial hemoglobin; [H^+]: Hydrogen ion concentration; [NH_4^+]: Ammonium ion concentration; [P_i]: Inorganic phosphate concentration; PCr: Phosphocreatine; Ca^{2+}: Calcium ion

Numerous studies on neuromuscular fatigue have emerged from research on ultramarathon running (Bontemps et al., 2020; Espeit et al., 2020; Gauche et al., 2006; Millet et al., 2002; Petersen et al., 2007; Racinais et al., 2007; Ross et al, 2007; Vernillo et al., 2015). The intensity, duration and energy demand of endurance running likely induce extreme fatigue, making these athletes the ideal study subjects. The aim of these studies was to determine whether the mechanism responsible for fatigue originated from the working muscle (peripheral fatigue) or from the central nervous system (central fatigue) and to what extent it influenced performance during and/ or after an exercise task.

The loss of maximum voluntary contraction (MVC) in skeletal muscle is commonly used to assess an athlete's overall state of neuromuscular fatigue (Gandevia, 2001). Millet et al. (2002) found a ~30% decrease in MVC of the knee extensors following a 65km ultramarathon in well-trained male athletes. Similarly, Martin et al. (2010) found a ~41% reduction in MVC of knee extensors of experienced ultramarathon runners following a 24-hour treadmill run. Likewise, a 22% and 17% reduction in MVC of the knee extensors and plantar flexors, respectively, was detected in elite marathon runners (Peterson et al., 2007). In elite ultra-trail running, a 24 to 39% decrease in MVC of the plantar flexors was also noted (Besson et al., 2020; Millet et al., 2011; Saugy et al., 2013; Temesi et al., 2015).

It is believed that central fatigue is responsible for the reduction in voluntary activation of the musculature involved during endurance running, which results in the inability of the working muscles to recruit all motor units and discharge them at the rates necessary for maximum force production (Ross et al., 2007). Some propose that the reduced central drive to the muscle may serve as a protective mechanism, preventing muscle damage during prolonged effort (Martin et al., 2010; Noakes, 2007). Others, however, found that peripheral fatigue can contribute to reduced force production due to changes within the muscle itself, especially in races with large elevation changes (Millet et al., 2018). Repeated eccentric contractions of the muscle, especially during braking phases in downhill segments, has been found to cause low frequency fatigue in skeletal muscles. Low frequency fatigue, caused by impaired excitation-contraction coupling due to reduced calcium release from the sarcoplasmic reticulum, is the direct result of damage to the muscle fibres (Millet et al., 2011).

It is important to note that central and peripheral fatigue often interact, and the differentiation between these two mechanisms remains unclear. Recognising the multifaceted nature of fatigue is vital, emphasising the significance of maintaining optimal pacing in endurance running. In the upcoming section, we will briefly elaborate on the physiological requirements of graded running as it pertains to a challenging event such as the Two Oceans Ultramarathon.

2.6.3 Physiological demands of graded running

Running is generally considered as a single mode of exercise, but uphill, level, and downhill running requires distinctly different physiological, neuromuscular, and biomechanical adaptations (Vernillo et al., 2017). Of all the factors that influence pacing, changes in elevation pose the greatest challenge as they demand the greatest change in energy expenditure. For instance, running speed was found to reduce by 0.1 to 0.3 km/h per 1% change in elevation (Mastroianni et al., 2000; Townshend et al., 2010). Knowledge regarding the physiological and biomechanical influence of graded running is therefore essential as it provides a more comprehensive understanding of how the human locomotive system responds to changes in elevation and how and athlete should regulate pacing behaviour appropriately (Lemire et al., 2021).

Gregor and Costill (1973) showed a 40% increase in oxygen consumption when changing from level to uphill running. Changing from level to downhill running, however, only led to a 27% decrease in oxygen consumption, indicating that that the increased metabolic demand of running uphill is not reversed by the decreased metabolic demand of running downhill. Staab et al. (1992) advise that long-distance runners pay careful attention to the length, location and gradient of hills when considering the severity of hilly segments in preparation for a race. Their study found that uphills located later in the race had a greater impact on running pace than earlier in the race. In view of these findings, it was advised that runners slow their pace on long uphills, thereby reducing the physiological demand as this may allow the athlete to increase their pace on the flat and downhill sections later in the race.

During flat marathons, runners generally adopt an even pace (Diaz et al., 2019) or negative split (speeding up in the second half) as described above. When considering the more challenging race profile of the Two Oceans Ultramarathon, modification of pacing strategy becomes an essential part of the athlete’s race planning. Theoretically, if the athlete ran faster during the first half of the race, it would allow for slowing down during the second half of the race when the elevation becomes significantly more challenging. This strategy would avoid the need to make up lost time during the downhill sections which could potentially lead to physiological failure (Doherty et al., 2020). In addition, if a runner is familiar with how the race elevation will change and how to adjust their pace accordingly, it might prevent a state of panic when they see they are slowing down during the uphill segments. Normally, the reaction is to increase effort to maintain a steady pace, leading to excessive fatigue and a subsequent dramatic decrease in running speed – resulting in a poor race performance. Prior knowledge of the race profile and how to adjust running speeds accordingly, would optimise pacing strategy and improve race outcomes.

2.7 SUMMARY OF THE LITERATURE

Previous pacing studies suggest that marathoners should ideally adopt even pacing during competition (Cuk et al., 2019; March et al., 2011). In modern marathon running, however, a tendency towards negative pacing has been found in world-record performances (Diaz et al., 2018). Although maintaining an even pacing profile by limiting variability in running speed might be ideal, one must consider the effect of elevation on running speed (Haney & Mercer; 2011).

Examining the pacing patterns of elite performers is particularly valuable, as these athletes refine their pacing strategies in preparation for competition to achieve their specific race goals. Understanding optimal pacing strategy in ultramarathon performance, can assist elite runners to improve their competitive approach. Similarly, recreational athletes attempting their first ultramarathon or those aiming to improve on previous attempts may gain valuable insights improved racing strategies. As female participation rates in the ultramarathon are rapidly increasing, more research is needed to understand the pacing trends adopted by both elite and non-elite athletes in ultra-races. The focus of this study, the Two Oceans Ultramarathon, therefore investigated pacing profiles of runners of various ability and their response to changes in elevation over a challenging 56-kilometre course.

Table 1: Summary of observational pacing studies conducted on international elite and mass participation endurance running events.

Study	Distance	Competition	Sex	Pacing Profile Observed
Elite events				
Renfree et al. (2013)	Marathon	World Championship	Females	Positive
Angus (2014)	Marathon	World record performance	Males	U-shaped, varied
Hanley (2016)	Marathon	Olympic Games, World Championships	Males, females	Positive
Diaz et al. (2018)	Marathon	World record performance	Males	Positive, negative
Diaz et al. (2019)	Marathon	World Marathon Majors	Males	Differed depending on course
Diaz et al. (2019)	Marathon	World record performances	Males, females	Negative, even
Hettinga et al. (2019)	Marathon	Olympic Games, World Championships	Males, females	Positive
Kais et al. (2019)	Marathon	World Marathon Majors	Males, females	Positive
Billat et al. (2020)	Marathon	World record performance	Males, females	Negative, even
Mass participation events				
Ely et al. (2008)	Marathon	Tokyo, Osaka, Nagoya (Japan)	Females	Positive, even
March et al. (2011)	Marathon	Midwestern U.S. marathon course	Males, females	Negative
Santos-Lozano et al. (2014)	Marathon	New York (USA)	Males, females	Positive
Deaner et al. (2015)	Marathon	14 different U.S. marathons	Males, females	Positive, even
Hubble & Zhao (2016)	Marathon	Houston (USA)	Males, females	Positive, even
Nikolaides & Knechtle (2018)	Marathon	Athens (Greece)	Males, females	Positive
Smyth (2018)	Marathon	Amsterdam, Berlin, Boston, Chicago, Hamburg, London, Los Angeles, New York, Rotterdam, Stockholm, Tokyo	Males, females	Varied
Cuk et al. (2019)	Marathon	Vienna (Austria)	Males, females	Positive
Ultramarathons				
Lambert et al. (2004)	100km	IAU World Challenge	Males	Positive, even
Renfree et al. (2015)	100km	World Masters Championships	Males, females	Varied

Knechtle et al. (2015)	100km	Lauf Biel, Switzerland	Males	Positive, negative
Tan et al. (2016)	101km & 161km	Craze Ultramarathon (Singapore)		Positive
Parise & Hoffman (2011)	161km	Western States Endurance Run (2006-2007)	Males, females	Positive
Hoffman (2014)	161km	Western States Endurance Run (1985-2013)	Males, females	Positive

CHAPTER 3: A COMPARISON OF PACING STRATEGIES ADOPTED BY ELITE VERSUS NON-ELITE FEMALE TWO OCEANS ULTRAMARATHON RUNNERS

3.1 INTRODUCTION

Marathon running enjoys popularity amongst male and female competitors alike. However, female marathon running first gained serious attention relatively recently, in the 1980s. Since then, the rapid improvement in female running performance has led to a growing amount of research focused on their participation in distance running. Despite the growing number of women participating in sporting events, female athletes are still significantly under-represented in Sports and Exercise Medicine literature (Costello et al., 2014). Female athletes possess several physiological attributes that may provide an advantage in ultradistance competition, including greater fatigue resistance, improved substrate (fat) utilisation and lower energy demands (Besson et al., 2022; Tiller et al., 2021). These differences emphasise the need to implement sex-specific strategies in race preparation and execution to potentially enhance female ultramarathon running performance (Kelly, 2023). The results of this study might add to research currently available on female endurance running, which suggest that female runners are more proficient in pacing compared to their male counterparts (Deaner et al., 2015).

3.2 METHODS

3.2.1 Study design

This research project has a retrospective, descriptive study design.

3.2.2 Sample

a) Inclusion criteria

All female runners, who successfully completed the 56km Two Oceans Ultramarathon, from 2007 until 2018, within the seven-hour cut-off time, were included in the study.

b) Exclusion criteria

1. Runners who did not finish the race or who had missing split times in their race results were excluded from the study.

2. Data from 2015 and 2019 were excluded. During these years the race organisers were forced to use an alternative route. The route therefore differs from previous years and was not included for analysis.
3. Data from 2020 and 2021 are not available due to the COVID-19 pandemic. In those years “virtual” races were run, and no official data are available.

3.2.3 Recruitment technique and sample size

The Two Oceans Ultramarathon database (www.twooceansmarathon.org.za) was utilised for this study. This database provides race results of thousands of runners following the event each year. Due to the public availability of the data no formal consent was needed from participants to use the information obtained from the website.

A stratified sampling technique was used to include the entire female population of runners that participated in the 2007, 2008, 2010, 2011, 2012, 2013, 2014, 2016, 2017 and 2018 editions of the 56km ultramarathon race.

3.3 STUDY PROCEDURE

3.3.1 Procedure

Microsoft Excel spreadsheets were used to capture the race results from each year that was analysed (Appendix I). Datasheets were filtered to include all runners that satisfied the inclusion criteria or eliminated according to the exclusion criteria. A total of 420 runners were removed from the study due to missing split times, resulting in a total of 9 682 eligible female participants for data analysis. All the eligible runners and their respective results from each year were subsequently combined into a single document and then sorted from fastest to slowest finisher. All duplicates (where a runner ran more than once in the sample period) were removed. In those instances, only the fastest result for each runner was retained for analysis.

Participants were categorised into seven distinct groups based on their finishing time. The first group, Group A, comprised of all runners who finished between 03h30 and 04h00, which included the “elite” female runners. The next selection of runners was grouped from 04h00 to 04h30 (Group B), then from 04h30 to 05h00 (Group C), followed by 05h00 to 05h30 (Group D), then 05h30 to 06h00 (Group E), 06h00 to 06h30 (Group F) and finally from 06h30 to the 07h00 cut-off time (Group G). All the finishers in each group were used for analysis.

From 2007, the race organisers started recording intermediate split times of all runners at four distinct distance segments: 28km, 42km, 50km and 56km. These timed intervals were used to calculate the split (segment) time of each runner, which was then used to calculate their average running speed in kilometres per hour (km/h) over that distance. The overall mean race pace (in km/h) for each runner was also calculated using their finish time at 56km.

In addition, the running speed of each athlete for the 28km segment was assigned a 100%-value and running speeds at all subsequent splits were "normalised" accordingly. In other words, the running speeds at all other segments were calculated as a percentage of their running speed over the first 28km (Appendix I). Similarly, the data were also expressed based on the overall mean race pace, where the mean pace was assigned a 100%-value and the running speed for each of the cohorts at the various distance intervals was calculated (normalised) as a percentage of their mean race pace.

3.3.2 Statistical analysis

Due to the complex nature of the data and the statistical analysis that needed to be performed, the expertise of a statistics consultant employed by the University of Cape Town was required. The Generalised Linear Mixed Effects Model (GLMM) was employed to ascertain if a statistically significant difference exists in the pacing profiles across the seven groups of runners. The response variable, pace (expressed in km/h), is a continuous measure determined at each of the four timing checkpoints (segments), for each participant as described above. Table 7 shows the average pace (in km/h) per segment for each group investigated (Groups A to G).

A subject-specific random effect was integrated into the model to accommodate the intra-subject correlation resulting from repeated measures. Pairwise comparisons were performed to identify significant differences in running pace within each group (Table 8) as well as between group A and progressively slower groups (Table 9) over the different segments of the race. These tables containing the results include the estimated values, standard errors, degrees of freedom, t-ratios, and p-values for each of the pairwise comparisons. The t-ratio column represents the t-statistic calculated by dividing the estimate by the standard error. The higher the absolute value of the t-ratio, the more significant the difference between the segments. The p-value column displays the p-value associated with the t-ratio, indicating the probability of observing such a difference by chance. Since multiple pairwise comparisons were made, the Bonferroni correction was applied to control for the increased chance of obtaining false positives. The Bonferroni correction adjusts the p-values by dividing the significance level (0.05) by the number of comparisons performed. In addition, post-hoc tests utilising the Tukey method were performed to determine whether the differences found between groups were statistically significant.

While a p-value informs the reader whether an effect exists, it does not demonstrate the size of the effect. Therefore, in addition to reporting on statistical significance, effect size was also calculated using Cohen's *d* index. Cohen classified effect sizes as small ($d = 0.2$), medium ($d = 0.5$) and large ($d \geq 0.8$) when measuring the standardised difference between two means of independent groups, or (mean of group 1) – (mean of group 2)/ pooled standard deviation.

3.3.3 Ethics considerations

Ethics approval was obtained from the Human Research Ethics Committee of the Faculty of Health Sciences of the University of Cape Town (HREC REF: 287/2022) prior to the commencement of this study (Appendix II: Ethics Approval Letter, Appendix III: Annual Progress Report).

a) Confidentiality of data and protection of participation privacy

All data were stored on a password protected computer and will be stored for a duration of 5 years following the study. Privacy and confidentiality of information obtained is thus ensured. Only the student researcher had access to the primary data collected and analysed. The personal information of participants was coded so that no participant could be identified from the datasheets that were used for analysis.

b) Potential risks and benefits to participants

There were no risks associated with this study as only past race results from a race results database were analysed. There were also no benefits to the runners whose data were analysed. However, in general terms, with each edition of the Two Oceans Marathon, runners are provided with a race pack containing an information booklet about the event. This could potentially provide the opportunity to publish a summary of this study – allowing for the dissemination of information gathered. Participants can then use this information when planning any future Two Oceans marathon race pacing strategy.

3.4 RESULTS

3.4.1 Descriptive characteristics of participants

The descriptive characteristics of the runners included in this study are summarised in Table 2. The sample in this study consisted of 9 682 female runners who successfully completed the Two Oceans Ultramarathon between 2007 and 2018. Most runners were South African (n=8173; 84.4%). The fastest runners (group A) were the youngest (33.6 ± 5.1 years) and the slowest runners (group G) were the oldest (39.5 ± 8.7y). Only 0.5% of runners were able to finish in four hours or less (49 of 9 682 participants). In contrast, 31.6% of participants (3 064 of 9 696) finished in the last 30 minutes before the cut-off time at seven hours (group G). More than half of all the runners (56.4%) needed six hours or more to finish the race (group F and G).

Table 2: Descriptive characteristics of participants (age, mean race pace, and finish time) from group A to G. Data are presented as mean ± standard deviation (SD).

	Group A (*n* = 49)	Group B (*n* = 105)	Group C (*n* = 512)	Group D (*n* = 1115)	Group E (*n* = 2441)	Group F (*n* = 2404)	Group G (*n* = 3056)
Age (y)	33.6 ± 5.1	37.3 ± 6.3	37.2 ± 6.8	38.5 ± 7.4	39.2 ± 8.1	39.4 ± 8.4	39.5 ± 8.7
Mean Race Pace (min:sec/km)	04:05 ± 00:08	04:37 ± 00:09	05:10 ± 00:09	05:41 ± 00:09	06:12 ± 00:09	06:44 ± 00:09	07:14 ± 00:09
Mean Race Pace (km/h)	14.71 ± 0.49	13.01 ± 0.42	11.62 ± 0.33	10.57 ± 0.27	9.68 ± 0.23	8.92 ± 0.20	8.30 ± 0.17
Finish time (hr:min:sec)	03:48:41 ± 00:07:28	04:18:34 ± 00:08:14	04:49:19 ± 00:08:00	05:18:12 ± 00:08:06	05:47:16 ± 00:08:13	06:16:57 ± 00:08:25	06:44:56 ± 00:08:20

Table 3: Total number of eligible male and female finishers per year from 2007-2018. The percentage of female participants were calculated for each year (Female Participation Rate) out of the entire field of runners.

Year	Female	Male	Total	Female Participation Rate (%)
2007	1499	5005	6504	23.05
2008	1361	4389	5750	23.67
2010	1818	5458	7276	24.99
2011	1418	4318	5736	24.72
2012	1990	5706	7696	25.86
2013	2152	5980	8132	26.46
2014	2232	5908	8140	27.42
2016	2453	6204	8657	28.34
2017	2661	6430	9091	29.27
2018	2592	6375	8967	28.91

Note: The total participants for each year in both male and female categories were calculated according to the same inclusion criteria (section 3.2.2a). Duplicates, however, were not removed.

In table 3 the total number of eligible female participants is listed for each year included in the study. In addition, the total number of male participants is also provided for each year. These totals for both male and female runners are based on the same inclusion and exclusion criteria stipulated in the Methods section (chapter 3.2.2). Duplicates, however, were not removed in cases where a runner participated in more than one edition of the race. When the percentage of female representation is calculated from the entire field of runners in each year, a steady increase is noted from 2007 to 2018, with an overall growth of nearly 6%.

Table 4 shows the top 10 performances when results from all 10 editions of the Two Oceans Ultramarathon in the study were combined. Only the fastest time from each runner was considered if they participated in more than one of the race editions included in the study. The top 10 overall female runners comprised of six Russian, two South African, one Belarusian and one Zimbabwean athlete. All four of the fastest females were of Russian descent. If the top 50 performances are considered between 2007 to 2018, without the removal of duplicates, all but one of the top 10 performances were achieved by Russian athletes (Table 5).

Table 4: The top 10 performances of all female Two Oceans Ultramarathon runners from 2007-2018 with duplicates (runners who participated more than once) excluded.

Athlete	Age	Country	Year	Finish Time
1. OLESYA NURGALIEVA	35	Russia	2011	03:33:59
2. MADINA BIKTAGIROVA	42	Russia	2007	03:35:05
3. LILIA YADZHAK	36	Russia	2007	03:35:16
4. ELENA NURGALIEVA	32	Russia	2008	03:35:25
5. MARYNA DAMANTSEVICH	33	Belarus	2017	03:37:08
6. TATYANA ZHIRKOVA	37	Russia	2008	03:39:24
7. GERDA STEYN	28	South Africa	2018	03:39:32
8. THABITA TSATSA	40	Zimbabwe	2013	03:39:54
9. NINA PODNEBESNOVA	34	Russia	2014	03:40:08
10. CHARNE BOSMAN	37	South Africa	2013	03:40:16

Table 5: The top 50 performances of all female Two Oceans Ultramarathon runners from 2007-2018 with duplicates included.

Athlete	Country	Year	Finish Time
1. OLESYA NURGALIEVA[4th attempt]	Russia	2011	03:33:59
2. OLESYA NURGALIEVA[2]	Russia	2008	03:34:53
3. MADINA BIKTAGIROVA[1]	Russia	2007	03:35:05
4. LILIA YADZHAK	Russia	2007	03:35:16
5. ELENA NURGALIEVA[2]	Russia	2008	03:35:25
6. ELENA NURGALIEVA[1]	Russia	2007	03:35:35
7. OLESYA NURGALIEVA[1]	Russia	2007	03:35:55
8. MARYNA DAMANTSEVICH	Belarus	2017	03:37:08
9. ELENA NURGALIEVA[4]	Russia	2011	03:37:55
10. TAYANA ZHIRKOVA[2]	Russia	2008	03:39:24
11. GERDA STEYN	South Africa	2018	03:39:32
12. THABITA TSATSA	Zimbabwe	2013	03:39:54
13. NINA PODNEBESNOVA[3]	Russia	2014	03:40:08
14. CHARNE BOSMAN[1]	South Africa	2013	03:40:16
15. SIMONA STAICU[1]	Hungary	2007	03:40:40
16. ELENA NURGALIEVA[5]	Russia	2013	03:41:42
17. OLESYA NURGALIEVA[3]	Russia	2010	03:41:53
18. DOMINIKA STELMACH	Poland	2018	03:41:57
19. MAMORALLO TJOKA[1]	Lesotho	2011	03:42:13
20. ELENA NURGALIEVA[3]	Russia	2010	03:42:19
21. SIMONA STAICU[2]	Hungary	2011	03:43:01
22. SHITAYE DEBELLU	Ethiopia	2014	03:43:38
23. NINA PODNEBESNOVA[1]	Russia	2011	03:43:57
24. ELENA NURGALIEVA[6]	Russia	2014	03:44:00
25. MAMORALLO TJOKA[2]	Lesotho	2013	03:44:40
26. CAROLINE WÖSTMANN	South Africa	2016	03:44:44
27. NINA PODNEBESNOVA[2]	Russia	2013	03:45:14
28. ELLIE GREENWOOD	Great Britain	2013	03:45:15
29. CHARNE BOSMAN[3]	South Africa	2018	03:45:22
30. NATALIA VOLGINA	Russia	2012	03:45:29

31. TANITH MAXWELL(1)	South Africa	2016	03:45:55
32. MAMORALLO TJOKA(3)	Lesotho	2014	03:46:13
33. ELIZABETH HAWKER	Great Britain	2011	03:46:47
34. MADINA BIKTAGIROVA(2)	Russia	2008	03:46:53
35. JENNA CHALLENOR	South Africa	2017	03:47:27
36. IMMACULATE CHEMUTAI	Uganda	2013	03:47:36
37. AMELEWORK BOSHO	Ethiopia	2016	03:47:40
38. CHARNE BOSMAN(2)	South Africa	2016	03:48:41
39. SAMUKELISO MOYO(1)	Zimbabwe	2007	03:49:00
40. SAMUKELISO MOYO(2)	Zimbabwe	2012	03:49:09
41. ADINDA KRUGER(1)	South Africa	2010	03:49:23
42. TATYANA ZHIRKOVA(1)	Russia	2007	03:49:30
43. TANITH MAXWELL(2)	South Africa	2018	03:49:49
44. ADINDA KRUGER(2)	South Africa	2012	03:50:13
45. ANN ASHWORTH	South Africa	2018	03:50:35
46. PAULINA NJEYA	South Africa	2014	03:50:49
47. MICHELLE WILLIAMS	South Africa	2013	03:50:59
48. OLESYA NURGALIEVA(5)	Russia	2014	03:51:47
49. FARWA MENTOOR	South Africa	2011	03:52:07
50. TSHIFHIWA MALOBOLA	South Africa	2010	03:52:22

Note: The superscript value next to an athlete's name indicates the number of attempts it took to accomplish that finishing time if they achieved a Top 50 position in more than one edition of TOM between 2007 and 2018. For example, Olesya Nurgalieva achieved her 03:33:59 finish time in 2011 on her fourth attempt and her 03:34:53 time in 2008 on her second attempt.

Table 6 includes a summary of elite female runners who achieved multiple finishes within the top 50 from 2007 to 2018. Although not included in this study, the previous and current course records set by Gerda Steyn in 2022 and 2023, respectively, are also shown in Table 6. The fastest result of each of these athletes were included in the study.

Table 6: A summary of the top performances of elite females who achieved multiple Two Oceans Ultramarathon finishes within the top 50.

Athlete	Country	Year	Finish Time	MRP (km/h)
OLESYA NURGALIEVA	Russia	2011	03:33:59	15.70
		2008	03:34:53	15.64
		2007	03:35:55	15.56
		2010	03:41:53	15.14
		2014	03:51:47	14.50
MADINA BIKTAGIROVA	Russia	2007	03:35:05	15.62
		2008	03:46:53	14.81
ELENA NURGALIEVA	Russia	2008	03:35:25	15.60
		2007	03:35:35	15.59
		2011	03:37:55	15.42
		2013	03:41:42	15.16
		2010	03:42:19	15.11
		2014	03:44:00	15.00
TATYANA ZHIRKOVA	Russia	2008	03:39:24	15.31
		2007	03:49:30	14.64
GERDA STEYN	South Africa	2023*	03:29:06**	16.07
		2022*	03:29:45	16.02
		2018	03:39:32	15.31
		2016	04:15:44	13.14
NINA PODNEBESNOVA	Russia	2014	03:40:08	15.26
		2011	03:43:57	15.00
		2013	03:45:14	14.92
CHARNE BOSMAN	South Africa	2013	03:40:16	15.25
		2018	03:45:22	14.91
		2016	03:48:41	14.69
SIMONA STAICU	Hungary	2007	03:40:40	15.23
		2011	03:43:01	15.07

*Not included in this study
**Current course record
MRP: Mean race pace

3.4.2 Pacing profiles displayed within groups

The pacing profile of all groups demonstrated a reverse J-shaped curve (Figure 7). All groups therefore displayed positive pacing early in the race, followed by negative pacing in the later stages of the race. Figure 7 illustrates how all groups of runners slowed down as the race progressed and then sped up in the final segment of the race (50-56km).

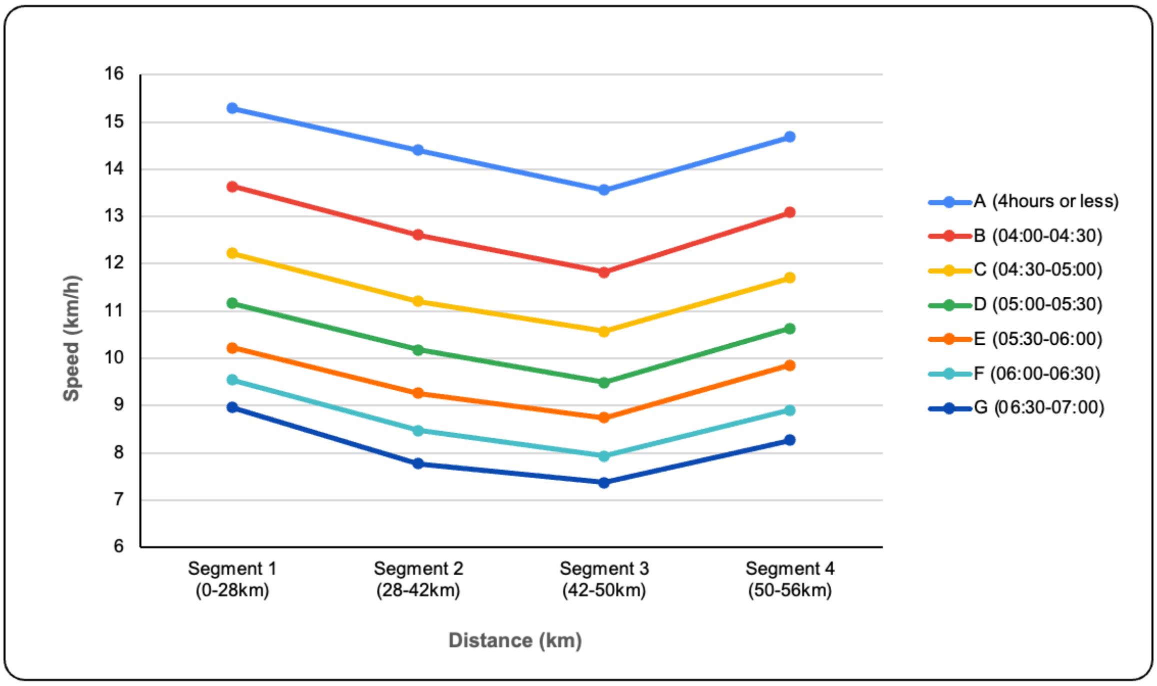

Figure 7: Average running speed (km/h) for each group (A to G) over each segment of the race. SD/SE bars have been omitted for clarity.

Table 7 shows the average running speed of each group over the four segments of the race. Group A ran the fastest over all four segments, followed by group B, C, D, E, F and G that displayed progressively slower running speeds over the length of the race. A peak running speed of 15.29km/h (95% CI = 15.156 - 15.417), was achieved by group A over segment 1 (0-28km) of the race.

Table 7: Average running speed (km/h) per segment for each group (A to G).
SE = Standard Errors; DF = Degrees of Freedom; Lower CL = Lower Confidence Level; Upper CL = Upper Confidence Level

Segment	Mean speed (km/h)	SE	DF	Lower CL	Upper CL
Group A					
Segment 1	15.286	0.066711	38698	15.156	15.417
Segment 2	14.398	0.066711	38698	14.267	14.529
Segment 3	13.565	0.066711	38698	13.434	13.695
Segment 4	14.677	0.066711	38698	14.546	14.807
Group B					
Segment 1	13.635	0.045572	38698	13.546	13.725
Segment 2	12.614	0.045572	38698	12.524	12.703
Segment 3	11.821	0.045572	38698	11.732	11.910
Segment 4	13.078	0.045572	38698	12.988	13.167
Group C					
Segment 1	12.220	0.020638	38698	12.180	12.261
Segment 2	11.209	0.020638	38698	11.169	11.250
Segment 3	10.567	0.020638	38698	10.526	10.607
Segment 4	11.699	0.020638	38698	11.658	11.739
Group D					
Segment 1	11.160	0.013985	38698	11.132	11.187
Segment 2	10.181	0.013985	38698	10.154	10.209
Segment 3	9.487	0.013985	38698	9.460	9.514
Segment 4	10.631	0.013985	38698	10.604	10.659
Group E					
Segment 1	10.218	0.009452	38698	10.200	10.237
Segment 2	9.261	0.009452	38698	9.243	9.280
Segment 3	8.753	0.009452	38698	8.734	8.771
Segment 4	9.857	0.009452	38698	9.839	9.876
Group F					
Segment 1	9.536	0.009524	38698	9.518	9.555
Segment 2	8.481	0.009524	38698	8.462	8.500
Segment 3	7.931	0.009524	38698	7.912	7.950
Segment 4	8.908	0.009524	38698	8.890	8.927
Group G					
Segment 1	8.963	0.008447	38698	8.947	8.980
Segment 2	7.775	0.008447	38698	7.758	7.791
Segment 3	7.367	0.008447	38698	7.350	7.383
Segment 4	8.267	0.008447	38698	8.251	8.284

The pairwise comparisons in Table 8 show that group A slowed the least from segment 1 to 2 (0.89 ± 0.09km/h; p<0.0001) and group G slowed the most (1.19 ± 0.0114km/h; p<0.0001). Interestingly, group A had the largest change in average running speed in segment 3 (0.833km/h; p<0.0001) and group G had the smallest change (0.408km/h; p<0.0001) when compared to their respective running speeds in segment 2.

Groups B and C slowed similarly as well as groups E and F (Table 8). From segment 1 to 2, groups E and F showed smaller changes in running speed compared to groups B and C. In general, the slower groups (E-G) showed smaller changes in running speeds than the faster groups (A-D) from segment 2 to 3. All the groups showed a significant increase in running speed in the final segment of the race. Group B sped up the most (1.26 ± 0.0615km/h; p<0.0001) and group G the least (0.9 ± 0.0114km/h; p<0.0001). All differences in running speeds within groups were statistically significant with p<0.0001 (Table 8).

Table 8: Pairwise comparison of mean differences in change of running speeds across different segments of each group. SE = Standard Errors; DF = Degrees of Freedom.

Group & Segment	Estimate	SE	DF	T-Ratio	P-Value
A1 – A2	0.8885	0.0900	38698	9.873	<0.0001
A2 – A3	0.8333	0.0900	38698	9.259	<0.0001
A3 – A4	-1.1119	0.0900	38698	-12.355	<0.0001
B1 – B2	1.0217	0.0615	38698	16.619	<0.0001
B2 – B3	0.7927	0.0615	38698	12.895	<0.0001
B3 – B4	-1.2567	0.0615	38698	-20.441	<0.0001
C1 – C2	1.0108	0.0278	38698	36.308	<0.0001
C2 – C3	0.6425	0.0278	38698	23.078	<0.0001
C3 – C4	-1.1321	0.0278	38698	-40.665	<0.0001
D1 – D2	0.9785	0.0189	38698	51.864	<0.0001
D2 – D3	0.6945	0.0189	38698	36.811	<0.0001
D3 – D4	-1.1442	0.0189	38698	-60.652	<0.0001
E1 – E2	0.9570	0.0128	38698	75.054	<0.0001
E2 – E3	0.5085	0.0128	38698	39.877	<0.0001
E3 – E4	-1.1045	0.0128	38698	-86.625	<0.0001
F1 – F2	1.0551	0.0128	38698	82.120	<0.0001
F2 – F3	0.5501	0.0128	38698	42.818	<0.0001
F3 – F4	-0.9775	0.0128	38698	-76.082	<0.0001
G1 – G2	1.1889	0.0114	38698	104.332	<0.0001
G2 – G3	0.4077	0.0114	38698	35.773	<0.0001
G3 – G4	-0.9004	0.0114	38698	-79.010	<0.0001

3.4.3 Pacing profiles compared between groups

Table 9 shows that group B had the smallest margin of difference in running speed compared to group A over all four segments. This was followed by group C, D, E, F, and group G who had the largest difference in running speeds over all four segments when compared to group A. All differences in pairwise comparisons between group A and progressively slower groups were statistically significant with p<0.0001.

Table 9: Pairwise comparison of mean differences in change of running speeds across different segments of each group compared to group A. SE = Standard Errors; DF = Degrees of Freedom.

Group & Segment	Estimate	SE	DF	T-Ratio	P-Value	Effect Size
A1 – B1	1.6510	0.0808	38698	20.435	<0.0001	3.235
A2 – B2	1.7842	0.0808	38698	22.084	<0.0001	2.797
A3 – B3	1.7436	0.0808	38698	21.582	<0.0001	1.851
A4 – B4	1.5988	0.0808	38698	19.790	<0.0001	1.509
A1 – C1	3.0664	0.0698	38698	43.912	<0.0001	6.02
A2 – C2	3.1887	0.0698	38698	45.663	<0.0001	4.984
A3 – C3	2.9979	0.0698	38698	42.932	<0.0001	3.181
A4 – C4	2.9777	0.0698	38698	42.642	<0.0001	2.811
A1 – D1	4.1266	0.0682	38698	60.542	<0.0001	8.098
A2 – D2	4.2165	0.0682	38698	61.862	<0.0001	6.594
A3 – D3	4.0778	0.0682	38698	59.826	<0.0001	4.33
A4 – D4	4.0454	0.0682	38698	59.351	<0.0001	3.821
A1 – E1	5.0683	0.0674	38698	75.223	<0.0001	9.941
A2 – E2	5.1368	0.0674	38698	76.239	<0.0001	8.031
A3 – E3	4.8120	0.0674	38698	71.418	<0.0001	5.117
A4 – E4	4.8193	0.0674	38698	71.528	<0.0001	4.547
A1 – F1	5.7503	0.0674	38698	85.332	<0.0001	11.275
A2 – F2	5.9169	0.0674	38698	87.804	<0.0001	9.25
A3 – F3	5.6338	0.0674	38698	83.603	<0.0001	5.989
A4 – F4	5.7681	0.0674	38698	85.596	<0.0001	5.443
A1 – G1	6.3230	0.0672	38698	94.031	<0.0001	12.412
A2 – G2	6.6234	0.0674	38698	98.498	<0.0001	10.359
A3 – G3	6.1978	0.0674	38698	92.169	<0.0001	6.585
A4 – G4	6.4093	0.0674	38698	95.315	<0.0001	6.047

Table 10 shows the normalised running speeds of each group over the various segments of the race as a percentage of the running speed over segment 1, which was assigned a 100% value. As with Figure 7, it is apparent that all runners slowed down significantly from segment 1 to segment 3 ($p<0.0001$), before speeding up in segment 4 (Figure 8). Runners from group A sustained their relative running speed over segment 2 and 3 the closest to their initial running speed. Progressively slower groups showed progressively larger differences in relative running speeds over segment 2 and 3 compared to their initial running speed (Table 10).

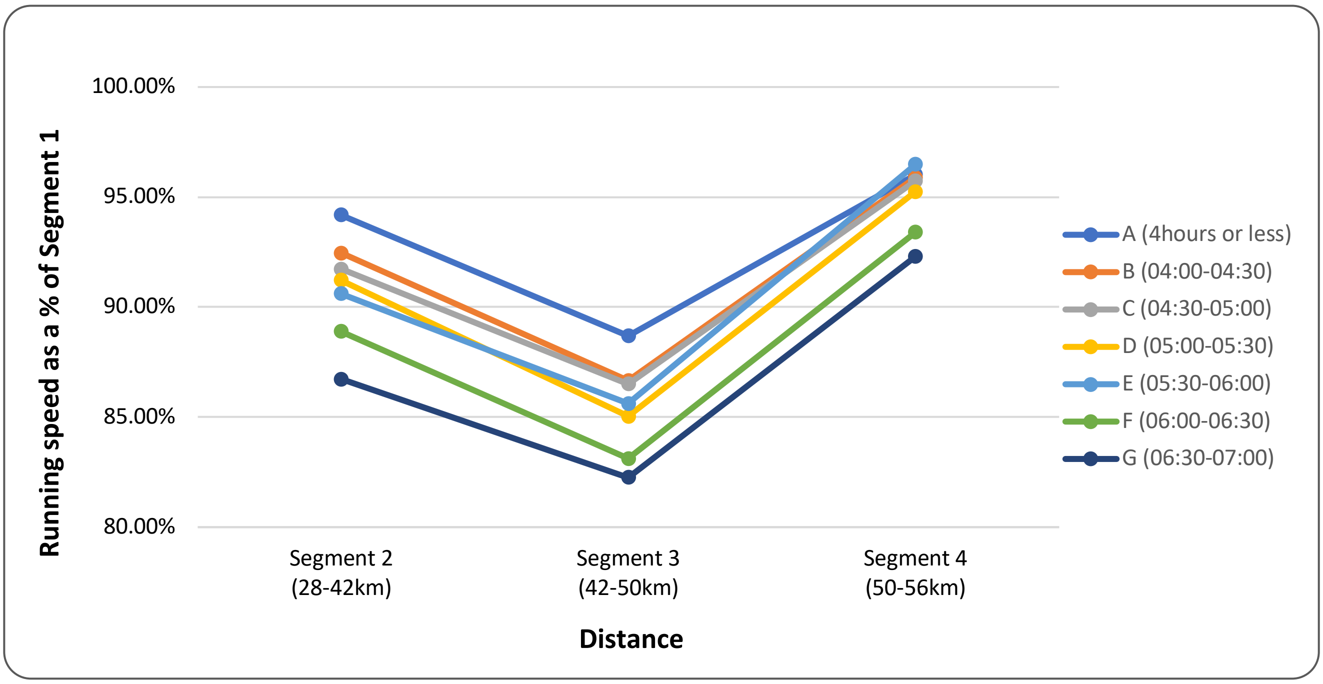

Figure 8: Normalised average running speed displayed as a percentage (%) of running speed over segment 1 (100%) for group A to G. SD/SE bars have been omitted for clarity.

Runners from group E (05:30 to 06:00) finished the race at running speeds closest to their initial running speed (96.73; 95% CI = 96.51 - 96.96). This finding is clearly seen above in Figure 8. Similarly, runners from group A, B, and C were able to complete the race at running speeds within 4% of their initial starting speed (Table 10). This contrasts with group F and G who finished within 7% and 8% of their initial running speeds, respectively.

Table 10: Estimated Marginal Means (EMMeans) analysis of running speed per segment as a percentage (%) of running speed displayed in segment 1 (100%) for group A to G. SE = Standard Error; DF = Degrees of Freedom; Lower CL = Lower Confidence Level; Upper CL = Upper Confidence Level.

Group & Segment	Estimated Mean (km/h)	SE	DF	Lower CL	Upper CL
Group A					
Segment 1	100.00	0.8133	38698	98.41	101.59
Segment 2	94.22	0.8133	38698	92.63	95.82
Segment 3	88.84	0.8133	38698	87.25	90.44
Segment 4	96.11	0.8133	38698	94.52	97.71
Group B					
Segment 1	100.00	0.5556	38698	98.91	101.09
Segment 2	92.60	0.5556	38698	91.51	93.69
Segment 3	86.93	0.5556	38698	85.84	88.01
Segment 4	96.14	0.5556	38698	95.05	97.23
Group C					
Segment 1	100.00	0.2516	38698	99.51	100.49
Segment 2	91.86	0.2516	38698	91.37	92.35
Segment 3	86.72	0.2516	38698	86.22	87.21
Segment 4	96.03	0.2516	38698	95.53	96.52
Group D					
Segment 1	100.00	0.1705	38698	99.67	100.33
Segment 2	91.36	0.1705	38698	91.03	91.70
Segment 3	85.24	0.1705	38698	84.91	85.57
Segment 4	95.50	0.1705	38698	95.17	95.83
Group E					
Segment 1	100.00	0.1152	38698	99.77	100.23
Segment 2	90.79	0.1152	38698	90.56	91.01
Segment 3	85.90	0.1152	38698	85.67	86.12
Segment 4	96.73	0.1152	38698	96.51	96.96
Group F					
Segment 1	100.00	0.1161	38698	99.77	100.23
Segment 2	89.06	0.1161	38698	88.84	89.29
Segment 3	83.36	0.1161	38698	83.13	83.58
Segment 4	93.63	0.1161	38698	93.40	93.86
Group G					
Segment 1	100.00	0.1030	38698	99.80	100.20
Segment 2	86.86	0.1030	38698	86.66	87.06
Segment 3	82.36	0.1030	38698	82.16	82.56
Segment 4	92.42	0.1030	38698	92.22	92.62

Figure 9 displays the normalised average running speed of each group over the four segments of the race as a percentage of their overall mean race pace (MRP) which was assigned a value of 100%.

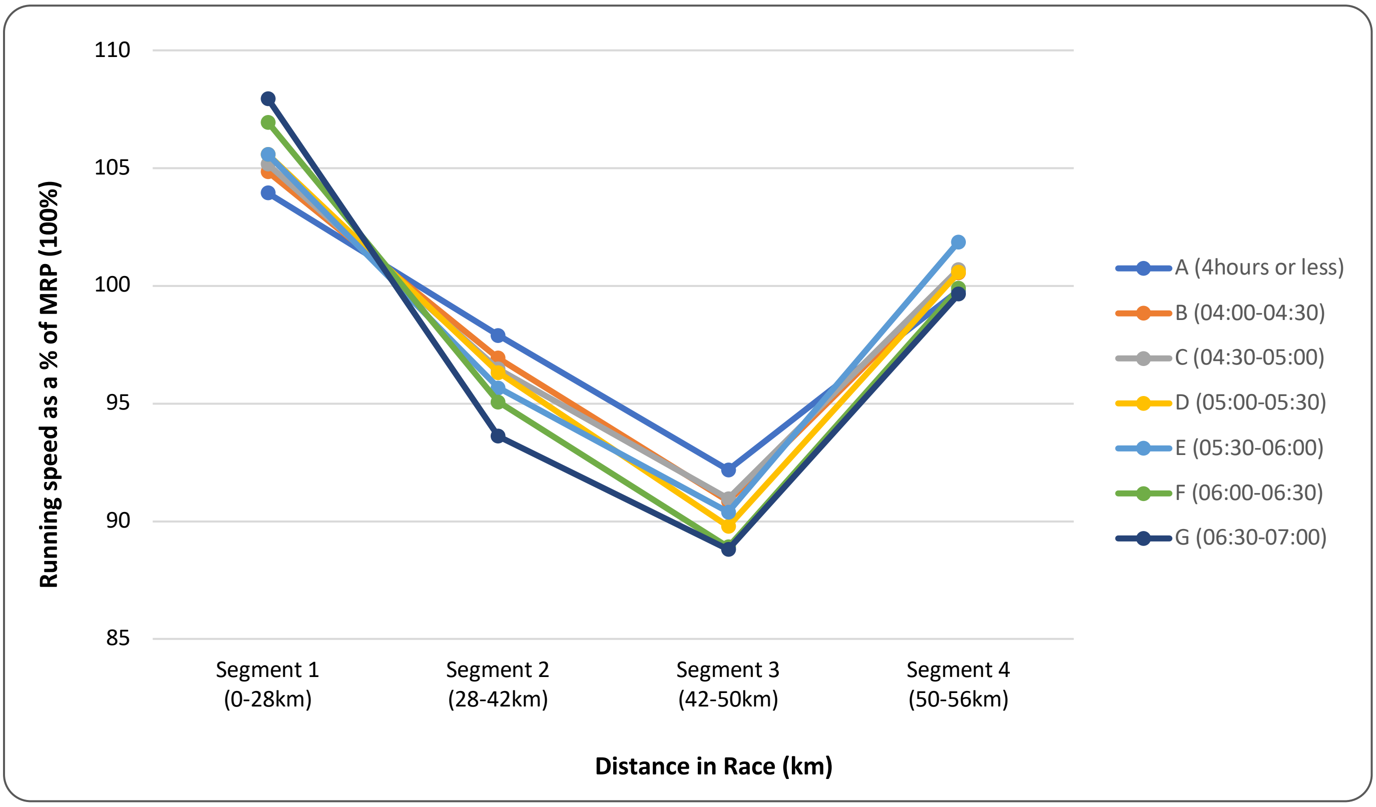

Figure 9: Normalised average running speed displayed as a percentage (%) of overall mean race pace (MRP). SD/SE bars have been omitted for clarity.

Table 11 shows the average running speed of the fastest group (group A) over segment 1 (0-28km) was the closest to their overall race pace. Group A ran the start of the race at 103.97% (95% CI = 102.74 - 105.20) and group B at 104.82% (95% CI = 103.98 - 105.66) of their MRP (when assigned a 100% value). Group C, D and E showed very similar trends in starting pace, with group F and G showing the most ambitious starting speeds of all the groups: 106.94% (95% CI = 106.76 - 107.11) and 107.98% (95% CI = 107.83 - 108.14), respectively. These findings are illustrated in Figure 9.

All the groups, except for group E, finished the race within 1% of their mean race pace. Group E had the largest increase in normalised average running speed over segment 4 to end the race at 101.84% (95% CI = 101.67 - 102.01) of their mean race pace (Table 11).

Table 11: Estimated Marginal Means (EMMeans) analysis of running speed over segment 1, 2, 3 and 4 of each group (A to G) as a percentage (%) of the Mean Race Pace (100%) for each group. SE = Standard Errors; DF = Degrees of Freedom; Lower CL = Lower Confidence Level; Upper CL = Upper Confidence Level.

Group & Segment	Estimated Mean (%)	SE	DF	Lower CL	Upper CL
Group A					
Segment 1	103.97	0.62686	38698	102.74	105.20
Segment 2	97.87	0.62686	38698	96.64	99.10
Segment 3	92.18	0.62686	38698	90.95	93.41
Segment 4	99.74	0.62686	38698	98.51	100.96
MRP	100	0.62686	38698	-	-
Group B					
Segment 1	104.82	0.42822	38698	103.98	105.66
Segment 2	96.97	0.42822	38698	96.13	97.80
Segment 3	90.88	0.42822	38698	90.04	91.72
Segment 4	100.55	0.42822	38698	99.71	101.39
MRP	100	0.42822	38698	-	-
Group C					
Segment 1	105.13	0.19392	38698	104.75	105.51
Segment 2	96.44	0.19392	38698	96.06	96.82
Segment 3	90.92	0.19392	38698	90.54	91.30
Segment 4	100.68	0.19392	38698	100.30	101.60
MRP	100	0.19392	38698	-	-
Group D					
Segment 1	105.62	0.13141	38698	105.37	105.88
Segment 2	96.35	0.13141	38698	96.09	96.61
Segment 3	89.78	0.13141	38698	89.53	90.04
Segment 4	100.62	0.13141	38698	100.36	100.88
MRP	100	0.13141	38698	-	-
Group E					
Segment 1	105.55	0.08881	38698	105.37	105.72
Segment 2	95.66	0.08881	38698	95.48	95.83
Segment 3	90.41	0.08881	38698	90.24	90.59
Segment 4	101.84	0.08881	38698	101.67	102.01
MRP	100	0.08881	38698	-	-
Group F					
Segment 1	106.94	0.08950	38698	106.76	107.11
Segment 2	95.09	0.08950	38698	94.92	95.27
Segment 3	88.92	0.08950	38698	88.74	89.09
Segment 4	99.88	0.08950	38698	99.70	100.05
MRP	100	0.08950	38698	-	-
Group G					
Segment 1	107.98	0.07938	38698	107.83	108.14
Segment 2	93.64	0.07938	38698	93.49	93.80
Segment 3	88.75	0.07938	38698	88.59	88.90
Segment 4	99.60	0.07938	38698	99.45	99.76
MRP	100	0.07938	38698	-	-

CHAPTER 4: DISCUSSION

4.1 TWO OCEANS ULTRAMARATHON RACE PACE CHARACTERISTICS

4.1.1 Pacing profiles displayed within groups

The most important finding with respect to the pacing profiles identified in this study is that all seven groups displayed a reversed J-shaped curve (Figure 7). This type of pacing profile is seen when athletes slow progressively during an event but then speed up towards the end. A J-shaped pacing pattern is therefore the result of an athlete adopting both positive and negative pacing strategies during competition. This competitive approach has previously been noted in both Olympic rowers and recreational cyclists (Garland, 2005; Tucker et al., 2004).

The pacing patterns that emerged in our study were consistent with findings from previous pacing studies on marathons and ultramarathons (refer to Table 1). In our study, the initial positive pacing patterns can be attributed to the relatively flat course profile in the first half of the race (Figure 1). The second half of the Two Oceans Ultramarathon has two significant climbs in short succession, making it considerably more challenging than the first half. From the 28km mark, runners must ascend 180m to the top of Chapman's Peak. Following the Chapman's Peak descent at the 40km mark, runners have a short section of flat running before starting the ascent to the top of Constantia Nek, climbing 250m over 4km. It was therefore no surprise that running speeds were noticeably slower over the second half of the race compared to the start. These slower running speeds over the uphill segments of the race can be attributed to the increase in physiological demands of running uphill (Bontemps et al., 2020; Minetti et al., 2002). In addition, the duration of the race can influence pacing patterns. Research has found that in endurance events lasting longer than four hours, there is a gradual decline in self-selected exercise intensity (Genitrini et al., 2022). This phenomenon can be explained by the complex interplay of various factors contributing to neuromuscular fatigue as described in Chapter 2.6 (p.18).

Interestingly, runners of all ability (group A to G) were able to speed up in the final segment of the race (50 to 56km). This phenomenon could be explained by the so-called "end spurt" in which an athlete increases their effort when 95% of a race is completed, irrespective of the length of the race (Catalano, 1973; Ely et al., 2008). The presence of an end spurt is typically seen in non-elite runners and is believed to be an indication of sub-optimal pacing strategy (Knechtle et al., 2022). If a runner did not effectively distribute their effort over the duration of the race, they may have a surplus of energy resources available towards the end of the race, allowing them to speed up in the final stages of the competition. These findings are supported by a study investigating pacing patterns in ultradistance road races (Tan et al., 2016). The authors found that their slowest group of finishers had a significantly larger number of runners that displayed an end spurt, compared to the faster groups. In that study, a group was deemed to have an end spurt if their average running speed over the last 5km split was significantly faster than their overall mean race pace. In our study, groups B, C, D and E ran the last segment of the race (50-56km) at speeds faster than their overall mean race pace (Table 11). The average running speeds of our fastest and slowest group over the final segment of the race did not exceed their overall mean race pace.

However, due to the complexity of the course profile of the Two Oceans ultramarathon, the increase in running speed over the final segment of the race must be interpreted with caution. The negative pacing patterns adopted by all the runners in the last segment of the race (Figure 6) can be explained by the downhill nature of the course from approximately 50 to 54 kilometres (Figure 1). This could account for the increase in pace in the last split of the race. It is therefore difficult to distinguish between an increase in running speed due to an easy finish versus a true end spurt achieved through an increase in effort.

4.1.2 Pacing profiles compared between groups

As one would expect, the fastest group (group A) was able to maintain the highest running speeds throughout the race, followed by progressively slower groups in order from group B to G (Table 7). However, an interesting finding emerged when comparing the change in running speeds over each race segment for each group. Group A showed the largest change in running speed from segment 2 to segment 3 (42-50km) which can be considered the most strenuous part of the race (refer to Table 8: A2-A3). A possible explanation might be the initial pace difference between group A and the progressively slower groups. Group A had the fastest average running speed over segment 1, which they were able to maintain more effectively over segment 2 than all other groups (Table 8: A1-A2). Because of the progressively slower running speeds displayed by groups B to G over segment 1 and 2, compared to group A, one could argue that these runners were able to keep their slower pace more consistent than group A from segment 2 to 3. Therefore, while groups B to G showed a larger decrease in pace from segment 1 to 2, they might have maintained this reduced speed more consistently through segment 3, resulting in a smaller absolute change in pace from segment 2 to segment 3 compared to group A. In addition, group A potentially experienced a larger speed reduction from segment 2 to 3 due to fatigue setting in following the faster speeds they adopted from the start of the race. Even though the strongest runners managed to maintain their running speed in segment 2 the closest to segment 1, this might have been more challenging to sustain over the subsequent segment (segment 3).

However, although group A showed the largest speed loss from segment 2 to segment 3, their greater initial starting speeds and minimal speed reduction in segment 1, enabled them to maintain their relative running speeds over segment 2 and 3 the closest to their initial starting speed compared to progressively slower groups (Table 10).

These findings agree with the results of Genitrini et al. (2022). In their study on ultra-trail running, those who finished in the top positions, ran the flat and downhill sections of the race faster, and the uphill sections of the race slower than the slower finishers. It is believed that stronger runners can increase their running speed over the flat and downhill sections of a race not only due to their superior fitness levels, but more importantly, due to their systematic exposure to downhill running during training. As a result, these athletes are more resilient against exercise induced muscle damage and fatigue (Bontemps et al., 2020). A possible explanation for the relatively slower pace displayed by the elite runners over the uphill segment of the race may be racing strategy. By increasing their running speed over the relatively flat first half of the race, these runners were able to “bank time” which would allow them to slow down over the uphill segments of the race and in doing so, preserve valuable energy resources to sustain them throughout the rest of the competition.

As mentioned above, slower finishers slowed down more than faster finishers in the first segment of the race (Table 8). A key finding in our study offers additional insight. The slowest groups (group F and G) started the race at relative speeds that were considerably faster than their mean race pace (Figure 7; Table 11). In less experienced runners, this ambitious early race pace leads to premature fatigue which potentially forces them to slow down. The subsequent reduction in running speed could exceed what would have occurred had they adopted a more realistic early race pace. In contrast, the fastest groups (group A and B) ran segment 1 (0-28km) at relative speeds that were closer to their mean race pace (Table 11). Both these groups started the race at running speeds within 5% of their mean running speed (Figure 7). This observation aligns with Smyth (2018) who pointed out that marathon runners, irrespective of skill level, have the best chance of achieving a personal best performance when starting the race within 5% of their mean race pace. An explanation for why elite and lesser runners pace differently may lie in their motivation and expectations from the race. Elite runners aiming to win or at least make podium are not too concerned with a fast start as long as they are positioned at the front of the race. Lesser runners know that they will not win the race and may be driven by the desire to run a personal best. To achieve that goal, these runners adopt and early running speed that is faster than the average pace of their current best marathon time. This fast pace, however, cannot be maintained and the runners are forced to slow down. Another observation amongst competitive participants has been that their rate of perceived exertion (RPE) might be lower than expected at the start of the race due to the excitement of the race or the absence of fatigue, causing them to adopt a faster early race pace (Renfree et al., 2014).

When considering all the findings above, the multifactorial nature of fatigue – including physiological, biomechanical, neuromuscular and cognitive factors – emphasises the importance of appropriate pacing strategies in endurance running success as highlighted by Garbisu-Hualde and Santos-Concejero (2020).

4.2 DESCRIPTIVE CHARACTERISTICS OF PARTICIPANTS

In addition to the findings above, several interesting descriptive characteristics emerged from the analysis of the race results. The participation trends, age and nationality of the top performers are worth mentioning.

4.2.1 Participation trends

Our findings with respect to participation trends in the Two Oceans Marathon agree with previous studies indicating a progressive increase in female participation in ultramarathon running (Senefeld et al., 2016; Waldvogel et al., 2019; Valentin et al., 2022). In addition, there has been a significant increase in overall female participation rates in ultramarathon races – especially races shorter than 80km. Although still small, the percentage of female runners participating in races shorter than 80km increased from 14% in 1996 to 23% in 2020 (Ronto, 2023). The analysis of the Two Oceans race data in the current study showed there was a 73% increase in the number of female finishers, from 1499 in 2007 to 2592 in 2018 (Table 3). In addition, female representation in the total field of finishers increased from 23.05% in 2007 to 28.91% in 2018, thus supporting the trends reported by Ronto (2023).

4.2.2 Age

Several determinants of success in ultramarathon running have been recognised. Age is considered one of the most important factors (Knechtle, 2012). The age range of the athletes that were able to maintain the fastest average race pace, 14.71 ± 0.49km/h, was 33.6 ± 5.1 years (Table 2). Our finding aligns with results from previous research on all ultramarathons (50km to 1000km) held worldwide between 1969 and 2012 (Romer et al., 2014). In that study, the age of the top 10 fastest females per year over 50km decreased from 39 ± 8 years (1988) to 32 ± 4 years (2012). In 100km events, however, the age of the top 10 fastest females remained stable at 34.9 ± 3.2 years. Interestingly, the peak running speed of the top ten female runners over 50km increased from 10.6 ± 1.0km/h (1988) to 15.3 ± 0.7km/h (2012) – which is similar to the running speeds our top finishers were able to achieve (Table 7).

In a study of 80km and 100km race distances (Waldvogel et al., 2019), the age of peak running speed was 33 years in both distances for both male and female runners when all participants were considered. In a study of all 50km ultramarathons held worldwide between 1975 and 2016 (Nikolaides & Knechtle, 2018), the age of peak running performance varied depending on methodology. In female runners, when considering all finishers, as well as only the top 10 finishers, in 5-year age gaps, runners between 35 to 39 showed the fastest running speeds. When considering all finishers in 1-year age-groups, females aged 36 maintained the highest running speeds. In their analysis of only top 10 finishers according to 1-year age groups, the age of peak running speed was 41 years.

The age ranges in the studies above are higher than the peak performance age range associated with marathon running: 25 to 35 years for males and females (Lara et al., 2014; Nikolaides et al., 2017; Zavorsky et al., 2017). It is believed that the peak performance age in the ultramarathon is older than the marathon, because most successful ultramarathoners move up to ultra-distances after achieving their best times in the marathon distance. Moreover, ultramarathon performance requires even more dedication to preparation and training compared to the marathon (Waldvogel et al., 2019). Successful ultramarathoners have approximately eight years of experience in ultra-distance running, with training characteristics that include higher training volume at a lower intensity compared to marathon runners (Knechtle, 2012). Knowledge regarding the peak performance age in endurance running is therefore essential in planning the career of an ultra-runner as well as optimising their training and preparation for competition.

4.2.3 Nationality

It has been stated that another important determinant of success in ultra-endurance sports is nationality (Knechtle et al., 2020). This somewhat surprising statement is borne out by the analyses performed in the current study. The fastest females in our study were of Russian descent. Specifically, nine out of the top ten overall performances between 2007 and 2018 were by Russian athletes (Table 5). This finding agrees with previous studies that determined Russian female athletes were the fastest and the youngest in the 100km Comrades Marathons from 1994-2017 (Nikolaides & Knechtle, 2019) as well as the fastest in 100km ultramarathons held worldwide between 1959 and 2016 (Knechtle et al., 2018). These studies contradict earlier research that found Japanese ultramarathoners were the fastest in the world over 100km (Cejka et al., 2014). Researchers investigating the nationality of top performers in ultrarunning were surprised to find that there was virtually no representation of East-African countries (Ethiopia and Kenya) in ultramarathons (Nikolaides et al., 2017). It is believed that East-African runners excel in marathon running due to their exceptional running economy, genetic predisposition, ideal physiological characteristics, and diet, as well as living and training at high altitude (Aschmann et al., 2018). In our study, only two East-African runners were found in the top 50 performers (Table 5) - both from Ethiopia. A plausible explanation is financial motivation. East-African athletes compete in the most lucrative races where they know they will be able to contend for a top position. They rely on their winnings to make a living out of running and to provide for their families and communities. In fact, 33% of elite Kenyan runners (800m to marathon-distance) stated that they became competitive athletes for economic reasons (Onywera et al., 2007).

4.3 LIMITATIONS OF STUDY

The main strength of this study is its robust sample size. Investigating 10 editions of the Two Oceans Ultramarathon race, provides the opportunity to potentially generalise findings to a larger population of endurance runners attempting a similar event.

This study was conducted by analysing existing open-access datasets. Although databases provide valuable real-life performance data from a substantial population of elite and non-elite runners, the data available provide little insights into the mechanisms that influence pacing. We assumed that all participants were adequately prepared and equally motivated to participate in this race. No training history or level of experience were available for the runners, information that would have added more value to the interpretation of the study’s results. This would help to ascertain whether superior performance in endurance running is determined by the ability to maintain a more even pacing pattern or whether the ability to maintain an even pacing profile is the result of an athlete's psychological and physiological attributes and/ or their training habits (Lambert et al., 2004). Furthermore, variables such as anthropometry (Knechtle et al., 2012), psychological factors (Krouse et al., 2011), nationality (Cejka et al., 2013) and nutrition status and strategies were not considered. These variables might have influenced the results of the study.

In addition, environmental factors such as headwind were not taken into consideration. Angus (2013) determined that small (0-10%) variations in power output occur in response to on-course headwinds or profile gradient. Since the route of the Two Oceans ultramarathon is relatively circular, one could argue that participants would be running with or against wind as the direction of the route changes. The same principle of up and downhill running can be applied to head- or tailwind conditions: with a downhill or tailwind runners will increase their effort slightly to make up for time lost and with an uphill or headwind decrease their effort slightly to preserve energy, potentially evening out the effect of these factors. As with running up and down an equal gradient hill, not as much time is regained with a tailwind as is lost with a headwind (Davies, 1980; Pugh, 1971). This study investigated 10 editions of the Two Oceans ultramarathon. Thus, the data we analysed would have been collected during races run under various environmental conditions encountered over the years.

It this study, it should be noted that the first split time was only available from the 28km mark, whereas subsequent splits were recorded at the next 14km, 8km, and 6km intervals, respectively. Future research should aim to utilise more frequently obtained data (e.g., 5km splits for the entire length of the race) to perform a more in-depth analysis of pacing patterns in elite and non-elite ultramarathon running. In this study we were reliant on the split times at positions in the race determined by the race organisers.

CHAPTER 5: SUMMARY AND CONCLUSION

The Two Oceans Ultramarathon is a unique event, as very few 56km road running races take place globally and limited research is available on events over this distance. As a mass-participation event, it provides the rare opportunity to study elite and recreational runners who compete side-by-side, despite stronger runners finishing in half the time than others. The challenging race profile adds further dimension to this study. When considering the race profile, modification of pacing strategy becomes an essential part of the athlete's race planning and preparation. By determining significant trends and potential differences between elite and non-elite ultramarathon pacing, this study can contribute to the current knowledge on ultramarathon running performance. Therefore, the overall aim of this study was to determine, analyse and compare the pacing profiles adopted by elite and non-elite female runners during the Two Oceans Ultramarathon from 2007 to 2018. Based on the findings of this study, the specific objectives as described in Section 1.2.2 (page 3) may be answered as follows:

> *To describe the pacing profiles displayed by the elite female runners and successively slower categories of runners.*

All runners, from the fastest to the slowest group, displayed the same pattern of change in pace throughout the race. Over the first three segments of the race there was a decline in running speed (positive pacing), followed by an increase in running speed over the fourth and final segment of the race to the finish line (positive pacing). The Two Oceans Ultramarathon race profile provides an explanation for the continued loss of running speed over the hilly segments of the race – segments 2 and 3 – followed by a faster finish due to the downhill nature of segment 4. Clinicians and coaches working with these athletes therefore need to be aware of the influence of race profile on pacing patterns during competition.

> *To compare how pacing profiles might differ between the elite female runners and the slower category female runners.*

The elite group of female runners started the race at running speeds that were closer to their mean race pace than progressively slower groups of runners. It is believed that this more conservative approach by the elite runners, enabled them to distribute their energy resources more effectively throughout the race, thereby finishing at running speeds much closer to their mean race pace than progressively slower groups. Although the elite group had a larger reduction in running speed from segment 2 to segment 3, their strong, sustainable start allowed them to still maintain their relative running speeds over all 4 segments the closest to their starting speed in segment 1 compared to all other groups. These findings highlight the importance of adopting the most appropriate early race pace, depending on the athlete's experience and fitness levels.

> *To establish how the different categories of female runners adapted their pace in response to the flat and hilly sections of the race and compare how it varied between runners of different ability.*

The elite group adopted a faster, sustainable race pace than the progressively slower groups over the first flat half of the race. In doing so, elite runners were able to slow down over the hilly segments of the race to potentially preserve energy, which allowed them to speed up over the final segment of the race. Due to the unrealistic early race pace adopted by the slower categories of runners, they were forced to slow down more than the elite runners over the first half of the race. Their more rapid reduction in pace over the first two segments of the race, however, enabled these runners to maintain their slowed speed over the hilly segments of the race (segment 2 to 3), whereafter they had sufficient energy reserves to speed up over the final segment of the race. These findings further emphasise the importance of pacing strategy as it relates to the course profile.

Based on the findings in this study, it is recommended that all runners should start the race at a realistic, sustainable pace that will allow them to manage their energy resources successfully throughout the duration of the event. Stronger, more competitive runners, striving for a specific time target, might benefit from adopting a faster approach to the start of the race, thereby making up for time lost over the slower second half of the race. On the other hand, slower or less experienced runners should be warned against and overambitious start to the race. By starting at an unrealistic early race pace, these runners might experience an early onset of fatigue, forcing them to reduce their running speed, which will lead to poor race outcomes. Future research should include additional information such as training history and experience level to determine its effect on pacing strategy. In addition, high-resolution data obtained at more frequent distance intervals (e.g., every 5km) will allow for a more in-depth analysis of pacing patterns in elite and recreational ultramarathoners.

CHAPTER 6: REFERENCES

Abbiss, C. & Laursen, P. (2008). Describing and understanding pacing strategies during athletic competition. *Sports Medicine*, *38(3)*, 239-252. [DOI: 10.2165/00007256-200838030-00004]

Angus, S. (2013). Did recent world record marathon runners employ optimal pacing strategies? *Journal of Sport Sciences, 32(1)*, 31-45. [DOI: 10.1080/02640414.2013.803592]

Aschmann, A., Knechtle, B., Onywera, V. & Nikolaidis, P. (2018). Pacing strategies in the New York City Marathon – does nationality of finishers matter? *Asian Journal of Sports Medicine*, *9(2)*, e57596. [DOI: 10.5812/asjsm.57596]

Besson, T., Rossi, J., Mallouf, T., Marechal, M., Doutreleau, S., Verges, S. & Millet, G. (2020). Fatigue and recovery after single-stage versus multistage ultramarathon running. *Medicine and Science in Sports and Exercise*, *52(8)*, 1691-1698. [DOI: 10.1249/MSS.0000000000 002303]

Besson, T., Macchi, R., Rossi, J., Morio, C., Kunimasa, Y., Nicol, C., Vercruyssen, F. & Millet, G. (2022). Sex differences in endurance running. *Sports Medicine, 52*, 1235-1257. [DOI: 10.1007/s40279-022-01651-w]

Billat, V., Demarle, A., Slawinski, J., Paiva, M. & Koralsztein, J. (2001). Physical and training characteristics of top-class marathon runners. *Medicine and Science in Sports and Exercise*, *33(12)*, 2089-2097. [DOI: 10.1097/00005768-200112000-00018]

Billat, V. (2005). Current perspectives on performance improvement in the marathon – from universalization to training optimization. *New Studies in Athletics*, *20(3)*, 21-39.

Billat, V., Carbillet, T., Correa, M. & Pycke, J. (2019). Detecting the marathon asymmetry with a statistical signature. *Physica A*, *515*, 240-247. [DOI: 10.1016/j.physa.2018.09.159]

Billat, V., Vitiello, D., Palacin, F., Correa, M. & Pycke, J. (2020). Race analysis of the World's best female and male marathon runners. *International Journal of Environmental Research and Public Health*, *17(4)*, 1177. [DOI: 10.3390%2Fijerph17041177]

Bontemps, B., Vercruyssen, F., Gruet, M. & Louis, J. (2020). Downhill running: What are the effects and how can we adapt? A narrative review. *Sports Medicine*, *50*, 2083-2110. [DOI: 10.1007/s40279-020-01355-z]

Bosch, A., Dennis, S., & Noakes, T. (1993). Influence of carbohydrate loading on fuel substrate turnover and oxidation during prolonged exercise. *Journal of Applied Physiology, 74(4)*, 1921-1927. [DOI: 10.1152/jappl.1993.74.4.1921]

Boudreau, A. & Giorgi, B. (2010). The experience of self-discovery and mental change in female novice athletes in connection to marathon running. *Journal of Phenomenological Psychology*, *41*, 234-267. [DOI: 10.1163/156916210X532144]

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. [DOI: 10.1123/ijspp.2016-0730]

Buman, M., Brewer, B. & Cornelius, A. (2009). A discrete-time hazard model of hitting the wall in recreational marathon runners. *Psychology of Sports and Exercise*, *10(6)*, 662-666. [DOI: 10.1016/j.psychsport.2009.04.004]

Burfoot, A. (2007). The history of the marathon: 1976 - Present. *Sports Medicine, 37(4-5)*, 284-287. [DOI: 10.2165/00007256-200737040-00003]

Casado, A., Hanley, B., Jiménez-Reyes, P. & Renfree, A. (2020). Pacing profiles and tactical behaviors of elite runners. *Journal of Sport and Health Science*, *10(5)*, 1-14. [DOI: 10.1016/j.jshs.2020.06.011]

Catalano, J. (1973). Effect of perceived proximity to end of task upon end-spurt. *Perceptual and Motor Skills*, *36(2)*, 363-372. [DOI: 10.2466/pms.1973.36.2.363].

Cejka, N., Knechtle, B., Rust, C., Rosemann, T & Lepers, R. (2015). Performance and age of the fastest female and male ultramarathoners worldwide from 1960 to 2012. *The Journal of Strength and Conditioning Research*, *29(5)*, 1180-1190. [DOI: 10.1519/JSC.0000000000000370]

Costello, J., Bieuzen, F. & Bleakly, C. (2014). Where are all the female participants in sports and exercise medicine research? *European Journal of Sport Science*, *14(8)*, 847-851. [DOI: 10.1080/17461391.2014.911354]

Comrades. Comrades Marathon History. 2021. [Cited July 2022]; Available from: https://www.comrades.com/histories

Cooke, R. & Pate, E. (1985). The effects of ADP and phosphate on the contraction of muscle fibres. *Biophysical Journal*, *48(5)*, 789-798. [DOI: 10.1016%2FS0006-3495(85)83837-6]

Cuk, I., Nikolaides, P. & Knechtle, B. (2019). Sex differences in pacing during half-marathon and marathon race. *Research in Sports Medicine, 28*, 1. [DOI: 10.1080/15438627.2019.1593835]

Davies, C. (1980). Effects of wind assistance and resistance on the forward motion of a runner. *Journal of Applied Physiology*, *48(4)*, 702-709. [DOI: 10.1152/jappl.1980.48.4.702]

De Koning, J., Foster, C., Bakkum, A., Kloppenburg, S., Thiel, C., Joseph, T., Cohen, J. & Porcari, J. (2011). Regulation of pacing strategy during athletic competition. *PLoS ONE, 6(1)*, e15863. [DOI: 10.1371/journal.pone.0015863]

Deaner, R., Carter, R., Joyner, M. & Hunter, S. (2015). Men are more likely than women to slow in the marathon. *Medicine and Science in Sports and Exercise*, *47(3)*, 607-616. [DOI: 10.1249/MSS.0000000000000432]

Diaz, J., Fernandez-Ozcorta, E. & Santos-Concejero, J. (2018). The influence of pacing strategy on marathon world records. *European Journal of Sport Science*, *18(6)*, 781-786. [DOI: 10.1080/17461391.2018.1450899]

Diaz, J., Renfree, A., Fernández-Ozcorta, E., Torres, M. & Santos-Concejero, J. (2019). Pacing and performance in the 6 World Marathon Majors. *Frontiers in Sports and Active Living*, *8(1)*, 54-66. [DOI: 10.3389/fspor.2019.00054]

Diaz, J., Fernandez-Ocorta, E., Torres, M. & Santos-Concejero, J. (2019). Men vs. women world marathon records' pacing strategies from 1998 to 2018. *European Journal of Sports Science*, *19(10)*, 1297-1302. [DOI: 10.1080/17461391.2019.1596165]

Doherty, C., Keogh, A., Smyth, B., Megyesi, P. & Caulfield, B. (2020). Devising a pace-based definition for "The Wall": An observational analysis of marathoner's subjective experiences of fatigue. *Journal of Athletic Training*, *55(5)*, 494-500. [DOI: 10.4085/1062-6050-243-19]

Espeit, L., Brownstein, C., Royer, N., Besson, T., Martin, V., Millet, G. & Lapole, T. (2020). Central fatigue aetiology in prolonged trail running races. *Experimental Physiology*, *106*, 663-672. [DOI: 10.1113/EP089177]

Ely, M., Martin, D., Cheuvront, S. & Montain, S. (2008). Effect of ambient temperature on marathon pacing is dependent on runner ability. *Medicine and Science in Sports and Exercise*, *40(9)*, 1675-1680. [DOI: 10.1249/MSS.0b013e3181788da9]

Gandevia, S. (2001). Spinal and supraspinal factors in human muscle fatigue. *Physiological Reviews*, *81(4)*, 1725-1789. [DOI: 10.1152/physrev.2001.81.4.1725]

Garbisu-Hualde, A. & Santos-Concejero, J. (2020). What are the limiting factors during an ultra-marathon? A systematic review of the scientific literature. *Journal of Human Kinetics*, *31(72)*, 129-139. [DOI: 10.2478/hukin-2019-0102]

Garland, S. (2005). An analysis of the pacing strategy adopted by elite competitors in 2000m rowing. *British Journal of Sports Medicine*, *39(1)*, 39-42. [DOI: 10.1136%2Fbjsm.2003.010801]

Gauche, E., Lepers, R., Rabita, G., Leveque, J., Bishop, D., Brisswalter, J. & Hausswirth, C. (2006). Vitamin and mineral supplementation and neuromuscular recovery after a running race. *Medicine and Science in Sports & Exercise*, *38(12)*, 2110-2117. [DOI: 10.1249/01.mss.0000235351.01438.5a]

Gibson, A., Lambert, E., Rauch, L., Tucker, R., Baden, D., Foster, C. & Noakes, T. (2006). The role of information processing between the brain and peripheral physiological systems in pacing and perception of effort. *Sports Medicine*, *36(8)*, 705-722. [DOI: 10.2165/00007256-200636080-00006]

Green, H. (1997). Mechanisms of muscle fatigue in intense exercise. *Journal of Sports Science*, *15(3)*, 247-256. [DOI: 10.1080/026404197367254]

Gregor, R. & Costill, D. (1973). A comparison of the energy expenditure during positive and negative grade running. *Journal of Sports Medicine and Physical Fitness*, *13(4)*, 248-252.

Haney, T. & Mercer, J. (2011). A description of variability of pacing in marathon distance running. *International Journal of Exercise Science*, *4(2)*, 133-140.

Hanley B. (2016). Pacing, packing and sex-based differences in Olympic and IAAF World Championship Marathons. *Journal of Sport Science*, *34(17)*, 1675-1681. [DOI: 10.1080/02640414.2015.1132841]

Hettinga, F., Edwards, A. & Hanley, B. (2019). The science behind competition and winning in athletics: using world-level competition date to explore pacing and tactics. *Frontiers in Sports and Active Living*, *8(1)*, 11-21. [DOI: 10.3389/fspor.2019.00011]

Hoffman, M. (2010). Performance trends in 161-km ultramarathons. *International Journal of Sports Medicine*, *31(1)*, 31-37. [DOI: 10.1055/s-0029- 1239561]

Hoffman, M. (2014). Pacing by winners of a 161km mountain ultramarathon. *International Journal of Sports Physiology and Performance*, *9*, 1054-1056. [DOI: 10.1123/ijspp.2013-0556]

Hubble, C. & Zhao, J. (2016). Gender differences in marathon pacing and performance prediction. *Journal of Sports Analytics*, *2*, 19-36. [DOI: 10.3233/JSA-150008]

Joyner, M. (2017). Physiological limits to endurance exercise performance: Influence of sex. *Journal of Physiology, 595(9)*, 2949-2954. [DOI: 10.1113/JP272268]

Kais, Ü., Mooses, K., Pind, R., Pehme, A., Kaasik, P. & Mooses, M. (2019). Pacing strategy of the finishers of the World Marathon Majors series. *Kinesiology*, *51(1)*, 22-27. [DOI: 10.26582/k.51.1.5]

Kelly, C. (2023). Is there evidence for the development of sex-specific guidelines for Ultramarathon coaches and athletes? A systematic review. *Sports Medicine – Open*, *9(1)*, 6. [DOI: 10.1186/s40798-022-00533-9]

Knechtle, B. (2012). Ultramarathon runners: Nature or Nurture? *International Journal of Sports Physiology and Performance*, *7(4)*, 310-312. [DOI: 10.1123/ijspp.7.4.310]

Knechtle, B, Rust, C., Rosemann, T. & Lepers, R. (2012). Age-related changes in 100-km ultramarathon running performance. *Age*, *34(4)*, 1033-1045. [DOI: 10.1007/ s11357-011-9290-9]

Knechtle, B. & Nikolaides, P. (2015). Ultra-marathon running. *Dansk Sportsmedicin*, *19(4)*, 6-10. [DOI: 10.5167/uzh-114975]

Knechtle, B., Rosemann, T., Zingg, M., Stiefel, M. & Rust, C. (2015). Pacing strategy in male elite and age group 100km ultra-marathoners. *Journal of Sports Medicine*, *6*, 71-80. [DOI: 10.2147/OAJSM.S79568]

Knechtle, B., Nikolaides, P. & Valeri, F. (2018). Russians are the fastest 100-km ultra-marathoners in the world. *PLoS One*, *13(7)*, e0199701. [DOI: 10.1371/journal.pone.0199701]

Knechtle, B., Di Gangi, S., Rüst, C. & Nikolaides, P. (2020). Performance differences between the sexes in the Boston Marathon from 1972 to 2017. *Journal of Strength and Conditioning Research*, *34(2)*, 566-576. [DOI: 10.1519/JSC.0000000000002760]

Knechtle, B., Rosemann, T. & Nikolaides, P. (2020). The role of nationality in ultra-endurance sports: The paradigm of cross-country skiing and long-distance running. *International Journal of Environmental Research and Public Health*, *17(7)*, 2543. [DOI: 10.3390/ijerph17072543].

Knechtle, B., Cuk, I., Villiger, E., Nikolaides, P., Weiss, K., Scheer, V. & Thuany, M. (2022). The effects of sex, age and performance level on pacing in ultra-marathon runners in the “Spartathlon”. *Sports Medicine - Open*, *8(69)*, 1-10. [DOI: 10.1186/s40798-022-00452-9].

Krouse, R., Ransdell, L., Lucas, S. & Pritchard, M. (2011). Motivation, goal orientation, coaching and training habits of women ultrarunners. *Journal of Strength and Conditioning Research*, *25(10)*, 2835-2842. [DOI: 10.1519/JSC.0b013e318204caa0]

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

Lambert, M., Dugas, J., Kirkman, M., Mokone, G. & Waldeck, M. (2004). Changes in running speeds in a 100km ultra-marathon race. *Journal of Sport Science and Medicine*, *3(3)*, 167-173.

Lara, B., Salinero, J. & Del Coso J. (2014). The relationship between age and running time in elite marathoners is U-shaped. *Age*, *36(2)*, 1003-1008. [DOI: 10.1007/s11357-013-9614-z]

Lemire, M., Hureau, T., Favret, F., Geny, B., Kouassi, B., Boukhari, M., Lonsdorfer, E., Remetter, R. & Dufour, S. (2021). Physiological factors determining downhill vs uphill running in endurance performance. *Journal of Science and Medicine in Sport*, *24(1)*, 85-91. [DOI: 10.1016/j.jsams.2020.06.004]

MacIntosh, B., Holash, R. & Renaud, J. (2012). Skeletal muscle fatigue – regulation of excitation-contraction coupling to avoid metabolic catastrophe. *Journal of Cell Science*, *125*, 2105-2114. [DOI: 10.1242/jcs.093674]

MacIntosh, B. & Rassier, D. (2002). What is fatigue? *Candian Journal of Applied Physiology*, *27(1)*, 42-55. [DOI: 10.1139/h02-003]

Maffetone, P., Malcata, R., Rivera, I. & Laursen P. (2017). The Boston Marathon versus the World Marathon Majors. *PLoS ONE, 12(9)*, e0184024. [DOI: 10.1371/journal.pone.0184024]

March, D., Vanderburgh, P., Titlebaum, P. & Hoops, M. (2011). Age, sex, and finish time as determinants of pacing in the marathon. *Journal of Strength and Conditioning Research*, *25(2)*, 386-391. [DOI: 10.1519/jsc.0b013e3181bffd0f]

Martin, V., Kerhervé, H., Messonnier, L., Banfi, J., Geyssant, A., Bonnefoy, R., Feasson, L. & Millet, G. (2010). Central and peripheral contributions to neuromuscular fatigue induced by a 24-h treadmill run. *Journal of Applied Physiology*, *108(5)*, 1224-1233. [DOI: 10.1152/japplphysiol.01202.2009]

Mastroianni, G., Zupan, M., Chuba, D., Berger, R. & Wile, A. (2000). Voluntary pacing and energy cost of off-road cycling and running. *Applied Ergonomics*, *31(5)*, 479-485. [DOI: 10.1016/s0003-6870(00)00017-x]

Mauger, A., Jones, A. & Williams, C. (2009). Influence of feedback and prior experience on pacing during a 4-km cycle time trial. *Medicine & Science in Sports & Exercise, 41(2)*, 451-458. [DOI: 10.1249/MSS.0b013e3181854957]

Meeusen, R., Watson, P., Hasegawa, H., Roelands, B. & Piacentini, M. (2006). Central fatigue: The serotonin hypothesis and beyond. *Sports Medicine*, *36(10)*, 881-909. [DOI: 10.2165/00007256-200636100-00006]

Millet, G., Lepers, R., Maffiuletti, N., Babault, N., Martin, V. & Lattier, G. (2002). Alterations of neuromuscular function after and ultramarathon. *Journal of Applied Physiology*, *92(2)*, 486-492. [DOI: 10.1152/japplphysiol.00122.2001]

Millet, G. (2011). Can neuromuscular fatigue explain running strategies and performance in ultra-marathons? The Flush Model. *Sports Medicine*, *41(6)*, 489-506. [DOI: 10.2165/11588760-000000000-00000]

Millet, G., Tomazin, K., Verges, S., Vincent, C., Bonnefoy, R., Boisson, R., Gergele, L., Feasson, L. & Martin, V. (2011). Neuromuscular consequences of and extreme mountain ultra-marathon. *PLoS One*, *6*, e17059. [DOI: 10.1371/journal.pone.0017059]

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. [DOI: 10.1139/apnm-2018-0161]

Minetti, A., Moia, C., Roi, G., Susta, D. & Ferretti, G. (2002). Energy cost of walking and running at extreme uphill and downhill slopes. *Journal of Applied Physiology*, *93*, 1039-1046. [DOI: 10.1152/japplphysiol.01177.2001]

Myrkos, A., Smilios, I., Kokkinou, E., Rousopoulos, E. & Douda, H. (2020). Physiological and race pace characteristics of medium and low-level Athens Marathon runners. *Sports, 8(9)*, 116. [DOI: 10.3390/sports8090116]

Nikolaides, P., Onywera, O. & Knechtle, B. (2017). Running performance, nationality, sex and age in the 10-km, half-marathon, marathon, and the 100-km ultramarathon IAAF 1999-2015. *Journal of Strength and Conditioning Research*, *31(8)*, 2189-2207. [DOI: 10.1519/JSC.0000000000001687]

Nikolaidis, P. & Knechtle, B. (2018). Pacing strategies in the Athens Classic Marathon: Physiological and psychological aspects. *Frontiers in Physiology*, *9*, 1539. [DOI: 10.3389/fphys.2018.01539]

Nikolaides, P. & Knechtle, B. (2018). Age of peak performance in 50-km ultramarathoners – is it older than in marathoners? *Journal of Sports Medicine*, *9*, 37-45. [DOI: 10.2147%2FOAJSM.S154816]

Nikolaidis, P. & Knechtle, B. (2019). Russians are the fastest and the youngest in the “Comrades Marathon”. *Journal of Sports Sciences*, *37(12)*, 1387-1392. [DOI: 10.1080/02640414.2018.1559979].

Noakes, T. (2000). Physiological models to understand exercise fatigue and the adaptations that predict or enhance athletic performance. *Scandinavian Journal of Medicine and Science in Sports, 10*, 123-145. [DOI: 10.1034/j.1600-0838.2000.010003123.x]

Noakes, T., Gibson, A. & Lambert, E. (2004). From catastrophe to complexity: A novel model of integrative central neural regulation of effort and fatigue during exercise in humans. *British Journal of Sports Medicine, 38(4)*, 511-514. [DOI: 10.1136/bjsm.2003.010330]

Noakes, T. (2007). The central governor model of exercise regulation applied to the marathon. *Sports Medicine*, *37(4)*, 374-377. [DOI: 10.2165/00007256-200737040-00026]

Onywera, V., Scott, R., Boit, M. & Pitsiladis, Y. (2007). Demographic characteristics of elite Kenyan endurance runners. *Journal of Sports Sciences*, *24(4)*, 415-422. [DOI: 10.1080/02640410500189033]

Parise, C. & Hoffman, M. (2011). Influence of temperature and performance level on pacing a 161km trail ultramarathon. *International Journal of Sports Physiology and Performance*, *6(2)*, 243-251. [DOI: 10.1123/ijspp.6.2.243]

Petersen, K., Hansen, C., Aagaard, P. & Madsen, K. (2007). Muscle mechanical characteristics in fatigue and recovery from a marathon race in highly trained runners. *European Journal of Applied Physiology*, *101(3)*, 385-396. [DOI: 10.1007/s00421-007-0504-x]

Pugh, L. (1971). The influence of wind resistance in running and walking and the mechanical efficiency of work against horizontal or vertical forces. *Journal of Physiology*, *213(2)*, 255-276. [DOI: 10.1113/jphysiol.1971.sp009381]

Racinais, S., Girard, O., Micallef, P. & Perrey, S. (2007). Failed excitability of spinal motoneurons induced by prolonged running exercise. *Journal of Neurophysiology*, *97(1)*, 596-603. [DOI: 10.1152/jn.00903.2006]

Renfree, A. & Gibson, A. (2013). Influence of different performance levels on pacing strategy during the Women's World Championship Marathon race. *International Journal of Sports Physiology and Performance*, *3(7)*, 279-285. [DOI: 10.1123/ijspp.8.3.279]

Renfree, A., Martin, L., Micklewright, D. & Gibson, A. (2014). Application of decision-making theory to the regulation of muscular work rate during self-paced competitive endurance activity. *Sports Medicine*, *44(2)*, 147-158. [DOI: 10.1007/s40279-013-0107-0]

Renfree, A., Do Carmo, E. & Martin, L. (2015). The influence of performance level, age and gender on pacing strategy during a 100km ultramarathon. *European Journal of Sports Science*, *16(4)*, 409-415. [DOI: 10.1080/17461391.2015.1041061]

Renfree, A. & Casado, A. (2018). Athletic races represent complex systems, and pacing behaviour should be viewed as an emergent phenomenon. *Frontiers in Physiology*, *9*, 1432. [DOI: 10.3389/fphys.2018.01432]

Romer, T., Rüst, C., Zingg, M., Rosemann, T. & Knechtle, B. (2014). Age and ultra-marathon performance – 50 to 1,000 km distances from 1969 – 2012. *SpringerPlus*, *3*, 693. [DOI: 10.1186/2193-1801-3-693]

Ronto, P. (2023, July 24). "The State of Ultra-Running 2020". *RunRepeat.* [cited: August 2023]; Available from: https://runrepeat.com/state-of-ultra-running.

Ross, E., Middleton, N., Shave, R., George, K. & Nowicky, A. (2007). Corticomotor excitability contributes to neuromuscular fatigue following marathon running in man. *Experimental Physiology*, *92(2)*, 417-426. [DOI: 10.1113/expphysiol.2006.035972]

Santos-Lozano, A., Collado, P., Foster, C., Lucia, A. & Garatachea, N. (2014). Influence of sex and level on marathon pacing strategy: Insights from the New York City race. *International Journal of Sports Medicine*, 35: 1-6. [DOI: 10.1055/s-0034-1367048]

Saugy, J., Place, N., Millet, G.Y., Degache, F., Schena, F. & Millet, G.P. (2013). Alterations of neuromuscular function after the world's most challenging mountain ultra-marathon. *PLoS One*, *8(6)*, e65596. [DOI: 10.1371/journal.pone.0065596]

Scheer, V. (2019). Participation trends of ultra endurance events. *Sports Medicine and Arthroscopy Review, 27(1)*, 3-7. [DOI: 10.1097/JSA.0000000000000198]

Senefeld, J., Smith, C. & Hunter, S. (2016). Sex differences in participation, performance and age of ultramarathon runners. *International Journal of Sports Physiology and Performance*, *11*, 635-642. [DOI: 10.1123/ijspp.2015-0418]

Shei, R. & Mickleborough, T. (2013). Relative contributions of central and peripheral factors in human muscle fatigue during exercise: A brief review. *Journal of Exercise Physiology*, *16(6)*, 1-17.

Shulman, R. & Rothman, D. (2001). The “glycogen shunt” in exercising muscle: A role for glycogen in muscle genetics and fatigue. *Proceedings of the National Academy of Sciences of the United States of America, 98(2)*, 457-461. [DOI: 10.1073/pnas.98.2.457]

Smyth, B. (2018). Fast starters and slow finishers: A large-scale data analysis of pacing at the beginning and end of the marathon for recreational runners. *Journal of Sports Analytics, 4*, 229-242. [DOI: 10.3233/JSA-170205]

Sparling, P., Nieman, D. & O’Connor, P. (1993). Selected scientific aspects of marathon racing: An update on fluid replacement, immune function, psychological factors and the gender difference. *Sports Medicine*, *15(2)*, 116-132. [DOI: 10.2165/00007256-199315020-00005]

Staab, J., Agnew, J. & Siconolfi, S. (1992). Metabolic and performance responses to uphill and downhill running in distance runners. *Medicine and Science in Sports and Exercise*, *24(1)*, 124-127.

Sullivan, G. & Feinn, R. (2012). Using effect size – or why the *P* value is not enough. *Journal of Graduate Medical Education*, *4(3)*, 279-282. [DOI: 10.4300%2FJGME-D-12-00156.1]

Tan, P., Tan, F. & Bosch, A. (2016). Similarities and differences in pacing patterns in a 161km and 101km ultra-distance road race. *The Journal of Strength and Conditioning Research*, *30(8)*, 2145-2155. [DOI: 10.1519/JSC.0000000000001326]

Taylor, J., Todd, G. & Gandevia, S. (2006). Evidence for a supraspinal contribution to human muscle fatigue. *Clinical and Experimental Pharmacology and Physiology*, *33(4)*, 400-405. [DOI: 10.1111/j.1440-1681.2006.04363.x]

Temesi, J., Arnal, P., Rupp, T., Feasson, L., Cartier, R., Gergele, L., Verges, S., Martin, V. & Millet, G. (2015). Are females more resistant to extreme neuromuscular fatigue? *Medicine and Science in Sports and Exercise*, *47(7)*, 1372-1382. [DOI: 10.1249/MSS.0000000000000540]

Tiller, N., Elliot-Sale, K., Knechtle, B., Wilson, P., Roberts, J. & Millet, G. (2021). Do sex-differences in physiology confer a female advantage in ultra-endurance sport? *Sports Medicine*, *51*, 895-915. [DOI: 10.1007/s40279-020-01417-2]

Townshend, A., Worringham, C. & Stewart, I. (2010). Spontaneous pacing during overground hill running. *Medicine & Science in Sports & Exercise*, *42(1)*, 160-169. [DOI: 10.1249/MSS.0b013e3181af21e2]

Tucker, R., Rauch, L., Harley, Y & Noakes, T. (2004). Impaired exercise performance in the heat is associated with an anticipatory reduction in skeletal muscle recruitment. *Pflügers Archiv*, *448(4)*, 422-430. [DOI: 10.1007/s00424-004-1267-4]

Tucker, R. & Noakes, T. (2009). The physiological regulation of pacing strategy during exercise: A critical review. *British Journal of Sports Medicine, 43*, 1-9. [DOI: 10.1136/bjsm.2009.057562]

Two Oceans Marathon. History. 2021 [cited July 2022]; Available from: https://www.twooceansmarathon.org.za/about-two-oceans/history/

Ulmer, H. (1996). Concept of an extracellular regulation of muscular metabolic rate during heavy exercise in humans by psychophysiological feedback. *Experientia, 52(5)*, 416-420. [DOI: 10.1007/BF01919309]

Valentin, S., Pham, L. & Macrae, E. (2022). Enablers and barriers in ultra-running: A comparison of male and female ultra-runners. *Sport in Society*, *25(11)*, 2193-2212. [DOI: 10.1080/17430437.2021.1898590]

Vernillo, G., Savoldelli, A., Zignoli, A., Skafidas, S., Fornasiero, A., La Torre, A., Bortolan, L., Pellegrini, B. & Schena, F. (2015). Energy cost and kinematics of level, uphill and downhill running: Fatigue-induced changes after a mountain ultramarathon. *Journal of Sports Sciences*, *33(19)*, 1998-2005. [DOI: 10.1080/02640414.2015.1022870]

Vernillo, G., Giandolini, M., Edwards, W., Morin, J., Samozino, P., Horvais, N. & Millet, G. (2017). Biomechanics and physiology of uphill and downhill running. *Sports Medicine*, *47(4)*, 615-629. [DOI: 10.1007/s40279-016-0605-y]

Waldvogel, K., Nikolaides, P., 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 & Public Health, 16(13)*, 2377. [DOI: 10.3390/ijerph16132377]

Whipp, B. & Ward, S. (1992). Will women soon outrun men? *Nature*, *355(6355)*, 25. [DOI: 10.1038/355025a0]

World Athletics. Results. 2023 [cited December 2023]; Available from: https://worldathletics.org/records

World Marathon Majors. How it works. 2022 [cited August 2022]; Available from: https://www.worldmarathonmajors.com/elite-series/how-it-works

Zavorsky, G., Tomko, K. & Smoliga, J. (2017). Declines in marathon performance: Sex differences in elite and recreational athletes. *PLoS ONE*, *12(2)*, e0172121. [DOI: 10.1371/journal. pone.0172121]

Zingg, M., Karner-Rezek, K., Rosemann, T., Knechtle, B., Lepers, R. & Rust, C. (2014). Will women outrun men in ultra-marathon road races from 50km to 1,000km? *SpringerPlus*, *3*, 97-109. [DOI: 10.1186/2193-1801-3-97]

APPENDIX I

EXAMPLES OF DATA PROCESSING SHEETS

To calculate the average pace in min/km and km/h for each runner in group A to G over segment 1 to 4 of the race as well as the mean race pace (MRP) of each runner over the entire distance of the race (56km).

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	PositionGender	FinishTime	Group	SEGMENT 1 (28km)	SEGMENT 1 Pace (min/km)	SEGMENT 1 Pace (km/h)	SEGMENT 2 (42km)	SEGMENT 2 Pace (min/km)	SEGMENT 2 Pace (km/h)	SEGMENT 3 (50km)	SEGMENT 3 Pace (min/km)	SEGMENT 3 Pace (km/h)	SEGMENT 4 (56KM)	SEGMENT 4 Pace (min/km)	SEGMENT 4 Pace (km/h)	MEAN RACE PACE	MEAN RACE PACE
2	Person 1	03:33:59	A	01:45:11	00:03:45	15,97	02:37:39	00:03:45	16,01	03:10:19	00:04:05	14,69	03:33:59	00:03:57	15,21	00:03:49	15,70
3	Person 2	03:35:05	A	01:44:41	00:03:44	16,05	02:40:57	00:04:01	14,93	03:13:21	00:04:03	14,81	03:35:05	00:03:37	16,56	00:03:50	15,62
4	Person 3	03:35:16	A	01:44:41	00:03:44	16,05	02:40:57	00:04:01	14,93	03:13:32	00:04:04	14,73	03:35:16	00:03:37	16,56	00:03:51	15,61
5	Person 4	03:35:25	A	01:49:10	00:03:54	15,39	02:41:43	00:03:45	15,98	03:13:22	00:03:57	15,17	03:35:25	00:03:41	16,33	00:03:51	15,60
6	Person 5	03:37:08	A	01:48:15	00:03:52	15,52	02:44:00	00:03:59	15,07	03:15:18	00:03:55	15,34	03:37:08	00:03:38	16,49	00:03:53	15,47
7	Person 6	03:39:24	A	01:49:13	00:03:54	15,38	02:42:45	00:03:49	15,69	03:16:00	00:04:09	14,44	03:39:24	00:03:54	15,38	00:03:55	15,31
8	Person 7	03:39:32	A	01:48:22	00:03:52	15,50	02:44:00	00:03:58	15,10	03:16:33	00:04:04	14,75	03:39:32	00:03:50	15,66	00:03:55	15,31
9	Person 8	03:39:54	A	01:45:23	00:03:46	15,94	02:41:29	00:04:00	14,97	03:16:19	00:04:21	13,78	03:39:54	00:03:56	15,27	00:03:56	15,28
10	Person 9	03:40:08	A	01:48:53	00:03:53	15,43	02:45:12	00:04:01	14,92	03:17:20	00:04:01	14,94	03:40:08	00:03:48	15,79	00:03:56	15,26
11	Person 10	03:40:16	A	01:47:15	00:03:50	15,66	02:44:10	00:04:04	14,76	03:17:54	00:04:13	14,23	03:40:16	00:03:44	16,10	00:03:56	15,25
12	Person 11	03:40:40	A	01:44:40	00:03:44	16,05	02:43:00	00:04:10	14,40	03:17:35	00:04:19	13,88	03:40:40	00:03:51	15,60	00:03:56	15,23
13	Person 12	03:41:57	A	01:46:52	00:03:49	15,72	02:43:30	00:04:03	14,83	03:17:34	00:04:16	14,09	03:41:57	00:04:04	14,76	00:03:58	15,14
14	Person 13	03:42:13	A	01:44:54	00:03:45	16,02	02:40:03	00:03:56	15,23	03:15:08	00:04:23	13,68	03:42:13	00:04:31	13,29	00:03:58	15,12
15	Person 14	03:43:38	A	01:45:48	00:03:47	15,88	02:42:13	00:04:02	14,89	03:18:32	00:04:32	13,22	03:43:38	00:04:11	14,34	00:04:00	15,02
16	Person 15	03:44:44	A	01:54:03	00:04:04	14,73	02:51:22	00:04:06	14,66	03:23:29	00:04:01	14,95	03:44:44	00:03:33	16,94	00:04:01	14,95
17	Person 16	03:45:15	A	01:51:58	00:04:00	15,00	02:49:47	00:04:08	14,53	03:23:17	00:04:11	14,33	03:45:15	00:03:40	16,39	00:04:01	14,92
18	Person 17	03:45:29	A	01:48:43	00:03:53	15,45	02:46:00	00:04:05	14,66	03:20:07	00:04:16	14,07	03:45:29	00:04:14	14,19	00:04:02	14,90
19	Person 18	03:45:55	A	01:49:04	00:03:54	15,40	02:47:51	00:04:12	14,29	03:22:36	00:04:21	13,81	03:45:55	00:03:53	15,44	00:04:02	14,87
20	Person 19	03:46:47	A	01:47:13	00:03:50	15,67	02:45:03	00:04:08	14,52	03:21:13	00:04:31	13,27	03:46:47	00:04:16	14,08	00:04:03	14,82
21	Person 20	03:47:27	A	01:51:43	00:03:59	15,04	02:49:32	00:04:08	14,53	03:23:22	00:04:14	14,19	03:47:27	00:04:01	14,95	00:04:04	14,77
22	Person 21	03:47:36	A	01:45:23	00:03:46	15,94	02:41:29	00:04:00	14,97	03:19:57	00:04:48	12,48	03:47:36	00:04:37	13,02	00:04:04	14,76
23	Person 22	03:47:40	A	01:51:17	00:03:58	15,10	02:47:56	00:04:03	14,83	03:22:36	00:04:20	13,85	03:47:40	00:04:11	14,36	00:04:04	14,76
24	Person 23	03:49:00	A	01:44:41	00:03:44	16,05	02:42:17	00:04:07	14,58	03:22:45	00:05:03	11,86	03:49:00	00:04:22	13,71	00:04:05	14,67
25	Person 24	03:49:23	A	01:52:21	00:04:01	14,95	02:50:51	00:04:11	14,36	03:25:34	00:04:20	13,83	03:49:23	00:03:58	15,12	00:04:06	14,65
26	Person 25	03:50:35	A	01:53:28	00:04:03	14,81	02:52:53	00:04:15	14,14	03:26:29	00:04:12	14,29	03:50:35	00:04:01	14,94	00:04:07	14,57
27	Person 26	03:50:49	A	01:48:53	00:03:53	15,43	02:46:15	00:04:06	14,64	03:24:32	00:04:47	12,54	03:50:49	00:04:23	13,70	00:04:07	14,56
28	Person 27	03:50:59	A	01:54:30	00:04:05	14,67	02:53:44	00:04:14	14,18	03:28:12	00:04:18	13,93	03:50:59	00:03:48	15,80	00:04:07	14,55
29	Person 28	03:52:07	A	01:50:48	00:03:57	15,16	02:50:25	00:04:15	14,09	03:27:00	00:04:34	13,12	03:52:07	00:04:11	14,33	00:04:09	14,48
30	Person 29	03:52:22	A	01:49:23	00:03:54	15,36	02:49:06	00:04:16	14,07	03:25:14	00:04:31	13,28	03:52:22	00:04:31	13,27	00:04:09	14,46
31	Person 30	03:52:26	A	01:48:45	00:03:53	15,45	02:51:41	00:04:30	13,35	03:27:54	00:04:32	13,25	03:52:26	00:04:05	14,67	00:04:09	14,46
32	Person 31	03:52:28	A	01:45:23	00:03:46	15,94	02:45:28	00:04:17	13,98	03:26:11	00:05:05	11,79	03:52:28	00:04:23	13,70	00:04:09	14,45
33	Person 32	03:52:38	A	01:53:45	00:04:04	14,77	02:52:58	00:04:14	14,19	03:27:44	00:04:21	13,81	03:52:38	00:04:09	14,46	00:04:09	14,44
34	Person 33	03:53:07	A	01:54:04	00:04:04	14,73	02:51:44	00:04:07	14,57	03:27:36	00:04:29	13,38	03:53:07	00:04:15	14,11	00:04:10	14,41
35	Person 34	03:53:08	A	01:50:34	00:03:57	15,19	02:51:32	00:04:21	13,78	03:27:52	00:04:32	13,21	03:53:08	00:04:13	14,25	00:04:10	14,41
36	Person 35	03:53:09	A	01:51:56	00:04:00	15,01	02:50:53	00:04:13	14,25	03:28:31	00:04:42	12,75	03:53:09	00:04:06	14,61	00:04:10	14,41
37	Person 36	03:53:09	A	01:52:30	00:04:01	14,93	02:51:50	00:04:14	14,16	03:28:02	00:04:32	13,26	03:53:09	00:04:11	14,33	00:04:10	14,41
38	Person 37	03:54:56	A	01:52:23	00:04:01	14,95	02:52:50	00:04:19	13,90	03:29:21	00:04:34	13,14	03:54:56	00:04:16	14,07	00:04:12	14,30
39	Person 38	03:54:59	A	01:54:24	00:04:05	14,69	02:56:25	00:04:26	13,54	03:31:02	00:04:20	13,87	03:54:59	00:04:00	15,03	00:04:12	14,30

To calculate the average pace of each runner from group A to G over segment 1 to 4 of the race as a % relative to their average pace over segment 1 which was assigned a 100% value.

	A	B	C	F	G	J	K	N	O	R	S	T	U	V
1	PositionGender	FinishTime	Group	SEGMENT 1 Pace (km/h)	SEGMENT 1 Speed is allocated a value of (100%)	SEGMENT 2 Pace (km/h)	SEGMENT2 Pace as % relative to SEGMENT 1	SEGMENT 3 Pace (km/h)	SEGMENT 3 Pace as % relative to SEGMENT 1	SEGMENT 4 Pace (km/h)	SEGMENT 4 Pace as % relative to SEGMENT 1	MEAN RACE PACE	MEAN RACE PACE	MEAN RACE PACE As % relative to SEGMENT 1
2	Person 1	03:33:59	A	15,97	100,00	16,01	100,24	14,69	92,00	15,21	95,24	00:03:49	15,70	98,31
3	Person 2	03:35:05	A	16,05	100,00	14,93	93,02	14,81	92,31	16,56	103,22	00:03:50	15,62	97,34
4	Person 3	03:35:16	A	16,05	100,00	14,93	93,02	14,73	91,79	16,56	103,22	00:03:51	15,61	97,26
5	Person 4	03:35:25	A	15,39	100,00	15,98	103,87	15,17	98,55	16,33	106,09	00:03:51	15,60	101,35
6	Person 5	03:37:08	A	15,52	100,00	15,07	97,09	15,34	98,81	16,49	106,24	00:03:53	15,47	99,71
7	Person 6	03:39:24	A	15,38	100,00	15,69	102,01	14,44	93,85	15,38	100,02	00:03:55	15,31	99,56
8	Person 7	03:39:32	A	15,50	100,00	15,10	97,39	14,75	95,12	15,66	101,04	00:03:55	15,31	98,72
9	Person 8	03:39:54	A	15,94	100,00	14,97	93,92	13,78	86,44	15,27	95,75	00:03:56	15,28	95,85
10	Person 9	03:40:08	A	15,43	100,00	14,92	96,67	14,94	96,81	15,79	102,33	00:03:56	15,26	98,92
11	Person 10	03:40:16	A	15,66	100,00	14,76	94,22	14,23	90,84	16,10	102,75	00:03:56	15,25	97,38
12	Person 11	03:40:40	A	16,05	100,00	14,40	89,71	13,88	86,47	15,60	97,16	00:03:56	15,23	94,86
13	Person 12	03:41:57	A	15,72	100,00	14,83	94,35	14,09	89,63	14,76	93,92	00:03:58	15,14	96,30
14	Person 13	03:42:13	A	16,02	100,00	15,23	95,10	13,68	85,43	13,29	83,00	00:03:58	15,12	94,41
15	Person 14	03:43:38	A	15,88	100,00	14,89	93,77	13,22	83,24	14,34	90,32	00:04:00	15,02	94,62
16	Person 15	03:44:44	A	14,73	100,00	14,66	99,49	14,95	101,46	16,94	115,01	00:04:01	14,95	101,50
17	Person 16	03:45:15	A	15,00	100,00	14,53	96,83	14,33	95,49	16,39	109,22	00:04:01	14,92	99,42
18	Person 17	03:45:29	A	15,45	100,00	14,66	94,89	14,07	91,05	14,19	91,84	00:04:02	14,90	96,43
19	Person 18	03:45:55	A	15,40	100,00	14,29	92,77	13,81	89,67	15,44	100,23	00:04:02	14,87	96,55
20	Person 19	03:46:47	A	15,67	100,00	14,52	92,69	13,27	84,70	14,08	89,86	00:04:03	14,82	94,55
21	Person 20	03:47:27	A	15,04	100,00	14,53	96,61	14,19	94,34	14,95	99,40	00:04:04	14,77	98,23
22	Person 21	03:47:36	A	15,94	100,00	14,97	93,92	12,48	78,27	13,02	81,67	00:04:04	14,76	92,60
23	Person 22	03:47:40	A	15,10	100,00	14,83	98,22	13,85	91,72	14,36	95,13	00:04:04	14,76	97,76
24	Person 23	03:49:00	A	16,05	100,00	14,58	90,87	11,86	73,91	13,71	85,46	00:04:05	14,67	91,43
25	Person 24	03:49:23	A	14,95	100,00	14,36	96,03	13,83	92,46	15,12	101,08	00:04:06	14,65	97,96
26	Person 25	03:50:35	A	14,81	100,00	14,14	95,48	14,29	96,49	14,94	100,89	00:04:07	14,57	98,42
27	Person 26	03:50:49	A	15,43	100,00	14,64	94,90	12,54	81,26	13,70	88,77	00:04:07	14,56	94,35
28	Person 27	03:50:59	A	14,67	100,00	14,18	96,65	13,93	94,92	15,80	107,69	00:04:07	14,55	99,14
29	Person 28	03:52:07	A	15,16	100,00	14,09	92,93	13,12	86,53	14,33	94,53	00:04:09	14,48	95,47
30	Person 29	03:52:22	A	15,36	100,00	14,07	91,59	13,28	86,49	13,27	86,39	00:04:09	14,46	94,15
31	Person 30	03:52:26	A	15,45	100,00	13,35	86,40	13,25	85,79	14,67	94,99	00:04:09	14,46	93,58
32	Person 31	03:52:28	A	15,94	100,00	13,98	87,70	11,79	73,95	13,70	85,92	00:04:09	14,45	90,67
33	Person 32	03:52:38	A	14,77	100,00	14,19	96,05	13,81	93,48	14,46	97,89	00:04:09	14,44	97,79
34	Person 33	03:53:07	A	14,73	100,00	14,57	98,90	13,38	90,87	14,11	95,79	00:04:10	14,41	97,86
35	Person 34	03:53:08	A	15,19	100,00	13,78	90,68	13,21	86,95	14,25	93,77	00:04:10	14,41	94,85
36	Person 35	03:53:09	A	15,01	100,00	14,25	94,94	12,75	84,98	14,61	97,37	00:04:10	14,41	96,02
37	Person 36	03:53:09	A	14,93	100,00	14,16	94,80	13,26	88,79	14,33	95,98	00:04:10	14,41	96,50
38	Person 37	03:54:56	A	14,95	100,00	13,90	92,96	13,14	87,93	14,07	94,13	00:04:12	14,30	95,67

To calculate the average pace of each runner from group A to G over segment 1 to 4 as a % relative to their overall mean race pace (MRP) which was assigned a value of 100%.

	A	B	C	F	G	J	K	N	O	R	S	T	U	V
1	PositionGender	FinishTime	Group	SEGMENT 1 Pace (km/h)	SEGMENT 1 Pace as % Relative to MRP	SEGMENT 2 Pace (km/h)	SEGMENT 2 Pace as % Relative to MRP	SEGMENT 3 Pace (km/h)	SEGMENT 3 Pace as % relative to MRP	SEGMENT 4 Pace (km/h)	SEGMENT 4 Pace Relative to MRP as %	MEAN RACE PACE	MEAN RACE PACE	MRP (100%)
2	Person 1	03:33:59	A	15,97	101,72	16,01	101,96	14,69	93,58	15,21	96,87	00:03:49	15,70	100
3	Person 2	03:35:05	A	16,05	102,73	14,93	95,56	14,81	94,83	16,56	106,03	00:03:50	15,62	100
4	Person 3	03:35:16	A	16,05	102,82	14,93	95,65	14,73	94,38	16,56	106,12	00:03:51	15,61	100
5	Person 4	03:35:25	A	15,39	98,66	15,98	102,48	15,17	97,23	16,33	104,67	00:03:51	15,60	100
6	Person 5	03:37:08	A	15,52	100,29	15,07	97,37	15,34	99,10	16,49	106,55	00:03:53	15,47	100
7	Person 6	03:39:24	A	15,38	100,44	15,69	102,46	14,44	94,26	15,38	100,46	00:03:55	15,31	100
8	Person 7	03:39:32	A	15,50	101,29	15,10	98,65	14,75	96,35	15,66	102,34	00:03:55	15,31	100
9	Person 8	03:39:54	A	15,94	104,33	14,97	97,99	13,78	90,18	15,27	99,90	00:03:56	15,28	100
10	Person 9	03:40:08	A	15,43	101,09	14,92	97,72	14,94	97,87	15,79	103,45	00:03:56	15,26	100
11	Person 10	03:40:16	A	15,66	102,69	14,76	96,75	14,23	93,28	16,10	105,51	00:03:56	15,25	100
12	Person 11	03:40:40	A	16,05	105,41	14,40	94,57	13,88	91,15	15,60	102,42	00:03:56	15,23	100
13	Person 12	03:41:57	A	15,72	103,84	14,83	97,98	14,09	93,07	14,76	97,53	00:03:58	15,14	100
14	Person 13	03:42:13	A	16,02	105,92	15,23	100,73	13,68	90,49	13,29	87,91	00:03:58	15,12	100
15	Person 14	03:43:38	A	15,88	105,69	14,89	99,10	13,22	87,97	14,34	95,46	00:04:00	15,02	100
16	Person 15	03:44:44	A	14,73	98,52	14,66	98,02	14,95	99,96	16,94	113,31	00:04:01	14,95	100
17	Person 16	03:45:15	A	15,00	100,59	14,53	97,40	14,33	96,06	16,39	109,87	00:04:01	14,92	100
18	Person 17	03:45:29	A	15,45	103,70	14,66	98,41	14,07	94,42	14,19	95,24	00:04:02	14,90	100
19	Person 18	03:45:55	A	15,40	103,57	14,29	96,08	13,81	92,87	15,44	103,81	00:04:02	14,87	100
20	Person 19	03:46:47	A	15,67	105,76	14,52	98,03	13,27	89,58	14,08	95,04	00:04:03	14,82	100
21	Person 20	03:47:27	A	15,04	101,80	14,53	98,35	14,19	96,04	14,95	101,19	00:04:04	14,77	100
22	Person 21	03:47:36	A	15,94	107,99	14,97	101,43	12,48	84,53	13,02	88,19	00:04:04	14,76	100
23	Person 22	03:47:40	A	15,10	102,29	14,83	100,47	13,85	93,82	14,36	97,31	00:04:04	14,76	100
24	Person 23	03:49:00	A	16,05	109,38	14,58	99,39	11,86	80,84	13,71	93,47	00:04:05	14,67	100
25	Person 24	03:49:23	A	14,95	102,08	14,36	98,03	13,83	94,39	15,12	103,19	00:04:06	14,65	100
26	Person 25	03:50:35	A	14,81	101,61	14,14	97,02	14,29	98,04	14,94	102,51	00:04:07	14,57	100
27	Person 26	03:50:49	A	15,43	105,99	14,64	100,59	12,54	86,13	13,70	94,09	00:04:07	14,56	100
28	Person 27	03:50:59	A	14,67	100,87	14,18	97,49	13,93	95,74	15,80	108,62	00:04:07	14,55	100
29	Person 28	03:52:07	A	15,16	104,75	14,09	97,34	13,12	90,64	14,33	99,02	00:04:09	14,48	100
30	Person 29	03:52:22	A	15,36	106,22	14,07	97,28	13,28	91,87	13,27	91,76	00:04:09	14,46	100
31	Person 30	03:52:26	A	15,45	106,87	13,35	92,33	13,25	91,68	14,67	101,51	00:04:09	14,46	100
32	Person 31	03:52:28	A	15,94	110,30	13,98	96,73	11,79	81,56	13,70	94,76	00:04:09	14,45	100
33	Person 32	03:52:38	A	14,77	102,26	14,19	98,21	13,81	95,59	14,46	100,10	00:04:09	14,44	100
34	Person 33	03:53:07	A	14,73	102,18	14,57	101,06	13,38	92,85	14,11	97,88	00:04:10	14,41	100
35	Person 34	03:53:08	A	15,19	105,43	13,78	95,60	13,21	91,66	14,25	98,86	00:04:10	14,41	100
36	Person 35	03:53:09	A	15,01	104,15	14,25	98,88	12,75	88,50	14,61	101,41	00:04:10	14,41	100
37	Person 36	03:53:09	A	14,93	103,62	14,16	98,24	13,26	92,01	14,33	99,46	00:04:10	14,41	100
38	Person 37	03:54:56	A	14,95	104,52	13,90	97,16	13,14	91,91	14,07	98,39	00:04:12	14,30	100

APPENDIX II

ETHICS APPROVAL

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

Room 45 E-52-E-Floor- Old Main Building
Groote Schuur Hospital
Observatory 7925
Telephone [021] 406 6492
Email: hrec-submissions@uct.ac.za
Website: www.health.uct.ac.za/fhs/research/humanethics/forms

23 May 2022

HREC REF: 287/2022

A/Prof A Bosch
Division of Physiological Sciences
Sports Science Institute, Newlands
Email: Andrew.bosch@uct.ac.za
Student: genine@gmphysio.co.za

Dear A/Prof Bosch

PROJECT TITLE : A COMPARISON OF THE PACING STRATEGIES ADOPTED BY ELITE VERSUS NON-ELITE MALE RUNNERS IN THE COMRADES MARATHON-
(MASTERS CANDIDATE-MRS GENINE MANCHIP)

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

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

This approval is subject to strict adherence to the HREC recommendations regarding research involving human participants during COVID -19. Please refer to guidance letter dated 02 February 2022 on our website:
http://www.health.uct.ac.za/fhs/research/humanethics/forms

Approval is granted for one year until the 30 May 2023.

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)

The HREC acknowledge that the student: Mrs Genine Manchip will also be involved in this study.

Please quote the HREC REF 287/2022 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, where necessary, before the research may occur.

HREC.ref287.2022

Yours sincerely

Signed by candidate

PROFESSOR M BLOCKMAN
CHAIRPERSON, FACULTY OF HEALTH SCIENCES HUMAN RESEARCH ETHICS COMMITTEE
Federal Wide Assurance Number: FWA00001637. Institutional Review Board (IRB) number: IRB00001938 NHREC-registration number: REC-210208-007
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 Research Council (MRC-SA), Food and Drug Administration (FDA-USA), International Council for Harmonisation of Technical Requirements for Pharmaceuticals for Human Use: Good Clinical Practice (ICH GCP), South African Good Clinical Practice Guidelines (DoH 2020), 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.ref287.2022

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

FACULTY OF HEALTH SCIENCES
Human Research Ethics Committee

Form FHS006: Protocol Amendment

HREC office use only (FWA00001637; IRB00001938)			
☑ Approved	☑ Type of review: Expedited	☐ Full committee	
This serves as notification that all changes and documentation described below are approved.			
Signature HREC Chairperson / Designee	Signed by candidate	Date	9/8/22

Note: All **Major** amendments must include a **Cover Letter** and a local **PI Synopsis** justifying the changes for the amendment. Please note that incomplete amendment submissions will not be reviewed.

Please email this form and supporting documents (if applicable) in a combined pdf-file to hrec-enquiries@uct.ac.za with subject line: FHS006 + (HREC Reference number).

The latest forms are found on our website.

http://www.health.uct.ac.za/fhs/research/humanethics/forms

Please also clarify your plan for research-related activities during COVID-19 lockdown.

Comments from the HREC to the Principal Investigator:
Note: The approval of this protocol amendment does not grant annual approval. Please complete the FHS016 / FHS017 form for annual approval at least one month before study expiration.

Principal Investigator to complete the following:

1. Protocol information

Date (when submitting this form)	14 July 13, 2022		
HREC REF Number	287/2022		
Protocol Title	A comparison of the pacing profiles adopted by elite versus non-elite male runners in the Comrades Marathon		
Protocol Number (if applicable)			
Principal Investigator	A/Prof Andrew Bosch		
Department / Office Internal Mail Address	HUB, Division of Physiological Sciences		
1.1 Is this a major or a minor amendment? (see FHS006hlp) Major (tick box) Minor (tick box)		x Major	☐ Minor

HUMAN RESEARCH ETHICS COMMITTEE
02 AUG 2022
HEALTH SCIENCES FACULTY UNIVERSITY OF CAPE TOWN

1.2 Does this protocol receive US Federal funding?	☐ Yes	x No
1.3 If the amendment is a major amendment <u>and</u> receives US Federal Funding, does the amendment require full committee approval? **Note:** Any protocol amendments for **Full Committee Review** MUST be submitted on the monthly HREC submission dates. (Please email an electronic copy to hrec-enquiries@uct.ac.za)	☐ Yes	☐ No
1.4 Did the initial study require UCT No-Fault Insurance	☐ Yes	x No

2. List of Proposed Amendments with Revised Version Numbers and Dates

Please itemise on the page below, all amendments with revised version numbers and dates, which need approval.
This page will be detached, signed and returned to the PI as notification of approval. Please add extra pages if necessary.

The revisions itemized below can be summarized in the following way: The study that was approved by HREC was to analyse past race results of male runners in the Comrades Marathon "Up" run. This amendment request is to include female runners, and to include the "Down" run as well in the analysis, and to include a second ultra-marathon, the Two Oceans Marathon. In all cases, its past race times that will be analysed. No data will be collected. The justification/ rationale for the amendment is that it makes sense to include females as well as males, and also to not do the analysis for "just" the "Up" run, but to include the equally important "Down" run and the other major ultra in the world, the Two Oceans Ultra-marathon.

Below are the amendments to accommodate the above. The amended text is highlighted. These amendments have also been included in the full protocol (included with this Amendment submission): Two such protocols have been submitted; one with the amendments highlighted as below, and one clean copy, without any highlighting.

Original title:
A comparison of the pacing profiles adopted by elite versus non-elite male runners in the Comrades Marathon

New title in amended protocol:
A comparison of the pacing profiles adopted by elite versus non-elite male and female runners in the Comrades and Two Oceans Marathons

In the original protocol, the following is stated as the "Aim":

Aim

This study aims to compare the pacing profiles used by elite male runners versus the rest of the male runners in the Comrades Marathon "up" run.

In the amended protocol, this is amended to:

This study aims to:

1. Compare the pacing profiles used by elite male runners versus the rest of the male runners in the Comrades Marathon "up" run (The original aim)

2. Compare the pacing profiles used by elite female runners versus the rest of the female runners in the

Comrades Marathon "up" run.

3. Compare the pacing profiles used by elite male runners versus the rest of the male runners in the Comrades Marathon "down" run.

4. Compare the pacing profiles used by elite female runners versus the rest of the female runners in the Comrades Marathon "down" run.

5. Compare the pacing profiles used by elite male runners versus the rest of the male runners in the Two Oceans Ultra marathon

6. Compare the pacing profiles used by elite female runners versus the rest of the female runners in the Two Oceans Ultra marathon

In the original protocol, there were 3 objectives. These remain as shown below, with the additional objectives added in yellow highlighting:

Objectives

1. To analyse the race results of the Comrades Marathon "Up" run to identify the pacing profiles adopted by the male elite and recreational runners.
2. To compare the pacing profiles of the top male runners to the rest of the field in the Comrades Marathon up run.
3. To compare the top 10 male runners' starting pace in the Comrades Marathon Up run to their pace in their most recent marathon.
4. To analyse the race results of the Comrades Marathon "Up" run to identify the pacing profiles adopted by the female elite and recreational runners.
5. To compare the pacing profiles of the top female runners to the rest of the field in the Comrades Marathon "Up" run.
6. To compare the top 10 female runners' starting pace in the Comrades Marathon "Up" run to their pace in their most recent marathon.
7. To analyse the race results of the Comrades Marathon "Down" run to identify the pacing profiles adopted by the male elite and recreational runners.
8. To compare the pacing profiles of the top male runners to the rest of the field in the Comrades Marathon "Down" run.
9. To compare the top 10 male runners' starting pace in the Comrades Marathon "Down" run to their pace in their most recent marathon.
10. To analyse the race results of the Comrades Marathon "Down" run to identify the pacing profiles adopted by the female elite and recreational runners.
11. To compare the pacing profiles of the top female runners to the rest of the field in the Comrades Marathon "Down" run.
12. To compare the top 10 female runners' starting pace in the Comrades Marathon "Down" run to their pace in their most recent marathon.
13. To analyse the race results of the Two Oceans Marathon to identify the pacing profiles adopted by the male elite and recreational runners
14. To analyse the race results of the Two Oceans Marathon to identify the pacing profiles adopted by the female elite and recreational runners

Research Question

Is there a difference in pacing profiles used by the elite male and female runners compared to the rest of the male and female runners in the Comrades Marathon in both the "up" and "Down" directions, and the Two

Oceans Ultra Marathon?

Methodology

Study design

The purpose of this study is to analyse the race results the previous 10 years of the Comrades Marathon "up" and "Down" runs and the Two Oceans Ultra Marathon. This study will use a retrospective study design.

Data Collection

This study will make use of publicly accessible data which can be accessed on the Comrades Marathon and Two Oceans web sites.[26] The complete set of results (from 2000 – 2019) of the Comrades Marathon "up" and "down" run and Two Oceans will be used for this study. This will provide 10 years of race results and intermediate (split) times, which prevents any significant influence of extreme environmental conditions or minor route changes from influencing the pacing profiles. Each set of results contains the following information on each runner who completed the race each year: The official finishing time, the time at each timing check point and the runners' overall position.

For data analysis, the eight timing check points within the race (see table 1) will be used. The relative average speed between each segment (one check point to the next) will be calculated individually for each participant.

A second part of this study will be to compare the starting pace of the elite male and female runners in the Comrades and Two Oceans Marathon, to their marathon pace at a time close to their Comrades/ Two Oceans performance. Their marathon pace will be determined from a best marathon time close to the Comrades or Two Oceans data being analysed, available from international race databases.

Participants

Inclusion Criteria

The latest 10 complete Comrades Marathon "up" and "Down" run and Two Oceans race results will be included for analysis. This includes results from the year 2000 to 2019. The entire database of each race will be used in this study, thus including all the male and female runners who finished the race. From these results, the top 10 male runners in each race will be used to establish the pacing strategy of the elite runners relative to their recent best marathon times.

Exclusion Criteria

~~This study will only consider male runners (female results will be analysed in a separate study) as pacing profiles may differ between male and female. Subsequent studies will compare pacing of males and females.~~ Runners' results will be excluded if there are split times missing or the data is incompletely loaded or if any runners feature in two or more races. When a runner appears in more than one race result, their first "appearance" will be used and others discarded to avoid statistical bias.

Confidentiality

The data used in this study (race times and intermediate times) extends over a decade and has been publicly available since the races took place (the race results are available on the Comrades and Two Oceans Marathon websites).

3. Protocol status (tick ✓)

☐	Open to enrolment
☐	No participants have been enrolled
	Closed to enrolment (tick ✓)
✓☐	Research-related activities are ongoing
☐	Research-related activities are complete, long-term follow-up only
	Research-related activities are complete, data analysis only

4. Proposed changes will affect: (tick ✓ all the categories that apply)

Protocol	
✓☐	Study objectives, design (including investigator's brochure, clinical activities, study length)
☐	Study instruments, questionnaires, interview schedules
☐	Sample size
☐	Recruitment methods
☐	Eligibility criteria (inclusion and exclusion criteria)
☐	Drug/device (composition, amount, schedule, route of administration, combination with other drugs/devices, safety information)
☐	Data collection/ analysis
☐	Principal Investigator. (Please attach revised conflict of interest and PI declaration statements. Refer: sections 7 and 8.4 in the New Protocol Application Form FHS013)
☐	Consent form and information sheet
☐	Recruitment materials (e.g. advertisements)
☐	Administrative (e.g. change in sponsor's name, change in contact information)
✓☐	Other. Please specify: Addition of female runners, addition of Comrades "Down" results, addition of results from Two Oceans marathon

**Note: Amendment changes involving study length, sample size, additional sites and eligibility criteria (i.e. inclusion of minors and /or pregnant woman) need to be declared to the Insurance office. Please liaise via fhs.sponsorship@uct.ac.za regarding the required documentation and information to be submitted to obtain an updated UCT No-fault Insurance Certificate- it should be included herewith*

4.1 In your opinion, will there be any **increase** in risk, discomfort or inconvenience to participants?	☐ Yes	☐ No NA
If yes, please provide a detailed justification/explanation:		

4.2 What follow-up action do you propose for participants who are already enrolled in the study?	
☐	Inform current participants as soon as possible
☐	Re-consent current participants with revised consent/assent forms (append)
☐	No action required
✓☐	Other. Please describe: No participants in study; past race times only

5. Detailed description of the change(s)

Please attach, for each amendment, a summary of all changes which clearly indicates:

i. Old wording (e.g. ~~strikethrough~~ text, CHANGED FROM and CHANGED TO)
ii. New wording (e.g. *italicized*, **bold**, tracked)
iii. Detailed rationale/ justification/ explanation for each change

Please refer to point (2) above

6. Ethics Review for Amendment Levy – cost including vat

Amendment Review Costs including VAT

Please tick amount to be billed:

Submission Type	*Description*	*New fee (Vat Incl.)*	*tick ✓*
Research funded solely from UCT departmental/ divisional/group budget	Major/ Minor Amendments	**R0,00**	✓☐
Non-sponsored student research for degree purposes at UCT/Other Universities & Colleges	Major/ Minor Amendments	**R0,00**	☐
Protocol amendment - Major (FHS006 Form)	Clinical Trial & International Grant Funded Research - Any changes to the protocol that requires Full Committee review	**R8 000.00**	☐
Protocol amendment - Major (FHS006 Form)	Clinical Trial & International Grant Funded Research - Any change to the protocol that requires Expedited review that does not require Full Committee Review	**R5 000,00**	☐
Protocol amendment - Minor (FHS006 Form)	Clinical Trial & International Grant Funded Research - Minor amendments, administrative changes that do not affect study design e.g. changes to informed consent form, changes in study staff, etc.	**R2 250,00**	☐
Protocol amendment - Major (FHS006 Form)	National grant funded research - Any change to the protocol that requires Full Committee review	**R7 000,00**	☐
Protocol amendment - Major (FHS006 Form)	National grant funded research - Any change to the protocol that requires Expedited review that does not require Full Committee review	**R2 500,00**	☐
Protocol amendment - Minor (FHS006 Form)	National grant funded research - Minor amendments, administrative changes that do not affect study design e.g. changes to informed consent form, changes in study staff, etc.	**R1 000,00**	☐

NB: Protocols funded by UCT (e.g. departmental funding / student research) and by certain grant funding organizations (e.g. MRC, NRF, CANSA,) are exempt from these charges.

Please provide details for invoicing, either complete section 1 or 2 :

1. Invoice billing – Directly to Sponsor	
Sponsor's name	
Billing Address of Sponsor:	
Vat Number:	
Contact person:	
Telephone number:	
Email Address:	
2. Internal Journal Billing:	
Fund Number:	
Cost Centre Number:	
Account Holder Name:	
Division of Account Holder:	

7. Amendment Submission checklist (tick ✓)

7.1 Please tick that all the documents are attached before submitting to the HREC. NB: Incomplete submissions will not be processed	
✓☐	Latest FHS006 form completed with all sections completed as per our website
✓☐	Cover Letter
✓☐	PI Justification/ Summary for the reasons for the amendment
✓☐	Protocol - Track changes & Clean Copy (where necessary)
NA☐	Informed Consent Forms (ICF), if applicable (Any changes made to ICF tracked & clean copy)
NA☐	Any other additional documentation in support of amendment
NA☐	Updated no fault insurance certificate (if applicable)

Please email this form and supporting documents (if applicable) in a combined pdf-file to hrec-enquiries@uct.ac.za with subject line: FHS006 + (HREC Reference number). The latest forms are found on our website.

8. Signature

My signature certifies that I will maintain the anonymity and/ or confidentiality of information collected in this research. If at any time I want to share or re-use the information for purposes other than those disclosed in the original approval, I will seek further approval from the HREC.			
Signature of PI	Signed by candidate	Date	14/07/2022

APPENDIX III
ANNUAL PROGRESS REPORT

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

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	30/05/24
☐ Not approved	See attached comments		
Signature Chairperson of the HREC/ Designee	Signed by candidate	Date Signed	29/3/2023

Note: Please email this form and supporting documents (if applicable) in a combined pdf-file to hrec-enquiries@uct.ac.za.
Please clarify your plan for research-related activities during COVID-19 lockdown.
Please use the latest form found on our website:
http://www.health.uct.ac.za/fhs/research/humanethics/forms

Comments to PI from the HREC

Principal Investigator to complete the following:

1. Protocol information

Date (when submitting this form)	28/03/2023		
HREC REF Number	287/2022	Current Ethics Approval was granted until	30/05/23
Protocol title	A comparison of the pacing profiles adopted by elite versus non-elite male runners in the Comrades Marathon		
Protocol number (if applicable)	1		
Are there any sub-studies linked to this study?	☐ Yes	x No	
If yes, could you please provide the HREC Reference number for all sub-studies? **Note:** A separate FHS016 must be submitted for each sub-study.			
Principal Investigator	Genine Manchip		
Department / Office Internal Mail Address	Supervisor: Prof Andrew Bosch Andrew.bosch@uct.ac.za		

HUMAN RESEARCH ETHICS COMMITTEE
29 MAR 2023
HEALTH SCIENCES FACULTY UNIVERSITY OF CAPE TOWN

28 February 2022 Page 1 of 7 FHS016

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