ACCURACY OF PREDICTION OF ENDURANCE RUNNING PERFORMANCE: RELATIONSHIP TO TRAINING HISTORY, MUSCLE PAIN AND RELATIVE PERCEPTION OF EFFORT

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DECLARATION

I, Dawn Nunes (NNSDAW001), 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 in this or any other university.

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LIST OF ABBREVIATIONS

BMI	Body mass index
CI	Confidence interval
DOMS	Delayed onset muscle soreness
EIMD	Exercise-induced muscle damage
GPS	Global positioning system
kg	Kilogram
$kg.m^{-2}$	Kilogram per metre squared
km	Kilometre
$km.h^{-1}$	Kilometres per hour
m	Metre
$m.s^{-1}$	Metres per second
n	Number
PB	Personal best
RPE	Relative perception of effort
s	Second
SD	Standard deviation
SMS	Short message service
UCT	University of Cape Town
VAS	Visual analogue scale
°C	Degrees Celsius

ABSTRACT

Background

Endurance running performance is a complex interaction between training factors, exercise-induced muscle damage, and fatigue. The accuracy of prediction of running performance allows for the consideration of the effects of teleoanticipatory factors such as pacing and prior experience on performance. However, previous studies have not adequately considered the role of predicting performance outcomes before competition, and the potential influence of self-regulated pacing and prior experience on running performance.

Aim

The aim of this descriptive analytical correlational study was to determine potential factors associated with the accuracy of prediction of running performance during a marathon race.

Specific objectives

(a) To determine whether there were differences in training history, pacing, muscle pain and the relative perception of effort (RPE) in three identified groups that accurately predicted race time, performed faster than the predicted time, or performed slower than the predicted time; and (b) to determine if demographic characteristics, training and competition history, self-identified pacing strategy, muscle pain and the relative perception of effort (RPE) were associated with the accuracy of predicting performance during the marathon.

Methods

Sixty-three healthy male and female runners were recruited through a short message service (SMS), word of mouth and at the 2013 Mandela Day marathon registration. Participants were included if they were over the age of 20 years, and were taking part in the marathon race. Participants were required to complete the marathon within the seven-hour cut-off time. Participants who had any lower limb musculoskeletal injury, medical condition or surgical intervention that prevented training for seven consecutive days in the three-month period prior to the race were excluded from the study. Participants who reported any flu-like symptoms during the two weeks preceding the race were also excluded from the study. In addition, participants with any missing race RPE or pain scores were excluded. Participants were allocated to one of three groups depending on their accuracy in predicting their final race time. A margin of two percentage points was considered as a meaningful difference in time. If the participants' actual race time was accurate within two percentage points of their predicted race time, it was considered accurate, and those participants formed the accurate group (n = 16). Participants on either side of the two percentage points formed the fast (n = 21) and slow (n = 26) groups respectively. All participants completed an informed consent form and a medical and training questionnaire at a familiarisation session before to the race. Participants were also familiarised with the tests and procedures for collecting data during the race. During the marathon, muscle pain and relative perception of effort (RPE) were recorded at 0 km, 10 km, 21.1 km, 30 km, and 42.2 km. A short compliance questionnaire was completed when participants finished the marathon. Official race times were obtained from the Championchip® website. Muscle pain was recorded for seven days after the marathon. Participants were also asked to report when they resumed running training after the race.

Results

Participants in the slow group were significantly younger ($p < 0.05$), had faster 10 km PB times ($p < 0.01$), and trained at a faster pace ($p < 0.01$) compared to participants in the accurate and fast groups. Participants in the slow group had faster actual ($p < 0.05$) and predicted ($p < 0.01$) marathon times ($p < 0.01$) compared to participants in the accurate and fast groups. There was a significant positive relationship between actual and predicted marathon times ($r = 0.71$, $p < 0.01$). There were no significant differences between groups in muscle pain and RPE during the race; however there were significant main effects of time for pain ($p < 0.01$) and RPE ($p < 0.01$) during the race. Muscle pain and RPE were significantly increased at 21 km, 30 km, and 42.2 km, compared to pre-race values. There were no significant differences in post-race pain between groups, but there was a significant main effect of time ($p < 0.01$) as muscle pain was significantly elevated for three days after the race. This study was also unable to identify any significant demographic, training and competition history, or race factors associated with the accuracy of prediction of marathon performance.

Conclusion

Linear increases in muscle pain and RPE were observed during the race in all groups. This study was unable to identify specific factors associated with the accuracy of prediction of running performance during a marathon race. However, it is possible that the slow marathon times and the low relative exercise intensity in all groups may have limited the effects of muscle pain and RPE on self-regulated pacing and performance. Future studies should have more stringent inclusion criteria to ensure runners are competing at moderate to high relative exercise intensities. In addition, future studies should carefully consider route profiles to ensure that the race profile does not potentially confound the accuracy of prediction of performance by limiting actual marathon times.

CHAPTER 1: INTRODUCTION AND SCOPE OF THE THESIS

1.1 INTRODUCTION

Competitive endurance running is a popular sport with an increase in runners taking part in the marathon distance annually [(1)(2)]. There are numerous training factors that are thought to contribute to improved endurance running performance. In order for optimal performance to be achieved, a balance in training variables for a marathon is required [(3)]. Improved performance in the marathon is multi-factorial and complex with little substantial evidence to show which factors contribute to running performance [(4)(5)]. Some studies have suggested training pace, fastest 10 km time, previous marathon experience, training distances greater than 100 km.wk-1, and frequency of runs may contribute to performance [(2)(6)(7)(8)(9)(10)(3)(11)(12)(13)]. However, previous studies did not consider the role of predicting performance outcomes before competition, and the potential influence of self-regulated pacing and prior experience on running performance.

There are numerous physiological and psychological factors that are responsible for training-induced improvements in exercise capacity [(14)]. One of these adaptations is the maximum rate of oxygen uptake (VO_{2max}). Endurance training increases VO_{2max}, which is considered to be a sign of cardiorespiratory, circulatory and muscular fitness [(15)(16)]. Exercise-induced muscle damage (EIMD) has a negative effect on endurance running performance [(17)], while other factors limiting exercise performance will depend on the type and intensity of exercise, the muscle groups involved, and the physical environment in which the exercise is performed [(18)].

An important factor that may influence endurance running performance is the concept of teleoanticipation, which is a feed-forward and feed-back mechanism using past experiences to pre-set exercise intensity for future sessions influencing time and distance [(19)]. Teleoanticipation is seen to regulate exercise performance without causing bodily harm [(20)]. Relative perception of effort (RPE) is the subjective intensity of effort that is experienced during physical exercise [(21)]. These ratings of perceived exertion reflect biological demands linked to maintaining homeostasis and the perceived finishing point of exercise [(22)].

Anthropometric and training variables have been examined in previous studies, but few studies have examined performance-related factors during endurance running events [(1)(5)(8)(23)(24)]. In addition, there is a lack of evidence for the role of teleoanticipation on endurance running performance. The accuracy of prediction of running performance allows for the consideration of the effects of teleoanticipatory factors such as pacing and prior experience on performance. More research is needed to determine whether there are any relationships between the accuracy of prediction of performance, and other factors that may influence performance outcomes, such as training history, muscle pain and RPE.

1.2 AIMS AND OBJECTIVES

1.2.1 Aim

The aim of this descriptive analytical correlational study was to determine potential factors associated with the accuracy of prediction of running performance during a marathon race.

1.2.2 Specific objectives

The specific objectives were:

- To determine whether there were differences in training history, pacing, muscle pain and the relative perception of effort (RPE) in three identified groups that accurately predicted race time, performed faster than the predicted time, or performed slower than the predicted time.

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1.2.3 Significance of this dissertation

There is a lack of evidence for the effects of teleoanticipatory factors on endurance running performance. This study will therefore provide further evidence for potential factors influencing endurance running performance. Practically, a better understanding of the role of teleoanticipatory factors such as prior experience and pacing may enhance training and coaching techniques for endurance runners, and may facilitate improvements in endurance running performance.

1.3 PLAN OF DEVELOPMENT

In preparation for the experimental phase of this dissertation, a comprehensive review of the literature on physiological adaptations associated with endurance running, factors influencing endurance running performance and prediction will be presented (Chapter 2). This will be followed by a descriptive analytical correlational study that was designed to investigate the accuracy of prediction in endurance running performance in a marathon and the relationship to training history, muscle pain and relative perception of effort (Chapter 3). A summary and conclusion section, including recommendations for future research, will complete this dissertation (Chapter 4).

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Running is an increasingly popular sport with many health benefits [1][7][18]. Some of these benefits include improved physical fitness, feeling of good health, pleasure and enjoyment [10][20]. An additional benefit is seen in endurance training where it has been shown to favourably change cardiovascular risk factors [25]. Running is accessible to most people as it can be performed in a variety of locations. There is a simplicity to running with little need for expensive equipment, enabling most people who would like to participate the opportunity to run [26].

To achieve top performances, athletes push themselves to the limit to achieve increased training loads and to maximise performance [27]. However, exercise performance is a complex interaction between the positive effects of training, and the negative effects of exercise-induced muscle damage, and fatigue [3]. The interactions between these factors are poorly understood with success being multi-factorial and complex [5].

The primary purpose of this literature review is to consider the factors that may influence an athlete's ability to accurately predict endurance running performance. Important physiological adaptations associated with endurance running training and competition will be considered. This will be followed by a review of potential factors influencing endurance running performance, including exercise-induced muscle damage, delayed onset muscle soreness (DOMS), fatigue, RPE, muscle pain, tapering, pacing and prior experience. The importance of performance prediction will be discussed.

An online search was conducted using Pubmed, EBSCO, Science Direct and Google Scholar. The following keywords were used: *"endurance running", "marathon performance", "rating of perceived exertion and running", "marathon training", "marathon predictor", "pacing strategy running", "central governor model", "teleoanticipation", "pacing running" and "training and tapering".*

2.2 RUNNING AS A SPORT

Distance running is a popular recreational exercise and is beneficial for health and well-being [28]. There has been a substantial increase in both male and female athletes who take up running and attempt marathons [1][2][29]. Competitive endurance running is increasing in popularity with more runners taking part in the marathon distance annually [1][2]. Running competitions are held in a variety of distances both nationally and internationally [1][3][8]. Ziegler [29] gave a survey to 402 runners within two weeks of completing a marathon to investigate what the perceived benefits of marathon running were. Recreational runners had overall greater perceived benefits than competitive runners, while a positive attitude to running and importance to life was more evident in the competitive runners. The study concluded that females had a more positive self-image and fulfilment in life than their male counterparts. This study shows some of the psychological benefits of taking part in a marathon [29]. Performance in endurance events is complex and there is little substantial evidence to show which factors contribute to improved running performance specifically in a marathon event [4][5]. With increased popularity in endurance running annually, there is a need to determine the factors that may be related to achieving a high performance in a marathon [1].

2.3 PHYSIOLOGICAL ADAPTATIONS ASSOCIATED WITH ENDURANCE TRAINING, EXERCISE-INDUCED MUSCLE DAMAGE AND FATIGUE

2.3.1 Endurance training

Endurance exercise causes a variety of physiological skeletal adaptations [26]. These adaptations result in an enhanced performance capacity. The aim of training to improve endurance performance should be to stimulate multiple physiological and metabolic adaptations. The main components of training are the volume, intensity and frequency of exercise sessions [26]. These training variables either enhance or decrease performance capacity [26]. There is a direct relationship between the volume of training and the training response; however there is a plateau which is reached where no further performance is gained. The exercise stimulus and training adaptations are specific to the type, frequency and duration of the exercise that is performed, and the muscles which have been recruited [26]. These adaptations result in an improved performance capacity [26].

One of these adaptations linked to performance is the maximum rate of oxygen uptake (VO_{2max}) [15][16]. This is a measure of the fastest rate at which oxygen can be used by the body during maximum exercise [15][16]. The maximum rate of oxygen uptake is usually considered to be a sign of cardiorespiratory, circulatory and muscular fitness. Over a longer period VO_{2max} increases with endurance training but decreases with de-training [15][16]. A study with previously untrained individuals showed that endurance training improves VO_{2max}, increases capillary density of working muscle, raises blood volume and decreases heart rate during exercise [16]. There is a positive relationship between aerobic performance and VO_{2max} [17].

Gibala et al [14] compared short-term sprint interval and traditional endurance training by randomly assigning eight men to each group. Both groups performed six training sessions over 14 days. The short-term sprint interval group consisted of four to six sets of 30's all-out cycling with a four-minute recovery period, while the endurance training group session included 90 to 120 minutes of continuous cycling. The main finding showed that regular endurance training facilitates improved exercise capacity by many physiological adaptations. In addition, both groups showed improvements in muscle oxidative capacity, muscle buffering capacity and exercise performance [14]. In conclusion, there are numerous physiological and psychological factors that are responsible for training-induced improvements in exercise capacity [14][15][16][17][26].

The optimal relationship between training history and performance involves deliberate practice for the specific event and detailed knowledge on measurable goals for improvement of performance [40][41]. The distinction of deliberate practice from other types of practice in sport has been difficult to analyse but when this distinction is made with specific practice the elite performances have been enhanced [40][41].

There are numerous training factors that are thought to contribute to improved endurance running performance. To achieve optimal performance, a balance in training variables for a marathon is needed [3]. Overuse musculoskeletal injuries could result from excessive training, while under-training may result in acute injuries during the marathon or not completing the marathon [3]. Sport-specific training techniques are vital for successful performance [42].

Billat et al [43] compared the physical and training characteristics of top-class and high-level marathon runners. Twenty marathon runners consisting of ten top-class male and female and ten high-level male and female runners performed their best marathon performance velocity in a 10 km run. The top-class male runners ran more total weekly kilometres than their high-level counterparts, and ran more than 200 $km.wk^{-1}$. The top-class female marathon runners had a high mileage two or three sessions per week at a high velocity. All the participants reported a similar intensity training distribution and ran few training sessions at marathon or half-marathon pace. These elite marathoners performed the majority of their training well above or below the marathon velocity. Training load distributed mainly above and below the lactate threshold is termed "polarization training" [43]. This type of training minimises the risk of over-training while still inducing training adaptations at both central and peripheral levels. Training distance and the average weekly distance over the preceding two to three months prior to the race was also found to be crucial for marathon success [43].
Similarly, a review of longitudinal studies of long-distance runners and other endurance athletes showed that obtaining a balance of specific practice activities in both low and high training intensities resulted in the most effective training [41]. These studies are supported by a literature review by Mujika [44] who found that there is a correlation between training intensity and marathon performance time. These studies suggest that a high mileage of over 200 $km.wk^{-1}$ with "polarization training", especially two to three months prior to competition, lead to better performance in the marathon distance. However, there needs to be a distinction made between the elite and recreational runners as training may vary significantly between these two groups of athletes [41]. These differences make the studies more difficult to compare.

Training mileage is an important component of preparation for a marathon [41]. Yeung et al [3] found that non-finishers in a marathon had a significantly lower average training mileage (8.57 km) than runners who completed the marathon (51.94 km). Additionally, there was a significant difference in the non-finishers understanding of what sufficient preparation for a marathon involved. The regression analysis showed that the longest training distance in one session per week was the best predictor for completing the marathon. There was a significant correlation between weekly training mileage and the runners' opinion towards an optimal mileage in training for a marathon. Tapering is another component of training for a marathon which affects performance levels [43].

2.3.2 Exercise-induced muscle damage

Unaccustomed exercises and exercise with an increased intensity or longer duration than the athlete is used to can lead to muscle damage [24][27][28][30]. Muscle soreness is an important indicator of exercise-induced muscle damage (EIMD) [31]. One of the main factors that exacerbate the muscle damage are muscle lengthening exercises because they result in a higher load per fibre ratio [31]. This follows with an acute loss of strength some days after the muscle lengthening exercises with a decreased ability to produce force which can take up to a week to recover [32][33]. Exercise-induced muscle damage occurs often in athletic populations, especially when over-training or overreaching [27]. Exercise-induced muscle damage is recognised commonly through the presence of muscle soreness, yet there is a poor correlation between this subjective muscle soreness and histological evidence of muscle damage and muscle function [27]. Subjective muscle soreness has been recorded using the visual analogue scale (VAS), questionnaires and numerical scales [27]. Exercise-induced muscle damage has a negative effect on endurance running performance [17]. Muscle damage causes an increase in physiological demands in endurance exercise. The symptoms of muscle damage include disruption of the intracellular muscle structure, sarcolemma and extracellular matrix, prolonged impairment of muscle function, delayed onset muscle soreness (DOMS), stiffness and swelling [25][27].

Skeletal muscle damage contributes significantly to DOMS and strength loss after muscle lengthening exercises. Both static and dynamic muscle contractions can result in EIMD [25]. The amount of strength loss after EIMD may vary between 5% to 10% and 60% depending on the type of muscle action and exercise used. Some metabolic factors also influence muscle damage [25]. Prolonged strength loss is the most indirect reliable measurement of muscle damage [28][31]. After exercise resulting in muscle damage, there is an impaired ability to produce force at lower stimulation frequencies, known as low frequency fatigue, which can take up to a week after the exercise to recover. Muscle soreness appears hours after the exercise and peaks at 24 to 48 hours post-exercise [28][31]. There is also an inflammatory response. The amount of muscle damage depends on the exercise intensity of the first bout. The effects of EIMD and DOMS on neuromuscular performance show that the isometric peak torque is compromised immediately after the exercise that causes DOMS, with a gradual recovery in the following days [28][31].

Muscle damage is usually the result of maximal and sub-maximal muscle lengthening exercises and a high volume of contractions, as seen in distance running [(17)]. Skeletal muscle damage may be the main contributing factor to muscle soreness and strength loss after muscle lengthening exercises. However, the relationship between muscle damage, muscle soreness and strength loss is unclear [(34)]. Further discussion of EIMD and DOMS is beyond the scope of this review. Please refer to a detailed article by Assumpcao et al [(17)] for more information on EIMD.

Studies have also shown that EIMD has a negative impact on the measures of athletic performance requiring muscle power [(52)]. Despite these findings the effect of EIMD on endurance running performance are unclear [(52)]. A significant increase in RPE have also been measured during sub-maximal running without major effects of EIMD on the physiological responses to aerobic exercise [(53)]. This study suggests that despite an increased RPE it does not necessarily lead to an increase in EIMD.

The main concern for EIMD for the athlete is the loss of muscle power, which leads to poor performance [(31)]. The affected muscles would be less powerful after EIMD as there is an increase in physiological demand after EIMD causing exercise efficiency to be altered. This may directly contribute to fatigue during prolonged exercise events [(31)].

A single blind, randomised, controlled, pre-test–post-test design was used for a study to determine the effect of EIMD on endurance running performance [(52)]. Thirty moderately trained runners were randomly assigned to EIMD or control group. The EIMD group jumped 100 times from a bench. The control group did not perform any muscle-damaging exercise. Before performing the intervention and 48 hours after the intervention, participants were tested during a constant speed sub-maximal treadmill run for 30 minutes. It was evident that the risk of having a significant decrease in endurance running performance was significantly higher in participants suffering from EIMD relative to participants in the control group. Highly trained runners might be less susceptible to EIMD compared with the studies' moderately trained runners because of the “repeated bout effect”. The “repeated bout effect” occurs when the muscle adapts after performing eccentric exercises so that when further eccentric exercises are performed the muscle is less vulnerable to these subsequent eccentric exercises with reduced muscle soreness. The mechanism to explain this effect, however, is not fully understood [(32)(34)]. Participants with EIMD showed a detrimental effect on performance and perceive higher effort when producing the same force, and produced less force for the same perceived effort. Interestingly, EIMD did not affect pacing strategy. These studies strongly suggest that central fatigue may be the brain's inflammatory response to EIMD during prolonged exercise and the results recommend that exercises aimed at preventing or reducing this type of muscle damage may improve performance in endurance events [(52)]. A further complication is DOMS which is a symptom of EIMD [(31)].

2.3.2.1 Delayed onset muscle soreness (DOMS)

The literature supports that lengthening muscle actions result in more muscle damage than isometric or shortening muscle actions [17][31][32][34][54]. Several studies have verified that the isometric peak torque is compromised immediately after muscle lengthening exercise which results in DOMS followed by a gradual recovery in the following days [17]. Symptoms linked with DOMS are discomfort at the site of injury and tendon insertion points, inflammation, compromised muscle function, loss of range of motion across the affected joint, and reduction in maximal force-generating capacity of the affected muscle [54]. Soreness usually occurs eight hours after the activity and within one to three days the maximal amount of pain is felt with associated post-exercise swelling [32][55]. This post-exercise swelling was seen in a study of 11 volunteers, 10 male and one female, who performed an exercise resulting in DOMS in their gastrocnemius muscle with their other leg as a control. This study showed oedema formation in the experimental leg which they concluded was responsible for the soreness perception [55]. DOMS sensation may persist for as long as five to seven days if the pain is severe, such as after a marathon, and healing seems associated with a rapid training effect [56].

Exercising the affected muscles seems to be the most effective way to reduce the pain, however this soreness returns on cessation of the exercise [55]. Sherman et al [57] recruited 10 trained male runners randomly allocating them into two equal groups. After their marathon race the first group was to rest while the exercise-recovery group followed a 20-45 minute running session a day plan for the first week post-race. Interestingly, the rest group recovered their work capacity by day three post-marathon while the exercise-recovery group were still impaired by day seven. This study indicates that it may be more beneficial for complete rest post-marathon to recover more quickly in their work capacity. In support of this study, a systematic review of evidence used for the recovery of DOMS showed that there was a lack of evidence to support the use of low-intensity exercise in the recovery of DOMS, inconclusive evidence to support the use of cryotherapy, and little evidence to prove the effectiveness of stretching. Massage proved to have some effect with the relief of symptoms and DOMS signs [58]. Robey et al [59] compared the effects of hot or cold water immersion, static stretching or no recovery (control) interventions on leg strength, rowing performance and signs for muscle damage at 72 hours following strenuous stair-climb running. None of the interventions accelerated recovery at 72 hours compared with the control group. The literature is inconclusive on the benefits of active exercise for DOMS. More research is needed to substantiate what effect active exercise has on the recovery of DOMS [58].

Interestingly, level running involves almost equal amounts of eccentric and concentric action [17][56]. When these alternating actions are repeated for an extended amount of time over long distances, tissue disruption and extensive amount of DOMS will result even in highly trained individuals and the symptoms are usually seen a few days after the run [17][56]. Nine well-trained distance runners and triathletes took part in a study with 30 minutes downhill running on a treadmill [54]. Forty-eight hours post-exercise muscle damage was evident which resulted in changes in the stride mechanics of the participants. There was also a greater reliance on anaerobic methods which altered their running economy during the DOMS period [54]. These studies show that there may be implications for training involving eccentric exercises on recovery to obtain optimal performance as the DOMS affects the athletes' strength loss as well as stride mechanics.

Many endurance athletes use resistance training as there is some evidence to show that it may benefit endurance performance [60]. However, these athletes may experience DOMS as a result of this higher intensity activity [61]. DOMS appears to have its greatest effect on the perception of effort. This significant effect of DOMS on RPE indicates that athletes with DOMS perceived exercising to be more difficult [61]. To prevent the effects of DOMS, appropriate planning of training and recovery is essential [31]. A further common occurrence after eccentric exercise is low frequency fatigue, which can negatively affect training strategies and recovery [32].

2.3.3 Fatigue

Muscle fatigue, defined as a loss of maximum force-generating capacity, may develop for a variety of reasons [30][32] and is dependent on the type and magnitude of exercise performed [32]. Muscle activation, type of muscle group involved, and the type of muscle contraction all play a role. The intensity and duration of the activity are one of the most important variables linked to fatigue [32][33]. There are two general divisions for strength loss in a fatigued state, namely central and peripheral fatigue. It is not known how central and peripheral fatigue influence sub-maximal muscle function or pacing strategies during distance running [36]. However, the rate of exertion is seen as the conscious interpretation of the actual fatigue cycle [38]. Central fatigue contributes to muscle fatigue in long-distance running. Spinal adaptation contributes to the reduced neural input in prolonged exercise. The cause of fatigue is multi-faceted in prolonged exercise. It is suggested that metabolic and structural changes take place in muscle fatigue after prolonged exercise [37]. Muscle fatigue is not only at the level of the muscle. Other contributing factors to central fatigue or perceived exertion include hypoxia and hyperthermia, environmental conditions, as well as mental fatigue. Hence no single factor is responsible for the development of muscle fatigue [18].

There are a number of physiological models which are used to explain and study the physiological and training-induced changes that may improve endurance performance [4][22]. These models explain how fatigue is probably delayed or the onset of fatigue is prevented. The cardiovascular/ aerobic; energy supply/ depletion; neuromuscular fatigue; muscular trauma; biomechanical; thermoregulatory; psychological/ motivational; and central governor models [4][22]. Further discussion of the different physiological models of fatigue is beyond the scope of this review. Please refer to Noakes [4] for more information on the physiological models of fatigue.

One of the currently used models is the central governor model. The purpose of the central governor is to regulate the amount of muscles that are recruited during exercise under conditions where the vital organs are threatened [15]. The central governor model predicts that the central nervous system sets the work rate for the anticipated exercise duration to maintain homeostasis in the body. The physical appearance of any increasing perception of fatigue may be shown in an alteration in the subconsciously regulated pace at which the exercise is performed [39]. This change in pacing strategy is a result of changing motor unit recruitment or de-recruitment by the central nervous system. Fatigue is seen as a sensory perception that is a result of a combination of physiological, biochemical and other sensory feedback from the periphery which may or may not be linked to the change in muscle force production [39]. Central fatigue may limit performance as it develops while muscles work at maximal capacity. There is a motor limit in which the required contractions can no longer be maintained and they deteriorate. A limit is reached as the task is no longer achievable due to possible detrimental consequences. Factors limiting exercise will depend on the type and intensity, the muscle groups involved, and the physical environment in which the exercise is performed [18].

Noakes [4] describes how exercise performance is limited by fatigue and enhanced by training through a number of physiological models (Section 2.3.3, page 6). Noakes argues that we lack knowledge of specific factors that determine fatigue. Noakes [4] states how fatigue and athletic performance need to be defined in order to work out which training adaptations are the most important for improving exercise performance or how to structure training to capitalise on these adaptations. Control is maintained by skeletal muscle recruitment during exercise and inhibitory effects of fatigue are produced by the brain [39].

Millet et al [36] proposes the flush model which is based on Noakes' central governor model [62]. The flush model emphasises the importance of peripheral fatigue changes which are not associated with exercise. The aim of the flush model is to explain the role of fatigue on performance in ultra-marathon running. According to this model there is always reserve for an “end spurt” as well as many factors which contribute to fatigue. Both perception of effort and decrease in muscle force during sustained exercise are especially important considerations when looking at the fatigued athlete. Central regulation is dependent on peripheral fatigue and spinal inhibition. The flush model shows how environmental conditions, mental fatigue, pain medication, cognitive or nutritional strategies may affect ultra-marathon performance. The flush model considers changes which are not associated with exercise. As peripheral fatigue progresses, greater muscle activation is required in order to maintain a similar mechanical power output in this fatigued state. RPE changes and the increase in muscle activation are correlated. As a greater muscle force is needed, the perception of effort increases especially in the fatigued state. The sense of effort and the response from afferent sensory feedback is most likely the regulator of exercise performance. Fatigue needs to address both perception of effort and the decrease in force which occurs during prolonged exercise [36]. Additionally, stride rate changes have been seen with progressive fatigue during endurance events. These kinematic changes are seen as a result of fatigue that could lead to overload injuries in endurance athletes [63].

2.4 SPECIFIC FACTORS INFLUENCING ENDURANCE RUNNING PERFORMANCE

2.4.1 Tapering

The aim of a taper is to reduce physiological and psychological stress of training and enhance sporting performance [27]. Tapering is a period of reducing the training load of athletes in the final days before competition to achieve optimal performance for the race. The effects of alterations in taper components on performance in athletes was analysed with a meta-analysis on six databases [45]. Twenty-seven of the 182 studies met the inclusion criteria. The components that can be altered in the taper period include the training volume, intensity, and frequency, as well as the pattern of the taper (i.e., progressive or step taper) and its duration. The progressive taper can be further divided into different types [27]. A linear taper involves a higher training load than the exponential tapers. The exponential taper can either be classified as a slow or fast time constant taper. The step taper is the final tapering strategy which is a non-progressive, standardised reduction of training load [27]. The results showed that a tapering intervention of two week duration with no change in training intensity or frequency, and a training volume exponentially decreased by 41% to 60% will most likely lead to significant improvements in performance. This conclusion was not for a specific sport, gender or fatigue status before tapering and it would be beneficial to determine whether this is an optimal taper or more research is needed to be more specific for these different variables, especially for the marathon [45].

Kubukeli et al [16] found that a taper of 50% single-step reduction in a high-intensity interval training at 70% of peak work rate produced a 6% improvement after two weeks. Optimum taper period may depend on the intensity of the athletes' preceding training and their need to recover optimally for their competition. Single step reductions in training volume only maintain exercise performance, while some progressive reductions in training volume may improve exercise performance [16]. The literature is undecided about the percentage of training load that is decreased in the taper period.

Houmard et al [46] stated that exercise performance improvements are shown with a 60% to 70% reduction in total training load without causing de-training symptoms in the taper period while Hickson et al [47] argued that a minimum of 70% training load is needed to maintain training-induced increases in VO_{2max}. Neary et al [48] showed similar findings to the meta-analysis with a reduction in training volume of at least 50%. In addition to the reduction in training loads, there needs to be caution with the timing of the taper period as de-training has been observed 14 to 21 days after a reduction in training [46]. Yet Mujika [44] found that a range between four and 28 days can show a positive physiologic and performance response to the taper period. More research is needed to determine the optimal tapering period without de-training effects.

Mujika [44] concluded that a taper could optimise performance by significantly reducing training volume, moderately reducing training frequency and a small, if any, reduction in intensity. In highly trained athletes initial performance level and training intensity are the most important factors [44]. There seems to be a need for a minimum training frequency to maintain adaptive physiological responses. It is evident that there is no consensus regarding an optimal tapering strategy for marathon races, however the evidence suggests that a reduction in training load, minimum training frequency and continued running intensity seem to be important components for an effective tapering period without a reduction in performance or de-training effects. Further details of the studies on tapering effects on performance are shown in Table 2.1.

Table 2.1: Summary of studies assessing the effects of tapering on performance.

Article	Study objective	Participants	Training intervention	Outcome measures	Results	Conclusion
Houmard et al (46)	Effects of reduced training on submaximal and maximal running responses.	5 highly trained collegiate distance runners.	Reduction in training with 8km.d^{-1}, 5 d.wk^{-1}, for 10 days.	Maximal oxygen consumption, maximal heart rate, and time to exhaustion during the maximum tests. Body weight and percent body fat. Submaximal treadmill runs to assess VO_{2max}, RPE, heart rate and post-run lactate levels.	60–70% reduction in total training load without causing de-training symptoms in the taper period was observed. De-training was observed 14-21 days after a reduction in training.	The reduced training program did not diminish nor improve aerobic capacity in highly trained distance runners. Case series study with a small sample size.
Neary et al (48)	Effects of taper on endurance cycling capacity and single muscle fibre properties.	22 male cyclists randomly assigned to one of 3 7-day taper groups.	The control group (CON, n=7) continued weekly training, the first experimental group (n=7) maintained training intensity but reduced duration, and the second experimental group (n=8) maintained training duration but reduced exercise intensity. Each cyclist completed a simulated 40-km time trial before and after tapering on a set of wind-loaded rollers using their own bicycle.	Muscle biopsies before and after tapering and analysed for mATPase, succinate dehydrogenase (SDH), cyctochrome oxidase (CYTOX), alpha-glycerolphosphate dehydrogenase (alpha-GPD), and beta-hydroxyacyl CoA dehydrogenase (beta-HOAD) in Type I and II fibres.	Significant ($p < 0.05$) increases in SDH (Type I) and mATPase, CYTOX, beta-HOAD, and SDH (Type II fibres) in the INT group, and significant increases in CYTOX (Type I) and beta-HOAD (Type I and II fibres) in the DUR group.	The metabolic properties of different fibre types are altered with tapering, that the type of taper protocol used influences their physiological adaptation, and that improvements in simulated 40-km endurance time were related to changes in metabolic properties of the muscle at the single fibre level. Training volume needs to be reduced by at least 50%. Randomly controlled trial with small sample size.

Table 2.1 cont: Summary of studies assessing the effects of tapering on performance.

Article	Study objective	Participants	Training intervention	Outcome measures	Results	Conclusion
Hickson et al (47)	Reduced training intensities and loss of aerobic power, endurance, and cardiac growth.	12 subjects divided into 2 equal groups.	All participants took part in an exercise program of cycling and running 40 $min.d^{-1}$, 6 $d.wk^{-1}$ for 10 weeks. After this period, one group had a one-third reduction in work rate and the second group had two-thirds reduction in work rates for 15-weeks.	VO_{2max}. Left ventricular mass was calculated from echocardiographic measurements.	VO_{2max} was not maintained at the 6-$day.wk^{-1}$ training levels with training intensity reduced by a third, but was still higher than pretraining levels. With intensity reduced by two-thirds, VO_{2max} declined to an even greater extent than with the one-third reduction. Short-term endurance was maintained in the one-third reduced group but was markedly reduced in the two-thirds reduced group. Long-term endurance was decreased significantly from training by 21% in the one-third reduced group (184 to 145 min) and by 30% in the two-thirds reduced group	Minimum of 70% training load is needed to maintain training-induced increases in VO_{2max}. Prospective comparative study.

2.4.2 Teleoanticipation

Teleoanticipation is a subconscious mechanism from the central nervous system which uses past experiences to pre-set the exercise intensity for future exercise sessions. Teleoanticipation is influenced by the length of time and distances involved in the athletic events [19], and occurs repeatedly through the exercise session [50]. Teleoanticipation may have an inherent ability to be refined by an individual's experience in completing fatiguing tasks. This ability to refine teleoanticipatory, or pacing strategies, could reason out how elite athletes are able to pace themselves appropriately over the course of their sporting event. Teleoanticipation alters the motor recruitment patterns to regulate pace to match the planned activities and resultant afferent input. Teleoanticipation regulates exercise performance and allows the athlete to complete the exercise task while maintaining a reserve capacity as a protective mechanism to prevent bodily harm [20].

Teleoanticipation is different to a purely feed-forward control strategy [51]. These feed-forward strategies have a large element of "guess work" compared with the teleoanticipation model. Teleoanticipation is specific for exercise and balances the amount of power needed and pacing strategies with the anticipated end point of exercise [51]. Teleoanticipation involves both feed-forward planning and feedback control. These signals are received from afferent changes linked to the external environment, peripheral metabolic structures and knowledge from previous exercise sessions [51].

2.4.3 Perception of effort

Perception of effort is the subjective intensity of effort, strain, discomfort and/ or fatigue that is experienced during physical exercise [21]. The perception of effort can be measured using the modified Borg scale [20]. The modified Borg 15-point relative perception of effort scale is the most widely used scale for quantification of perceived exertion [20]. The RPE is an accepted method of assessing exercise intensity [64] and is the single best indicator of the degree of physical strain [65]. Borg's scale has been validated by correlating RPE with heart rate and/ or VO_2 responses during treadmill or water immersion testing [21].

There are three main effort variables that determine the subjective response to an exercise stimulus; physiological, perceptual and performance [66]. These effort variables show the relationship between the physiological demands of the exercise performance and the perception of effort linked to this performance variable [66]. One of the most important symptoms of exertional intolerance is fatigue [67]. A limit to exercise seen in a subjective RPE is linked with many of the proposed physiological limits to exercise [68]. RPE increased more rapidly in the glycogen-depleted state which showed its influence by afferent physiological feedback. This invites the possibility that the RPE is a key component of a system that exists to protect the athlete from excessive exercise [68]. Ratings of perceived exertion reflect biological demands linked to the maintenance of homeostasis as well as the perceived finishing point of exercise [39]. This perception of effort tends to change more gradually with the activity compared to the constant change in the subconscious pacing strategy [39].

Effort perception may involve a feed-forward system at the start of exercise that is continually being updated by afferent feed-back from different areas of the body once exercise has begun [(69)]. The central governor model, a development of Ulmer's teleoanticipation theory, proposes that projected ''finishing points'' are taken into account by the brain and afferent feedback from the muscles to regulate an appropriate pacing strategy [(69)]. The capacity to monitor the passage of time is the brain's algorithm. The internal clock and the teleoanticipatory pacing are supported by the ability of athletes to reproduce identical pacing strategies with similar known duration and minimal external information regarding distance covered or time elapsed [(50)]. Both subconscious pacing strategies and conscious perception of effort use an internal clock based on scalar rather than absolute time [(50)]. Overall, studies suggest a decrease in speed with time in ultra-marathon running in all levels of athletes. The speed is thought to be progressively reduced to keep the RPE below the maximal level as proposed by the teleoanticipation and central governor model [(36)].

There are many factors that influence the perception of effort. Robertson and Noble [(21)] discuss peripheral perceptual signals and non-specific mediators which are involved in the perception of effort. The peripheral perceptual signals include blood pH, blood lactic acid, muscle lactic acid and selected peripheral mediators. The non-specific mediators include catecholamines and b-endorphins; body core and skin temperature; and pain responsiveness [(21)]. Interestingly, the pain sensation during exercise seems to be focused on the involved muscular ischemia. There are both neurophysiological pathways and psychological mediators of exertional perceptions which explain how the perception of effort is multi-factorial and involves a complex interaction between these factors [(21)].

Scalar rather than absolute parameters appear to be used when RPE is set for a particular event of different distance or duration [(50)]. Practice and experience has been shown to improve a particular RPE value as the athlete has shown the ability to increase in exercise intensity [(50)]. This feed-forward and feed-back system uses an expectation of exercise duration which sets an initial work rate in which RPE generates a subconscious "template" [(68)]. Current literature suggests that external feedback may have variable effects on physiological responses and perceived effort. These specific effects are yet to be documented. It is unclear how time or distance deception in self-paced performance trials affects RPE and pacing strategies.

The effect of distance feedback on pacing strategy and perceived exertion during cycling was investigated with fifteen competitive, endurance-trained male cyclists [(19)]. These cyclists were given deceptive distance feedback while performing in a 20 km time trial. Despite this deception, the cyclists had similar finishing times irrespective of whether they were provided with correct or incorrect distance splits which determined that their performance was not altered by this deception. Their pacing strategy was fixed throughout the exercise which appears that it was set before the exercise began and is regulated in a subconscious feed-forward manner. This study suggests that this anticipatory response may be more important than performance feedback once the exercise is in progress [(19)]. Previous studies support that the RPE is set in a feed-forward manner and that changes in the power output are regulated to enable the RPE rises in a linear manner for the exercise duration and completes the exercise bout without harming the body [(69)(70)].

The RPE is seen as an important component in regulating exercise performance [71][72]. Athletes pace themselves according to their level of perceived exertion. Exercise performance and perception of effort are linked closely together with pacing strategies [71][72]. The relationship between sense of effort and sensations from afferent sensory feedback seem to be the main regulator of performance [71][72]. Pires et al [73] asked athletes to exercise to exhaustion at an absolute work rate on two occasions. However, on the second session they were deceptively informed that they would work at a lower rate when in fact it was the same. The athletes showed no change in the RPE scores despite the deception [73].

Increases in RPE rises may provide information of how close to the end of exercise the athlete is at any time during the exercise session [62][69][70]. One possibility is that the RPE is the main determinant of the fatigue point in this model of exercise, prolonged sub-maximal exercise at a fixed work rate [62][69][70]. This suggests that practice is required if RPE is to be employed with confidence as a prescriptive device where most judgements are likely to be made in the intermediate effort levels of the scale [33].

2.4.4 Pacing

Physiological demands of marathon running have been well established while less is known about pacing strategies in a marathon [74]. Pacing can be described as a strategy used to avoid catastrophic failure in any peripheral physiological system [50] and it is a subjective competitive strategy in which an individual manipulates speed to achieve their performance goal [75]. Pacing is based on a control system that estimates optimal power output [36]. For endurance running events pacing strategies may be adopted within the first few hundred metres [39].

From a physiological perspective, pacing may be influenced by a “central programmer” [75]. The central governor model proposes that the subconscious brain receives afferent feedback from the muscles and takes into account projected ‘‘finishing points’’ to regulate an appropriate pacing strategy [20][39]. The motor unit recruitment throughout the anticipated duration of exercise is altered continually within the pacing strategy to preserve homeostasis within the body and prevent over-exertion to the detriment of the body [20][39]. Some studies suggest that the pacing strategy is set before exercise commences and it is not affected by external feedback [19][70]. At a subconscious level there seems to be a specific workload and exercise intensity which has been termed “teleoanticipation” [74] (Section 2.4.2, page 12). Tucker and Noakes [70] propose a centrally mediated pacing strategy for self-paced exercise of all durations. Tucker [68] postulated that in self-paced exercise, athletes set their initial exercise intensity using physiological input such as skin temperature, expected exercise duration and as a result of previous experience. The brain anticipates the endpoint of exercise and then regulates the exercise intensity and alters the adopted pacing strategy specifically to ensure that the body is able to cope with the effort without endangering vital functions [19][69][70].

Abbiss and Laursen [22] describe six pacing strategies: positive, negative, all-out, even, parabolic-shaped and variable pacing. A similar group of pacing strategies was described by St Claire Gibson et al [50] with all-out, slow start, even paced, and variable paced strategy. An all-out pacing strategy is when the runner begins the event at maximal possible pace and continues with this pace for the duration of the event. The slow start strategy is when an athlete starts at a submaximal pace and increases this pace for the duration of the event. The even paced strategy is when a constant submaximal pace is used for the duration of the event. A variable pace is when the athlete starts the race with maximal pace, has a moderate pace in the middle of the event and ends with an increase in pace [50]. Despite different pacing strategies for different distances of exercise, the overall pacing strategies are controlled with similar underlying principles [50]. Pacing strategy chosen is dependent on a variety of factors such as the athlete's physiological capacity, the duration and distance of the event, the type of exercise and competition level, the environment in which the event is performed, and the motivation, knowledge, and experience of the athlete[69].

An optimal pacing strategy for exercise is determined by certain factors; knowledge of the endpoint and the duration of the event, an internal clock using scalar timing, and memory of pacing strategies from previous events [50]. Hettinga [38] proposes that the pacing strategy begins from the start of the exercise session comparing actual with expected fatigue. During long duration exercise, self-selected pacing becomes more even, with the ability to increase running speed significantly at the end of the event [38]. The pacing strategy adopted is determined by information about the distance or time to be covered during the event, the force output, muscle metabolic rate and core temperature changes which is appropriate in the context of the overall pacing strategy [76]. The differences between faster and slower runners with pacing strategies have been previously noted at the marathon and ultra-marathon distance with faster runners able to regulate their speed more accurately than slower runners [77][78]. However, few other studies have addressed the pacing of athletes specifically for endurance events [76].

Lambert et al [78] studied changes in running speeds in a 100 km ultra-marathon race. Sixty-seven runners were divided into groups of 10 with the last group consisting of seven runners and these groups were compared with each other. The study found that the faster runners ran with fewer changes in speed, they started the race at a faster speed than the slower runners, and they were able to maintain this speed for a longer distance compared with the slower runners. This study supports a positive or even pacing strategy being an optimal pacing strategy for running endurance events. Similarly, Maughan et al [79] found in 62 male marathon runners that the fastest runners were able to maintain more or less the same pacing strategy throughout the marathon compared with the slower runners. The slower runners slowed down progressively for the duration of the marathon.

Pacing strategies may be inherent, or hereditary, to a certain degree, however most athletes become better at pacing their events with practice suggesting that prior experience refines their pacing [20]. Williams [80] conducted a study on cyclists with a 4 km time trial where no information or complete information was given during the trial as to how far the cyclists had gone. The untrained cyclists were not affected by the information for pacing strategy while the trained cyclists could improve their pacing strategy with the information gained. The study concluded that task familiarity and training experience influenced the ability to learn pacing strategies by training the brain mechanism responsible [80]. World class marathoners are often older than runners of shorter distances, which suggests that experience may be a factor affecting pacing. Arch et al [74] conducted a study including 186 male and 133 female marathoners who completed three consecutive marathons. Their aim was to examine the effects of age, sex and finish time on marathon pacing and they concluded that women who are older and faster marathoners maintain a more consistent pace throughout the race than younger, slower marathon men. Previous experience of similar past events performed by an athlete would be the basis for a particular pacing strategy initiated by the brain algorithm. This supports the theory from Ulmer [75] where the brain uses the end point as an anchor and creates a particular algorithm for a particular exercise bout and moderates the power output throughout the exercise session. The summary of factors influencing pacing is detailed in Table 2.2.

Table 2.2: Summary of studies assessing the effects of pacing on performance.

Article	Study objective	Participants	Training intervention	Outcome measures	Results	Conclusion
Hettinga [38]	Optimal pacing strategy: from theoretical modelling to reality in 1500 m speed skating.	7 national-level speed skaters.	Self-paced skating 1500 m.	Velocity (every 100 m) and body position (every 200 m) with video was used to calculate total mechanical power output. An energy flow model was applied to the self-paced trial simulating a range of pacing strategies, and a theoretically optimal pacing profile was imposed in a second race.	Final time for the second race was 2 seconds slower than the self-paced race. There was higher power over the first 300 m for the second race. The faster first lap resulted in a higher aerodynamic drag coefficient.	Pacing strategy begins from the start of exercise. Experienced athletes with a fast start protocol had a negative effect on performance. Case series with small sample size.
Faulkner, Parfittand, and Eston [69]	The rating of perceived exertion during competitive running scales with time.	5 male and 4 female runners.	All participants competed in both a 7-mile and a half marathon race.	Heart rate, split mile time, and RPE were recorded throughout the races.	Rate of increase in RPE was greater in the7-mile run. There were no differences when expressed against percentage time-indicating the brain used a scalar timing mechanism.	RPE scales with the proportion of exercise time that remains. Case series with small sample size.

Table 2.2 cont: Summary of studies assessing the effects of pacing on performance.

Article	Study objective	Participants	Training intervention	Outcome measures	Results	Conclusion
Lambert et al [78]	Changes in running speeds in a 100 km ultra-marathon race.	67 male runners divided into groups of 10 with the last group consisting of 7 runners.	100 km ultra-marathon.	Race times and 10 km split times were recorded and analysed.	Faster runners ran faster at the start of the race, finished their race within 15% of their starting speed, and maintained their starting speed for longer. Slower runners showed a greater percentage decrease in their mean running speed, and were unable to maintain their initial speed for as long as the faster runners.	The faster runners ran a more even pace, started the race at a faster running speed and were able to maintain their initial speed for a longer distance before slowing down. Case-control study with good sample size.
Maughan et al [79]	Rectal temperature after marathon running.	62 male runners.	Dundee marathon.	Race times recorded during race at 8 km, 16.1 km, 24.1 km, 32.2 km and 42.2 km. Rectal temperatures immediately after the race.	Mean running speed decreased progressively for the duration of the marathon. The fastest runners were able to maintain an even pace, while the slower runners slowed down progressively. The highest post-race temperatures maintained a steady pace during the race. The lowest post-race temperatures decreased their pace as the race progressed.	Faster runners maintained a more even pace while the slower runners decreased their speed progressively as the race progressed. Runners experiencing fatigue or injury are at risk of hypothermia in low ambient temperatures. Case-control study.
Arch et al [74]	Age, sex, and finish time as determinants of pacing in the marathon.	186 male and 133 female marathoners.	Completed three consecutive marathons.	1.6 km time splits measured electronically.	Age, sex, and run time ($p < 0.01$ for each variable) were simultaneously independent determinants of pacing.	Women who are older and faster marathoners maintain a more consistent pace throughout the race than younger, slower marathon men. Case-control study with good sample size.

Table 2.2 cont: Summary of studies assessing the effects of pacing on performance.

Article	Study objective	Participants	Training intervention	Outcome measures	Results	Conclusion
Albertus et al (19)	Effect of distance feedback on pacing strategy and perceived exertion during cycling.	15 well-trained cyclists.	Performed a peak power output test, familiarisation trial and four 20 km cycling time trials. Every 1 km they were provided with distance feedback. For the control trial cyclists received accurate feedback at the 1 km splits. For the increase trial, cyclists received inaccurate feedback at 0.775 km and increasing by 25 m each subsequent km split. The decrease trial inaccurate feedback was given at 1.25 km and decreasing by 25 m each subsequent 1 km split. The random trial, distance splits were randomised.	Finishing times. RPE during the time trials. Heart rate during the time trials.	No significant difference finishing times between the different trials. Pacing strategies were not altered. RPE scores were similar for all trials. Average heart rate varied significantly between trials ($p < 0.05$).	Exercise performance, pacing strategy, and RPE during a 20 km cycling time trial are not altered by incorrect distance feedback. Case series study.
Williams et al (80)	Influence of feedback and prior experience on pacing during a 4 km cycle time trial.	18 well trained male cyclists randomly assigned to a control group (CON) or experimental group (EXP).	Four consecutive 4-km time trials, separated by a 17-min recovery. The CON group received prior knowledge of distance to be cycled and received distance feedback throughout each time trial. The EXP group received neither but knew that each time trial was the same distance.	Completion time. Mean speed and power output. End blood lactate.	EXP group was significantly slower than the CON group ($p < 0.001$). Differences between groups in completion time reduced over successive time trials. ($p < 0.0005$). Mean speed and power output also significant between groups (p , 0.0005)	Distance feedback is not essential in developing an appropriate pacing strategy. Prior experience of an unknown distance appears to allow the creation of an internal, relative distance that is used to establish a pacing strategy. Randomised controlled trial.

2.4.5 Factors predicting performance

Many previous studies have examined anthropometric and training variables, but few have actually looked at performance-related factors during an event in an attempt to establish how these factors might contribute to the accuracy of performance prediction [(1)(5)(8)(23)(24)]. Franklin, Forgac, and Hollerstein [(7)] showed that more experienced marathon runners had a better ability to estimate their final marathon time. There was a correlation between predicted and actual time, which was higher for the experienced runners compared to first- and second time marathoners. They found that first time marathon runners tended to run slower – through visual inspection of their findings [(7)]. This was also seen in a study by McKelvie [(2)] showing how experienced marathoners were more accurate than first- or second-time marathon runners and that their previous marathon experience and number of completed marathons were also significant factors for prediction of final marathon time. Pre-race experience was also shown to be good predictors in a study on predictor variables for a 100 km race time in male ultra marathoners [(8)]. The researcher's recruited 169 participants over four subsequent years for the 100 km ultra-marathon run in Biel, Switzerland. Elite runners with more running experience competed faster in 10 km races. Female marathoners with more weekly training volume and more experience competed faster in a 10 km race. Another study found a significant correlation between number of completed marathons and final time [(9)]. In female marathon runners, a higher aerobic capacity and experience was associated with faster marathon times [(10)].

McKelvie et al [(2)] described the next important predictor was the maximum mileage per week for marathon time predictions. The main predictor variable, which showed significant correlation with final time, was the total mileage run in 12 weeks prior to the marathon. Weekly volume of training was also seen as a good predictor for a 100 km race time predictor variable [(8)]. Other studies found that male runners training with more distance run per training unit [(3)] and completing more than 100 km per week [(11)] were also good predictor variables for marathon race time. Supporting these findings, a study of middle aged and older runners [(81)] showed that weekly running distance showed a significant correlation with endurance running performance for 51 male competitive runners; however, there was no explanation for how the authors collected their data. In an experimental design with 55 runners completing the marathon and attending physiotherapy post marathon race, the study showed that the longest mileage covered per training session is the best indicator for a successful completion of a marathon. The runners who completed the marathon had a mean longest mileage covered in a training session of 27.51 km, while the non-finishers had 5.44 km as their mean longest mileage covered [(3)]. A cross-sectional observational field study [(1)] on predictor variables for marathon race time in 29 recreational female marathoners, showed that maximal distance, number of training sessions run per week, and the running speed of the sessions were significantly related to the marathon race time. There was no significant association between the years as an active runner, weekly kilometres, the minimal distance run per week, the hours run per week, the distance run per training session, the duration of each training session, and the marathon race time. This study shows there were a number of predictor variables rather than one isolated variable for marathon race time [(1)]. Hewson and Hopkins [(13)] showed in long-distance runners that moderate intensity training runs were related to increased race performance in both male and female marathoners. It seems that distance covered and the intensity of the training sessions are important factors for race performance.

Interestingly, a study using the Glasgow marathon [82] with 88 men and women first time marathon runners showed there was no practical relationship between the average weekly mileage training and race times. These studies suggest that the experienced runners benefit more from a greater mileage per week with increased performance while the novice runners show no significant difference in performance [81][85]. Hagan et al [83] studied 35 female distance runners in a marathon. Nineteen runners were classified as novice having done less than three marathons and 16 were experienced marathon runners having run three, or more, marathons. The participants in this study recorded their training for 12 weeks prior to the marathon race. Marathon performance time was recorded on completion of the race and the results found that the main prediction of marathon performance time in the novice runners was their distance run per day while the workout pace of the experienced runners was one of the best predictive factors. Both studies suggest that training pace and distance covered are important factors for prediction of performance in the marathon for female athletes; however they show contrasting results for novice runners in a marathon. Weekly distance was seen to have an influence on performance in Hagan's study [83], while in the Glasgow marathon [82] there seemed to be no relationship between weekly mileage and race times. Summers et al [12] conducted a large-scale study of non-elite middle-age runners in which they reported a significant correlation between finishing time, length of run, frequency of run and longest run in training. These studies do not agree with a main variable which may influence the prediction of performance, but rather that there are a variety of variables which could impact performance.

Little is known what determines optimal pacing; it is the most difficult skill for an athlete to learn [80]. There is no apparent evidence suggesting that a faster start determines faster overall times. A study [84] of pacing for a 5 km run showed that an early faster run speed rather than the overall speed resulted in the fastest finishing time. This pacing resulted in runners slowing their speed during the end stages of the time trial, while the runners who had an even pace resulted in an increase in running speed. This study suggests that an even pace may be more suitable for longer distances. Other studies support an even pace strategy for distances up to 100 km for optimal race performance [85]. Lima-Silva et al [86] demonstrated with 24 endurance athletes running 10 km that the better performing athletes – who also had a better running economy - started their race at a velocity above the average velocity used in the entire race, positive pacing strategy, compared with the slower runners. Staab [87] investigated a 30-minute self-paced treadmill run. The results showed how an uneven distribution in effort was shown to result in a greater physiological demand for runners. The literature reviewed have small sample sizes, however their findings are relevant and specific in that they have used distance runners. These studies agree that a positive or even pacing strategy result in an optimal race performance.

Few studies have examined the influence of pacing on exercise performance specifically at the marathon distance. More research is needed to determine which of the different possible pacing strategies are optimal for different sports and for different distances or if there is no single optimal pacing strategy [50]. The literature outline the importance of previous training influencing the pacing strategy and it seems to suggest that an even pacing for the marathon distance is an optimal pacing strategy. Further research is needed in this area to verify or negate these findings. The pacing strategy is also seen to be regulated by the perception of effort [71].

A number of qualitative factors as predictors of marathon success have been suggested by a number of authors who have developed equations which enable runners to anticipate their marathon time from their performance in shorter distances–mainly their 10km time. This suggests that training speed might be associated with marathon performance [(2)]. This was shown in a study on physical training and personality factors as predictors for marathon time and training injuries involving 105 finishers in the National Capital Marathon, held in Ottawa, Canada. Training pace and speed were the most important predictors of the final marathon time. Pace and fastest 10 km time were the variables that were strongly associated with final time [(2)]. Mean speed of training sessions was also highly significantly and negatively correlated to half marathon race times in a study on predictor variables for half marathon race time in recreational female runners [(6)]. Supporting these findings, a half marathon study [(23)] with 84 male runners found that weekly kilometres run, the minimal and maximal distance, hours, number of training sessions and running pace per week were related to the half marathon performance in the bivariate analysis. However, after the multivariate analysis, only the training pace was significant to performance. Also, anthropometry was significant to half marathon performance [(23)]. From these studies, training pace is seen to be an important component for running performance; however more studies are specifically needed for the marathon distance.

Conversely, Knechtle et al [(84)] investigated performance in 63 male recreational ultra-runners in a 24 hour race. They found that the longest training run, personal best marathon time and total kilometres run were the best predictors for performance in the ultra-marathon race. There was no relationship between hours run per week or intensity of training related to performance in the race. This study focuses on a 24 hour ultra-marathon event so interpretation of these findings linking it to the marathon may differ due to the vast difference in distance required for this event compared to the marathon distance. Table 2.3 summarises the studies of factors predicting performance.

Table 2.3: Summary of studies of factors predicting performance.

Article	Study objective	Participants	Training intervention	Outcome measures	Results	Conclusions
Takeshima and Tanaka (81)	Prediction of endurance running performance for middle-aged and older runners	51 male competitive runners aged 43 to 79 years.	Continuous cycling test on a Monark cycle ergometer. 4 minutes unloaded cycling initially followed by a work rate of 15 watts at the fifth minute and increased by 15 watts every minute until volitional exhaustion.	Lactate threshold, VO_{2max}, training history, age.	Age, VO_{2max} and lactate threshold had high relationships for endurance running performance. Age was the second most influential predictor of endurance running performance. Weekly running distance showed significant correlations with endurance running performance.	Endurance running performance of middle-aged and older runners can be predicted by lactate threshold, age and weekly running distance or possibly a combination of these variables. Case series study.
Yeung et al (3)	Marathon finishers and non-finishers characteristics : A preamble to success	113 runners divided into two groups. 58 runners dropped out of the marathon at the 10 km point while 55 runners consulted physiotherapy after the marathon.	Marathon in Hong Kong.	Questionnaire, characteristics and training profiles.	Significant differences between the two groups in weekly training distance ($p = 0.00$), longest and shortest training distance per week ($p = 0.00$) and personal opinion on optimal training distance per week for a marathon ($p = 0.00$).	Non-finishers are poorly prepared. Longest mileage covered per training session is the best indicator for a successful completion of a marathon. Case – control study.

Table 2.3 cont.: Summary of studies of factors predicting performance.

Article	Study objective	Participants	Training intervention	Outcome measures	Results	Conclusions
Grant et al (82)	First time marathoners and distance training.	88 men and women first time marathon runners with age range 18 – 70.	Marathon race.	21.1 km and final race time, mean training mileage for 12 weeks prior to the marathon race, daily prediction for the marathon on the three preceding days of the marathon.	All runners averaged 37.2 miles per week during the last 12 weeks of training. Weekly mileage is a poor predictor of marathon performance. The correlation for predicted race time was not statistically significant for any of the three predictions.	First-time marathoners do not need exceptional mileage in order to complete the marathon and do not decrease their pace in the latter part of the race. First-time marathoners are able to predict their race time better near the day of the race. No practical relationship between the average weekly mileage training and performance for novice runners. Case series study.
Hagan et al (83)	Marathon performance in relation to maximal aerobic power and training indices in female distance runners.	35 female distance runners with age range 19 – 54. 19 were classified as novice having done less than 3 marathons and 16 were experienced marathon runners having completed 3 or more marathon race s.	Marathon race.	VO_{2max}, physical characteristics, training history recorded 12 weeks prior to the marathon race.	48% of the marathon performance time could be attributed to average training distance per day for the novice runners. 76% of the variation in marathon performance time could be related to body mass index and training pace for the experienced runners.	For novice runners, distance run per day is the most important factor while for experienced runners, BMI and workout pace is the most important factor for performance. Small sample size study with a new classification of novice and experienced runners.

Table 2.3 cont.: Summary of studies of factors predicting performance.

Article	Study objective	Participants	Training intervention	Outcome measures	Results	Conclusions
McKelvie et al [2]	Physical training and personality factors as predictors of marathon time and training injury.	105 male marathon runners.	Marathon race.	Questionnaire including training and marathon performance.	The difference between actual and predicted race time were significant ($p < 0.01$) but with a wide SD (22.3 ± 5.22). Number of marathons completed, fastest 10 km time, total mileage run 12 weeks preceding the marathon, maximum mileage per week, length of longest run and training pace all showed significant correlations with final time ($p < 0.01$).	Training pace and speed best predictors for performance in a marathon. Pace and fastest 10 km were strongly associated. Maximum mileage per week 12 weeks preceding marathon was the next predicting factor. Previous marathon experience and number of completed marathons was also a predicting factor for performance in a marathon. Case series study.
Knechtle, B et al [6]	Predictor variables for half marathon race time in recreational female runners.	42 recreational female.	Half marathon race.	BMI, body fat, skin-folds, speed of training sessions and race time.	Speed of training sessions showed a positive association between training speed and half marathon performance ($p = 0.0001$). Mid-axilla skin folds were significant to race time prediction ($p = 0.04$).	Mean speed of training sessions were related to fast half marathon race times. Anthropometric variables were related to half marathon race time in recreational female half marathoners. Case series study with small sample size.
Schmidt, Wiebke and Knechtle [1]	Predictor variables for marathon race time in recreational female runners.	29 recreational female marathoners.	Marathon race.	Anthropometric characteristics, training variables including volume, and speed in training.	Circumference of calf ($P = 0.02$) and the speed of the training sessions ($P = 0.0014$) were related to marathon race time	A low circumference of calf and a high running speed in training are associated with a fast marathon race time in recreational female runners in a marathon. Case series study with small sample size.

Table 2.3 cont.: Summary of studies of factors predicting performance.

Article	Study objective	Participants	Training intervention	Outcome measures	Results	Conclusions
Celestino, Tapp, and Brumet [9]	Locus of control correlates with marathon performance.	97 male runners made up of 74 male finishers and 23 male non-finishers of the marathon race.	Marathon race.	Rotters internal-external locus of control measure and number of previous marathons completed.	There was a significant difference between groups for the internal-external measurement. There was a significant negative correlation between finish time and external-internal measurement ($p < 0.01$). Number of previous marathons correlated negatively with finish time ($p < 0.01$).	Relationship between internal-external scores and marathon performance showed distance runners tend to be more introverted. Finish time was correlated with number of previous marathons completed. Case-control study.
Lima-Silva et al [86]	Effect of performance level on pacing strategy during a 10-km running race.	24 male endurance runners divided into low performing (n = 8) and high performing (n = 8) groups. The middle group (n = 8) were excluded from further analysis.	All participants performed an incremental exercise test on a treadmill, three 6 minute bouts of running at 9, 12 and 15 km.hr^{-1}, and a self-paced, 10 km running performance trial There were at least 48 hours between each test.	Descriptive and physiological variables, pacing strategy during the 10 km trial, VO_2, VO_{2max}.	The high performing group had a significantly higher peak running velocity than the low performing group ($p < 0.01$). Time to complete the 10 km running race was significantly different between the low performing and high performing groups ($p < 0.001$). Running velocity was significantly different between the groups at each 400 m ($p < 0.001$) and over the entire race distance ($p < 0.001$).	High and low performance runners adopt different pacing strategies during a 10 km race. A higher velocity at the start of the race above average velocity was seen with the higher performance runners. Comparative study with small sample size.

Table 2.3 cont.: Summary of studies of factors predicting performance.

Article	Study objective	Participants	Training intervention	Outcome measures	Results	Conclusions
Christensen and Ruhling [10]	Physical characteristics of novice and experienced women marathon runners.	23 non-elite female marathon runners. 10 classified as novice and 13 as experienced having raced in one marathon previously.	Multi-stage progressive exercise test on a treadmill using a modified Balke protocol and a marathon race.	Heart rate, VO_{2max}, marathon finish times and skin-fold measurements .	VO_{2max} and years of training were significantly smaller in the novice group ($p < 0.01$). No differences between heart rate, age, body size and composition between groups.	A greater aerobic capacity and experience is linked with performance in a marathon. Comparative study with small sample size.
Scrimgeour et al [11]	The influence of weekly training distance on fractional utilization of maximum aerobic capacity in marathon and ultra-marathon runners.	30 male marathon and ultra-marathon runners divided into 3 groups of 10 based on mileage per week. Group A trained less than 60 $km.wk^{-1}$, group B 60 to 100 $km.wk^{-1}$, group C more than 100 $km.wk^{-1}$.	Horizontal treadmill testing and training history.	VO_{2max},, steady state VO_2 and training distance per week.	Runners training more than 100 km per week had significantly faster running times (average 19.2%) compared to the other two groups. VO_{2max} during competition was not different between groups.	Peak treadmill running speed can predict performance in endurance running events. Training more than 100 $km.wk^{-1}$ may increase running economy or runners that train more than 100 $km.wk^{-1}$ may have developed superior running economy. Comparative study with small sample size.
Summers et al [12]	Middle-aged, non-elite marathon runners.	363 middle-aged non-elite runners attempting first marathon.	Marathon race.	Pre-race and post-race questionnaire.	Correlations between training information and actual finishing time showed that length and frequency of runs and longest run correlated significantly with final time ($p < 0.001$).	Length of run, frequency of run and longest run in training are linked with performance in a marathon. Case series study with good sample size.

Table 2.3 cont.: Summary of studies of factors predicting performance.

Article	Study objective	Participants	Training intervention	Outcome measures	Results	Conclusions
Franklin, Forgac, and Hollerstein [7]	Accuracy of predicted marathon time: relationship of training mileage to performance.	63 first-time marathoners, 29 second-time marathoners and 35 experienced marathon runners.	Marathon race.	Predicted marathon time, actual marathon time, and training history.	Both first-time and second-time marathoners underestimated their actual marathon time. Experienced runners closely approximated their estimated time. Experienced marathoners predicted pace and performance more accurately ($p < 0.05$) Training mileage/ week and actual marathon time had an inverse relationship for all groups.	This study shows the accuracy of predicted pace among experienced marathoners and the relationship between training mileage per week and marathon performance. Comparative study with good sample size.
Knetchtle, Rosemann and Lepers [8]	Predictor variables for a 100 km race time in male ultra-marathoners	169 male ultra-marathon runners.	4 subsequent years for 100 km ultra-marathon.	Anthropometry, training, pre-race experience and training.	Training speed ($p < 0.0001$), mean weekly running kilometres ($p < 0.0001$), and age ($p < 0.0001$) were the best correlations for a 100 km race time.	Age and both training variables of intensity and weekly training volume, and pre-race experience predict race time in a 100 km ultra-marathon. Case series study with good sample size.

Table 2.3 cont.: Summary of studies of factors predicting performance.

Article	Study objective	Participants	Training intervention	Outcome measures	Results	Conclusions
Gosztyla et al [84]	The impact of different pacing strategies on 5 km running time trial performance.	11 moderately trained women distance runners.	2 preliminary 5 km time trials for baseline data. The average 1.63 km split pace of the fastest preliminary trial was manipulated for the first 1.63 km of the experimental trials and run either equal to (EVEN), 3% faster than (3%), or 6% faster than (6%) the current baseline average 1.63 km pace for each participant.	Respiratory exchange ratio, heart rate and VO_{2max} and running pace.	The 6% trial resulted in the fastest overall 5 km time, finishing 13 seconds faster than the 3% trial and 32 seconds faster than the EVEN trial. No differences ($p > 0.05$) were found among the experimental trials for overall 5 km finishing time.	Early faster running speed resulted in faster finishing time. Suggests even pace more suitable for longer distances. Case series study with small sample size.
Parise and Hoffman [85]	Influence of temperature and performance level on pacing a 161 km trail ultra-marathon.	50 ultra-marathon runners (42 men, 8 women) divided three groups based on finish time (under 22 hours, 22 to 24 hours and 24 to 30 hours).	161 km ultra-marathon trail race over 2 consecutive years.	13 check points during the race to record pacing.	For all groups mean pace was slower for the first race compared with the second ($p < 0.001$).	Extreme heat impairs all runners' ability to perform in 161 km ultra-marathons, but faster runners are at a greater disadvantage compared with slower competitors because they complete a greater proportion of the race in the hotter conditions. Pace varied considerably relative to the terrain. Overall runners slowed down over the course of the race. Case-control study.

Table 2.3 cont.: Summary of studies of factors predicting performance.

Article	Study objective	Participants	Training intervention	Outcome measures	Results	Conclusions
Staab et al [87]	Metabolic and performance responses to uphill and downhill running in distance runners.	11 trained male distance runners	Three 30-minute self-paced competitive races on a treadmill with varying gradients.	Pace, VO_2, RPE, heart rate, blood lactate,	Runners do not maintain constant energy expenditure when racing uphill. Lactate accumulated on uphill stages even though pace decreased. Running pace increased on down hills but not enough to maintain a constant VO_2. The uphill and downhill runs were significantly slower ($p < 0.05$) than the control run.	Uneven distribution of pacing negatively affects performance. Case series study with small sample size.
Hewson and Hopkins [13]	Specificity of training and its relation to the performance of distance runners.	119 female and 234 male coached distance runners.	Training history.	Retrospective questionnaires.	A beneficial effect of specificity was evident in a significant ($p < 0.01$) correlation between performance and seasonal mean weekly duration of moderate continuous running for runners specialising in longer distances. Only other significant correlates of performance were seasonal mean relative training paces of moderate ($r = -0.18$) and hard ($r = -0.42$) continuous running.	Mean weekly duration of moderate continuous intensity training runs, moderate and hard training paces correlates with performance. Retrospective study with good sample size.

2.5 SUMMARY

The marathon is one of the most challenging running races and is increasing in popularity annually [88]. However, factors that contribute to an improved running performance in a marathon are not well substantiated [4][5]. There are a variety of metabolic and physiological skeletal adaptations that take place with endurance exercise and these adaptations result in an improved performance capacity [63]. Exercise-induced muscle damage increases the physiological demand in endurance exercise [25][27] and negatively effects endurance running performance [17], however the effects of EIMD on endurance running performance remains unclear [52]. A number of physiological models are used to explain the physiological and training-induced changes that may improve endurance performance [4][22]. The central governor model is one which is currently used. The purpose of the central governor model is to regulate the amount of muscle recruited during exercise without causing bodily harm [15][39]. Factors limiting exercise will depend on the type and intensity of the exercise, the muscle groups involved, and the physical environment in which the exercise is performed [18].

A balance in training variables for a marathon is needed as excessive training may result in over-use injuries, while under-training may result in acute injuries during the marathon or not completing the marathon [3]. Tapering strategies are an important component of training, however there is no consensus regarding an optimal tapering strategy for marathon races [27]. The evidence suggests that a reduction in training load, minimum training frequency and continued running intensity seem to be important components for an effective tapering period without a reduction in performance or de-training effects [16][44][45][46][47][48]. Delayed onset muscle soreness will affect RPE and the athlete with DOMS will perceive exercise to be more difficult [61]. Appropriate planning of training and recovery is essential to prevent the effects of DOMS [31]. Fatigue can also negatively affect training and recovery [31] and could lead to overuse injuries in endurance athletes as a result of kinematic changes [61].

Perception of effort is used to assess exercise intensity [89] and is the best indicator for the degree of physical strain [65]. Practice and experience has been shown to improve RPE [50]. Physiological demands of marathon running have been well established while less is known about pacing strategies in a marathon [74]. Pacing may be influenced by a "central programmer" [75]. At a subconscious level there seems to be a specific workload and exercise intensity which has been termed "teleoanticipation" [90]. Teleoanticipation involves both feed-forward planning and feedback control [51] and is a subconscious mechanism from the central nervous system which uses past experiences to pre-set the exercise intensity for future exercise sessions [19]. Teleoanticipation regulates exercise performance and maintains homeostasis in the body to prevent bodily harm [20]. Most athletes become better at pacing with practice suggesting experience refines their pacing [20].

Many previous studies have examined anthropometric and training variables, but few have actually looked at performance-related factors during an event in an attempt to establish how these factors might contribute to the accuracy of performance prediction [(1)(5)(8)(23)(24)]. More research is required to determine which variables influence the accuracy of prediction of endurance running performance.

CHAPTER 3: ACCURACY OF PREDICTION OF ENDURANCE RUNNING PERFORMANCE: RELATIONSHIP TO TRAINING HISTORY, MUSCLE PAIN AND RELATIVE PERCEPTION OF EFFORT

3.1 INTRODUCTION

Endurance running has become a popular sport [(1)(2)(6)]. The marathon, in particular, is one of the most challenging endurance events with increased participation annually [(88)]. Performance in endurance running involves a variety of physiological and training variables [(8)]. However, the relationship between these factors is complex and poorly understood [(4)(5)]. To date, relatively few studies have investigated factors influencing endurance running performance [(1)(5)(8)(23)(24)]. Teleoanticipation is an important factor that may influence endurance running performance. Teleoanticipation is a complex a feed-forward and feed-back mechanism that uses past experiences to pre-set exercise intensity for future sessions [(19)], thereby regulating exercise performance and maintaining homeostasis. The relative perception of effort (RPE) is an important subjective marker of exercise intensity [(21)], and may reflect the physiological demands associated with maintaining homeostasis and the perceived finishing point of exercise [(22)]. More research is needed to determine whether there are any relationships between the accuracy of prediction of performance, and other factors that may influence performance outcomes. Accordingly, the aim of this study was to determine potential factors associated with the accuracy of prediction of running performance during a marathon race. The specific objectives of this dissertation have been described in Section 1.2.2, page 2).

3.2 METHODS

3.2.1 Research design and recruitment

This study had a descriptive analytical correlational design. Sixty-three healthy male and female runners volunteered to take part in this study. Participants were recruited through a short message service (SMS), word of mouth and at the Mandela Day marathon registration (Appendix I). Permission to obtain race participants' contact details and to access their phone numbers were provided by the race organiser. The researcher also recruited runners at the pre-race exhibition that took place daily for three days before the race.

3.2.2 Participants

3.2.2.1 Inclusion criteria

Male and female runners, over the age of 20, participating in the 2013 Mandela day marathon were recruited for this study. Participants were required to complete the marathon within the seven-hour cut-off time.

3.2.2.2 Exclusion criteria

Participants who had any lower limb musculoskeletal injury, medical condition or surgical intervention that prevented training for seven consecutive days in the three-month period prior to the race were excluded from the study. Participants who reported any flu-like symptoms during the two weeks preceding the race were also excluded from the study. In addition, participants with any missing race RPE or pain scores were excluded.

3.2.2.3 Sample size determination

Data from a previous study which measured muscle soreness during the recovery period after the Comrades marathon was used to ensure that the sample size would provide sufficient statistical power (91)**.** Muscle soreness was selected to determine the required sample size, as it was one of the main outcome measures of this study. Required sample size for pain scores was calculated using a smallest meaningful difference of three, and a between-subject standard deviation of 2.5. With statistical significance accepted as $p < 0.05$, groups of 12, 16 and 19 participants would provide 80%, 90% and 95% statistical power for muscle soreness respectively.

3.2.2.4 Group allocation: accuracy of prediction of running performance

The accuracy of prediction of running performance allows for the consideration of the effects of teleoanticipatory factors such as pacing and prior experience on performance. Participants were required to predict their race time for the marathon when they completed the medical and training questionnaire before the race. The participants were then allocated to one of three groups depending on their accuracy in predicting their final race time. The group allocation was only performed once data collection had been completed. Group one consisted of participants who completed the race in a faster time than their predicted race time (fast group). Group two consisted of participants who completed the race in a slower time than their predicted time (slow group). Group three consisted of participants who accurately predicted their time (accurate group). A margin of two percentage points was considered as a meaningful difference in time. If the participants' actual race time was accurate within two percentage points of their predicted race time, it was considered accurate, and those participants formed the accurate group. Participants on either side of the two percentage points formed the fast and slow groups respectively. Therefore, 16 participants formed the accurate group, 26 participants formed the slow group, and the fast group comprised of 21 participants respectively.

The calculation for group allocation is important to determine where each participant is allocated (Section 3.2.2.4, page 38). For example, a prediction within 2% for a 180 minute actual marathon race time should fall between 174.4 minutes and 183.6 minutes to be allocated to the accurate group. A predicted race time of less than 174.4 minutes means the participant was allocated into the slow group, while a predicted race time of more than 183.6 minutes means the participant was allocated to the fast group. The calculation is described below.

$$\frac{\text{Actual marathon time (min)}}{\text{Predicted marathon time (min)}} \times \frac{100}{1}$$

3.2.3 Measurement instruments

3.2.3.1 Informed consent

All participants were required to complete an informed consent form at the familiarisation session (Appendix II). The possible risks and benefits of the study, how confidentiality would be maintained, and the participants' right to withdraw at any stage were discussed.

3.2.3.2 Medical and training questionnaire

Participants were required to complete a medical and training questionnaire at the familiarisation session (Appendix III). The questionnaire obtained information regarding: predicted race time for the marathon; demographic information; training history; competition history, tapering history; proposed pacing strategies during the race; medical history; medication use; injury history; and surgical history. The questionnaire also included a section on flexibility history; however, these data were not included for analysis in this study. This questionnaire was based on the questionnaire that was used successfully in the 2000, 2001, 2006 and 2007 Ironman research studies and the Two Oceans marathon research study. Two experts in endurance exercise assessed the modified questionnaire for content validity. The validators were requested to comment on the importance and relevance of the questions and whether the questions were clear, concise and easily understood. In addition, the validators were requested to give input and ideas that had possibly not been addressed in the questionnaire, which could contribute to the objectives of the study. Feedback predominantly involved changing the structure of some questions for better understanding and clarity. The researcher and supervisors consolidated the feedback and compiled an updated version of the questionnaire. The panel of experts concurred that the final version of the questionnaire was thorough and addressed all components of the study objectives.

3.2.3.3 Visual analogue scale for pain

Subjective muscle pain scores were obtained using a Visual Analogue Scale (VAS) for pain (Appendix IV). The VAS had pain scores from zero to ten, where zero represented *"no pain"*, five represented *"moderate pain"*, and 10 represented *"maximal pain"*. Subjective pain scores were obtained before the start of the marathon (0 km); at 10 km, 21.1 km and 30 km during the race; and at the finish of the race (42.2 km). During the race, participants were required to place a sticker indicating their appropriate pain score on a race bracelet (Appendix IV). Participants were also required to provide daily post-race pain scores for seven days after the race. The VAS is a valid and reliable tool to measure muscle pain [(92)].

3.2.3.4 Relative perception of effort

Relative perception of effort (RPE) was obtained using the modified Borg scale (Appendix IV) [(65)]. The modified Borg scale ranges from six to twenty, where seven represented an *"extremely light"* level of exertion, thirteen represented a *"somewhat hard"* level of exertion, and 20 represented a *"maximal"* level of exertion. Relative perception of effort scores were obtained before the start of the marathon (0 km); at 10 km, 21.1 km and 30 km during the race; and at the finish of the race (42.2 km). During the race, participants were required to place a sticker indicating their appropriate RPE score on a race bracelet (Appendix IV). The modified Borg scale is a valid and reliable measuring tool for RPE [(20)].

3.2.3.5 Mandela Day marathon

The Mandela day marathon was held on Sunday the 25th August 2013 starting at 7h00 from Manaye Hall, Imbali, and finishing at the Nelson Mandela capture site in Tweedle near Howick, Kwazulu-Natal, South Africa. The cut-off time for the marathon was seven hours. The average temperature in August for Howick is 12.3 °C, and race day conditions were 12 °C with 96% humidity and a 10.4 $km.h^{-1}$ wind [93]. The marathon began at 699 m above sea level with the highest elevation of 1213 m above sea level near the 18 km mark and 1109 m elevation at the finish [94]. There were 1621 runners who officially completed the marathon. The race profile is shown in Figure 3.1.

Figure 3.1: Mandela Day marathon profile. The profile was obtained from a global positioning system (GPS) recording from a study participant's watch during the race.

3.2.3.6 Post-race compliance questionnaire

A post-race compliance questionnaire was given to participants after they completed the marathon. This questionnaire determined whether participants became ill, sustained an injury; or used medication or any type of recovery aid during the race (Appendix V).

3.2.3.7 Feasibility study

A feasibility study was conducted in July 2013[#]. Five runners taking part in the Savages half marathon race were recruited for the feasibility study. The feasibility study assessed all pre-race measures (informed consent and the medical and training questionnaire) and tested the feasibility of capturing information during the race. Feedback was obtained from all participants regarding the ease and understanding of answering the questionnaire and the testing procedures during the race. Changes as a result of feedback included minor adjustments to the methodology for capturing race data, and more refinements to the wording of the questionnaire. Data from the feasibility study were not included for analysis in the primary research study.

3.2.4 Testing procedure

A familiarisation session at registration in the week prior to the marathon was attended by all participants. Participants were informed about the purpose of the study and the nature of the testing procedures and gave written informed consent before taking part in the study. Participants were requested to complete the medical and training questionnaire and were then familiarised with all the tests and procedures for collecting data during the race. Participants were given a race pack that included details about race day data collection, a race bracelet (Appendix II and Appendix IV), stickers and safety pins.

Subjective ratings on muscle pain and RPE were obtained at 0 km, 10 km, 21.1 km, 30 km, and 42.2 km. There were two ways in which these ratings were collected. Firstly, each participant wore a yellow laminated race bracelet on their wrist or the front of their shorts fastened with two safety pins. The race bracelet had the modified Borg and Visual Analogue Scale (VAS) with stickers that the participants used at each data collection point to record their RPE and pain scores on the corresponding values (Appendix IV). Secondly, there were two research assistants stationed at each data collection point wearing neon orange t-shirts. One research assistant alerted participants to the upcoming data collection point while the other recorded the data and gave visual reminders to the respective scales for muscle pain and RPE with a large yellow poster depicting these scales (Appendix IV). Participants shouted out their muscle pain and RPE scores, in this order, at each data collection point and simultaneously recorded the scores on their bracelet. The participants were told to run on the left side of the road so that research assistants could easily identify them.

At the end of the race the race bracelets were collected and a post-race compliance questionnaire (Appendix V) was used to ask the participants about illnesses, injuries, any medication taken or recovery aid used during the race. The official race time for each participant was obtained from the Championchip® website (www.championchip.co.za) and was compared to their predicted times. Muscle pain was recorded daily for seven days after the marathon and these data, together with participants' timing of their first training run after the race, were collected electronically via email or by SMS.

Ethics approval was obtained in June 2013, prior to the feasibility study.

3.2.5 Statistical analyses

Data were analysed using Statistica software (StatSoft, Inc. (2011) STATISTICA version 10.0 www.statsoft.com). Normality was assessed using the Shapiro Wilkes test. A one-way analysis of variance (ANOVA) was used to determine differences in descriptive and training history data between the fast, accurate and slow groups. A Pearson's chi-squared test was used to assess differences in categorical variables between groups (pacing strategies). An ANOVA with repeated measures was used to determine the main effects of group (fast, accurate and slow) and time (within race changes at 0 km, 10 km, 21.1 km, 30 km, and 42 km), and the interactions between group and time for race variables (RPE and muscle pain) and post-race pain scores. Levene's test was used to assess if the variances of each variable in the two groups were equal. Unequal N HSD *post-hoc* analyses were performed where necessary. The relationship between accurate and predicted race times was determined using a Pearson's product moment correlation. All data are presented as the mean ± standard deviation. Statistical significance was accepted as $p < 0.05$.

3.2.5.1 Regression analyses of factors influencing the accuracy of predicting performance in a marathon

Multiple regression analyses were used to determine which variables were predictive of accurately predicting marathon race time. Data were analysed using SPSS SOFTWARE Statistics 21 (IBM SPSS (2012) Version 21 www.ibm.com). Forward stepwise regression analyses were used to predict the probability that a participant would be able to accurately predict their marathon finishing time. The predictor (independent) variables were age, BMI, gender, pacing strategy, taper, marathon experience, training frequency, training duration, training distance, pre-race training (week before the marathon), last long distance run, change in RPE during the marathon, change in pain during the marathon, flu symptoms, previous injury and sites of pain. Model 1 compared gender, age and BMI; model 2 compared pacing, taper and marathon experience; model 3 compared frequency of training, duration of training and distance in training; model 4 compared pre-race training and last long distance run; model 5 compared the change in RPE and pain; and model 6 compared flu symptoms, previous injury and sites of pain. The predictor variables were coded as described in Table 3.1. All logistical regression tables show the p – values. Statistical significance was accepted at $p < 0.05$.

Table 3.1: Predictor variables coded for regression analyses.

Predictor variable	Coded 0	Coded 1
Age (years)	0-39 years	40 years and above
BMI ($kg.m^{-2}$)	0-24.9	25 and above
Gender	Male	Female
Pacing strategy	No	Yes
Taper	No	Yes
Marathon experience (n)	Novice (0-2 marathons)	Experienced (3 or more marathons)
Training frequency (n)	0-3 sessions per week	4 sessions or more per week
Training duration (min)	0-300 minutes per week	301 minutes or more per week
Training distance (km)	0-50 km per week	51 km or more per week
Pre-race training (km)	0-30 km in preceding week	31 km or more in preceding week
Last long distance run (days)	0-10 days	11 days or more
Change in RPE 0-42.2 km (Borg scale, 6-20)	0-5 rating of RPE	6 or more rating or RPE
Change in pain 0-42.2 km (VAS scale, 0-10)	0-3 rating of pain	4 or more rating of pain
Flu symptoms (6 weeks before marathon)	No	Yes
Previous injury	No	Yes
Sites of pain	No	Yes

3.2.6 Ethical considerations

This study was granted ethical approval from the University of Cape Town, Faculty of Health Sciences Human Research Ethics Committee (HREC REF 252/2013) (Appendix VI). This study adhered to the ethical principles outlined in the Declaration of Helsinki (Seoul version, 2008[#]). Once ethical approval was granted, informed consent forms were given to all participants prior to their involvement in this research study (Appendix II). The possible risks associated with the study and the participants' right to withdraw at any point were discussed in the familiarisation session. Participants were also given an opportunity to ask questions or voice concerns relating to the study at this session. Written informed consent was obtained from each participant. All data were kept confidential.

The researcher is aware that there is a new version of the Declaration of Helsinki (Brazil, 2013) but the research was conducted prior to the release of the 2013 version.

3.2.6.1 Risks to participants

There were no risks to the participants with completing the questionnaire or the subjective scoring of muscle pain and RPE. There may have been inherent risks to participants associated with taking part in a marathon race, due to the endurance component of distance running and the strenuous nature of the sport. However, all participants were experienced runners with weekly training in preparation for the marathon race. Participants may also have been at risk of injury during the race due to the observer bias principle. Participants could have momentarily lost their concentration when they were expected to give their RPE and muscle pain responses to the research assistants. This could have resulted in a change in their pacing strategy and possibly their race performance. This risk was minimised through education during the familiarisation session explaining the testing procedure.

In addition, safe participation in the marathon event was a primary concern. Therefore, all participants were asked whether they had had a check-up with their general practitioner in the 10 days before the race. This was recommended for all participants. In addition, participants were excluded from the study if they reported any flu-like symptoms two weeks prior to the race, and were referred to their doctor for further assessment. The detailed medical history section of the questionnaire was retained to determine whether participants were excluded from the study based on injury or illness, and if they needed referring for further medical care.

3.2.6.2 Benefits to participants

Each participant received the results of the study and were provided with evidence-based information on pacing and training strategies specifically for running (Appendix VII). There was no remuneration for taking part in this study.

3.3 RESULTS

3.3.1 Participants

One hundred and nine participants (males n = 72; females n = 37) were recruited for this study. Thirty-six participants were excluded due to incomplete race data, and a further 10 participants were excluded as there was no official race finish time recorded. Therefore, 63 participants (males n = 35; females n = 28) were included for data analysis. The participants were divided into three groups depending on their accuracy in predicting their final race time. Group one was the slow group with 26 participants (males n = 18; females n = 8), group two was the fast group with 21 participants (males n = 9; females n = 12) and group three was the accurate group with 16 participants (males n = 8; females n = 8). The study sample is summarised in Figure 3.2.

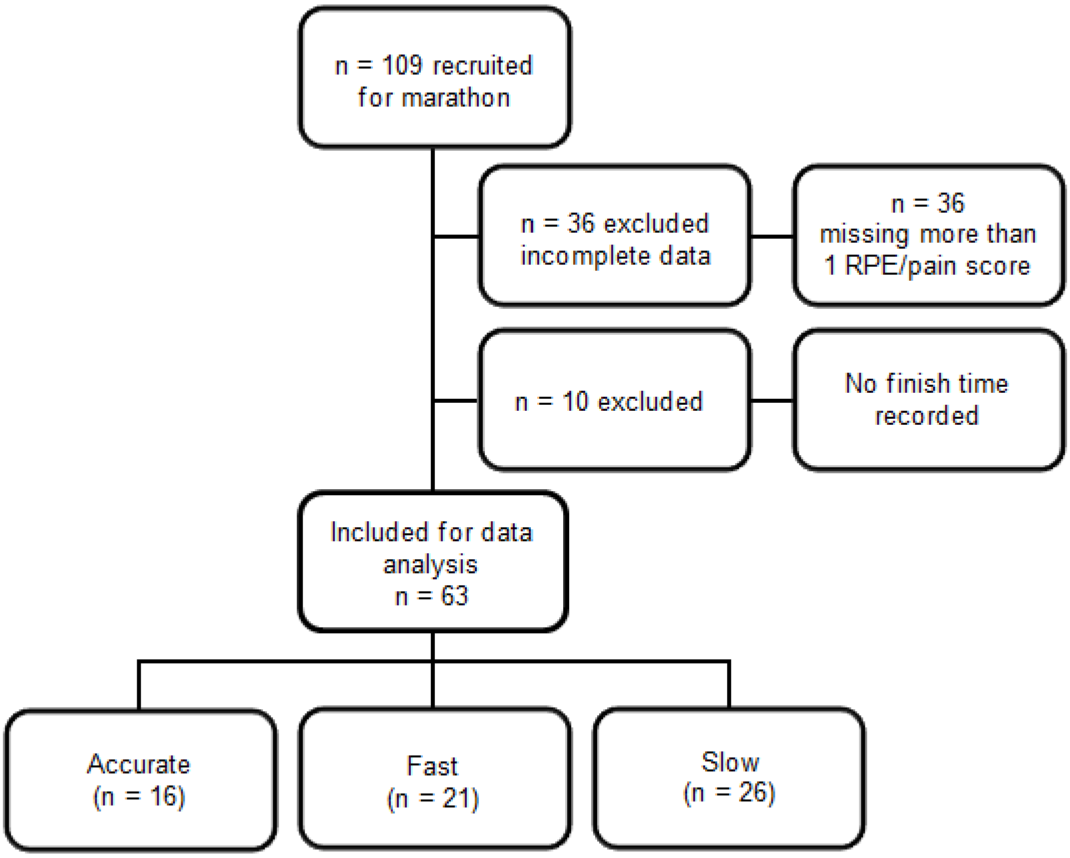

Figure 3.2: Summary of study sample.

3.3.2 Descriptive characteristics

The descriptive characteristics of participants in the accurate, fast and slow groups are shown in Table 3.2. There were no significant differences in body mass, stature and body mass index (BMI) between groups. There was a significant difference in age between groups ($F_{(2, 59)} = 4.01$, $p = 0.02$). Participants in the slow group were younger than participants in the accurate and fast groups. Some participants did not complete the descriptive characteristics section of the questionnaire. Five participants in the accurate group, one participant in the fast group and six participants in the slow group were missing some descriptive information, as reflected in Table 3.2.

Table 3.2: Descriptive characteristics for accurate (n = 16), fast groups (n = 21) and slow (n = 25). Data are expressed as mean ± standard deviation (SD).

Variables	Accurate (n = 16)	Fast (n = 21)	Slow (n = 25)	p
Age (years)	48.5 ± 5.9 (n = 16)	48.5 ± 9.2 (n = 21)	42.3 ± 9.2 (n = 25)	0.02*
Body mass (kg)	66.6 ± 11.3 (n = 14)	69.6 ± 13.9 (n = 20)	69.9 ± 9.2 (n = 22)	0.68
Stature (m)	169.1 ± 13.2 (n = 11)	169.2 ± 8.8 (n = 20)	170.9 ± 8.0 (n = 20)	0.82
Body mass index (kg.m^{-2})	23.2 ± 2.8 (n = 11)	24.1 ± 3.1 (n = 20)	24.2 ± 1.9 (n = 20)	0.56

* $p < 0.05$

3.3.3 Medical, surgical and injury history

Eighteen participants (29%) experienced flu symptoms six weeks prior to the marathon. No participants reported any surgical history in the three months before the race. Twenty participants (32%) reported a previous injury and 18 participants (29%) reported sites of pain. These sites of pain are shown in Figure 3.3. None of the reported sites of pain prevented training for seven consecutive days in the three-month period prior to the race. Therefore, these participants were not excluded on the basis of current sites of pain.

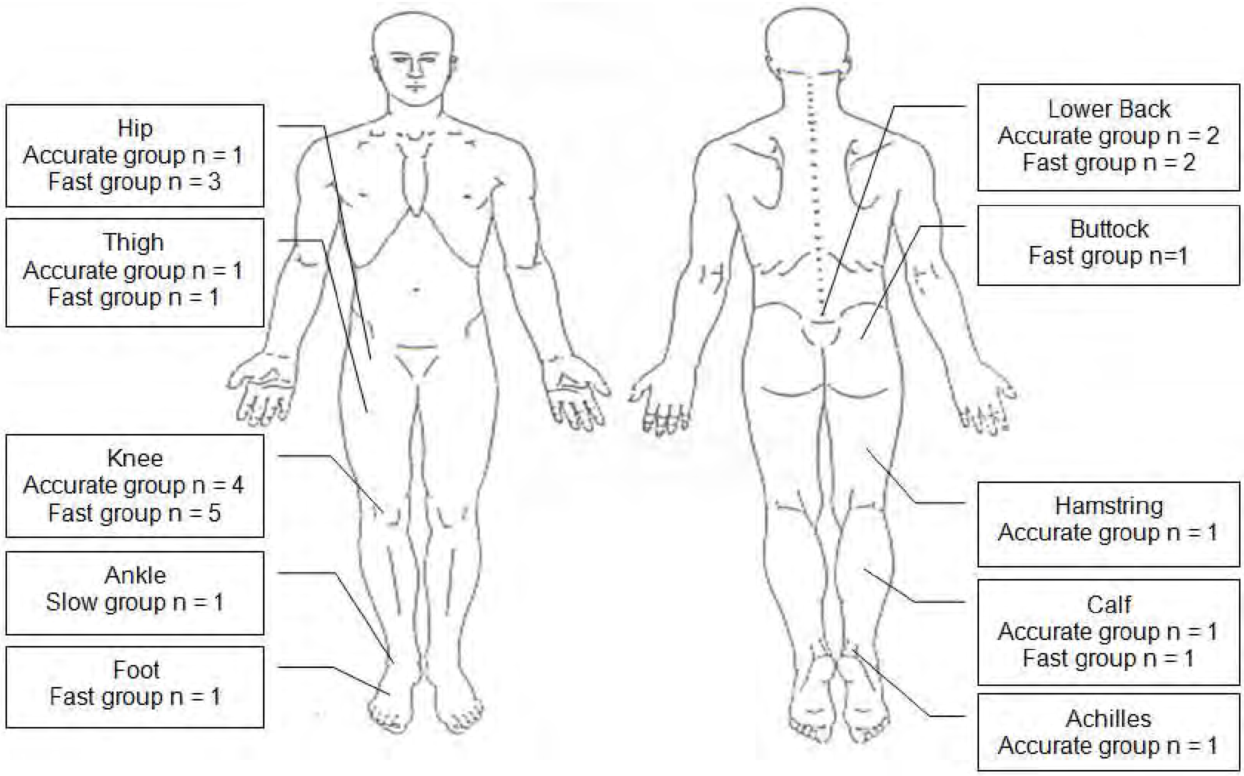

Figure 3.3: Cumulative numbers of anterior and posterior anatomical sites of participants with sites of pain (n) in the accurate (n = 7), fast (n = 10) and slow (n = 1) groups. Data are expressed as numbers.

3.3.4 Training characteristics

The training characteristics of participants in the accurate, fast and slow groups are shown in Table 3.3. There was a significant difference for 10 km personal best (PB) time ($F_{(2, 26)} = 12.61$, $p = 0.0002$). Participants in the slow group had faster times than participants in the accurate and fast groups. There were no significant differences between groups for the 42.2 km PB times. There was a significant difference for training pace ($F_{(2,40)} = 9.84$, $p = 0.0003$). Participants in the slow group had a faster training pace than participants in the accurate and fast groups. Forty-eight (76%) participants reported using a tapering strategy before the race. There was no significant difference in taper length between groups. There were no significant differences for number of marathon races completed, training mileage seven days before marathon, average training frequency, average training duration, average training distance and tapering strategy between groups. Some participants did not complete the training characteristics section of the questionnaire. Nine participants in the accurate group, eleven participants in the fast group and fourteen participants in the slow group were missing some training characteristics information.

Table 3.3: Training characteristics for accurate (n = 16), fast (n = 21) and slow groups (n = 26). Data are expressed as mean ± standard deviation (SD).

	Accurate (n = 16)	**Fast (n = 21)**	**Slow (n = 26)**	**p**
10 km PB (min)	53.7 ± 7.7 (n = 7)	60.7 ± 5.2 (n = 10)	43.4 ± 10.1 (n = 12)	0.0002**
42.2 km PB (min)	269.7 ± 28.3 (n = 11)	273.9 ± 52.3 (n = 19)	252.1 ± 56.7 (n = 20)	0.37
Number of marathon races completed	21.8 ± 23.5 (n = 16)	19.2 ± 34.3 (n = 21)	10.4 ± 10.8 (n = 26)	0.26
Training pace ($m.s^{-1}$)	2.6 ± 0.28 (n = 11)	2.5 ± 0.3 (n = 18)	3.1 ± 0.5 (n = 14)	0.0003**
Training mileage 7 days before marathon (km)	29.4 ± 32.3 (n = 12)	31.3 ± 29.1 (n = 20)	19.6 ± 15.5 (n = 18)	0.36
Average training frequency ($d.wk^{-1}$)	3.7 ± 1.5 (n = 15)	3.5 ± 1.4 (n = 19)	4 ± 1.1 (n = 25)	0.44
Average training duration ($min.wk^{-1}$)	271.7 ± 183.7 (n = 15)	281.6 ± 141.1 (n = 19)	294.3 ± 136.7 (n = 26)	0.89
Average training distance ($km.wk^{-1}$)	37.6 ± 24.2 (n = 16)	45.8 ± 19.6 (n = 20)	52.3 ± 30.7 (n = 26)	0.21
Taper length (days)	10.0 ± 4.5 (n = 6)	9.2 ± 4.7 (n = 12)	10.4 ± 4.7 (n = 17)	0.78

*** $p < 0.01$*

3.3.5 Marathon times

The predicted and actual average marathon times for accurate, fast and slow groups are shown in Table 3.5 There was a significant interaction between groups for actual average marathon times ($F_{(2, 60)} = 3.9$, $p = 0.03$). Participants in the slow group had faster marathon times than participants in the accurate and fast groups. Similarly, there was a significant interaction between groups for predicted average marathon times ($F_{(2, 60)} = 29.73$, $p = 0.0001$). Participants in the slow group had faster predicted marathon times than participants in the accurate and fast groups.

Table 3.4: Predicted and actual average marathon times for accurate (n = 16), fast (n = 21) and slow (n = 26) groups. Data are expressed as mean ± standard deviation (SD).

	Accurate (n = 16)	**Fast (n = 21)**	**Slow (n = 26)**	**p**
Predicted average marathon times (min)	318 ± 40.2	361 ± 39.0	253 ± 58.7	0.0001**
Actual average marathon times (min)	316 ± 39.7	323 ± 25.2	290 ± 53.2	0.03*

** p < 0.05; ** p < 0.01*

There were significant positive correlations for all groups for the actual and predicted times ($r = 0.71$, $p = 0.0001$, 95% confidence interval (CI) 0.75 – 0.90) (Figure 3.4). A positive correlation indicates that as the predicted marathon time increased, actual marathon time also increased.

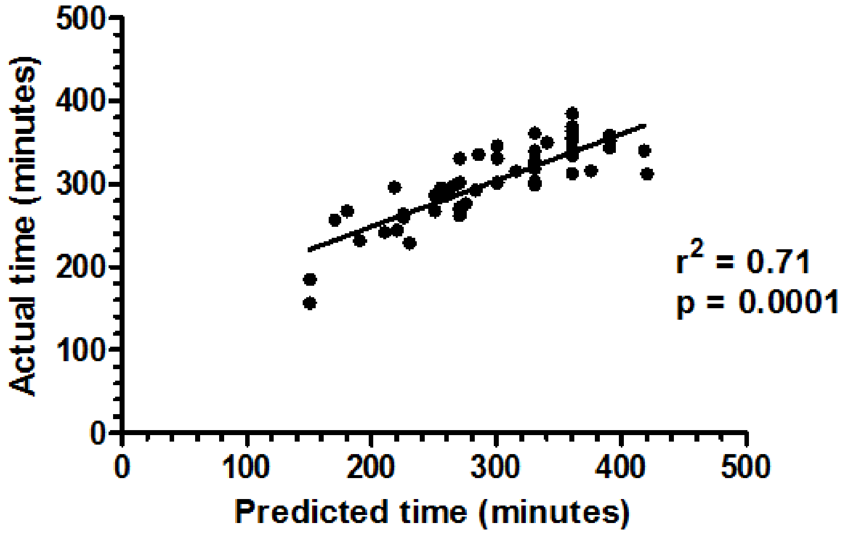

Figure 3.4: Relationship between actual and predicted marathon race times for accurate (n = 16), fast (n = 21) and slow (n = 26) groups.

3.3.6 Compliance

Forty-eight participants (76%) completed the post-race compliance questionnaire. Four participants (6%) reported that they sustained an injury during the race (muscle cramps). Four runners (6%) used medication during the race (n = 3 used anti-inflammatory medication; n = 1 used muscle relaxant medication). Three participants (5%) used a recovery aid during the race (ice, massage and/ or stretching).

3.3.7 Pain and RPE during the marathon

3.3.7.1 Pain

The average pain scores during the marathon of participants in the accurate, fast and slow groups are shown in Figure 3.5. There were no significant differences between groups, however there was a significant main effect of time ($F_{(4, 240)} = 84.86$, $p = 0.00001$). Pain was significantly increased at 21.1 km ($p = 0.0005$), 30 km ($p = 0.0003$) and 42.2 km ($p = 0.0003$) compared to pre-race (0 km) values.

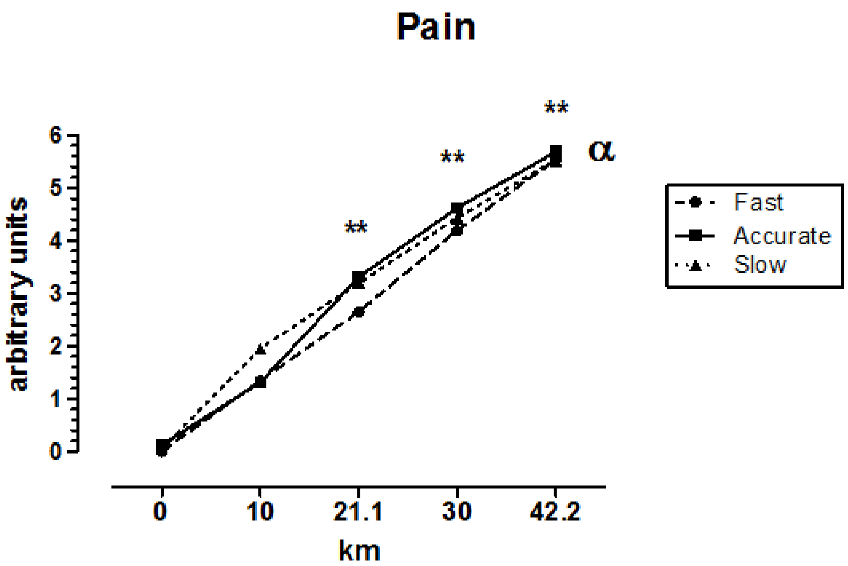

Figure 3.5: Average pain scores during the marathon for accurate (n = 16), fast (n = 21) and slow (n = 26) groups.

Significant differences:
α: main effect of time (p = 0.00001)
*** 21.1 km vs. 0 km (p = 0.0005)*
*** 30 km vs. 0 km (p = 0.0003)*
*** 42.2 km vs. 0 km (p = 0.0003)*

3.3.7.2 Relative perception of effort

The average RPE scores during the marathon of participants in the accurate, fast and slow groups are shown in Figure 3.6. There were no significant differences between groups, however there was a significant main effect of time ($F_{(4, 240)}$ = 148.44, p = 0.00001). The relative perception of effort was significantly increased at 21.1 km (p = 0.0003), 30 km (p = 0.0003 for all groups) and 42.2 km (p = 0.0003 for all groups) compared to pre-race (0 km) values.

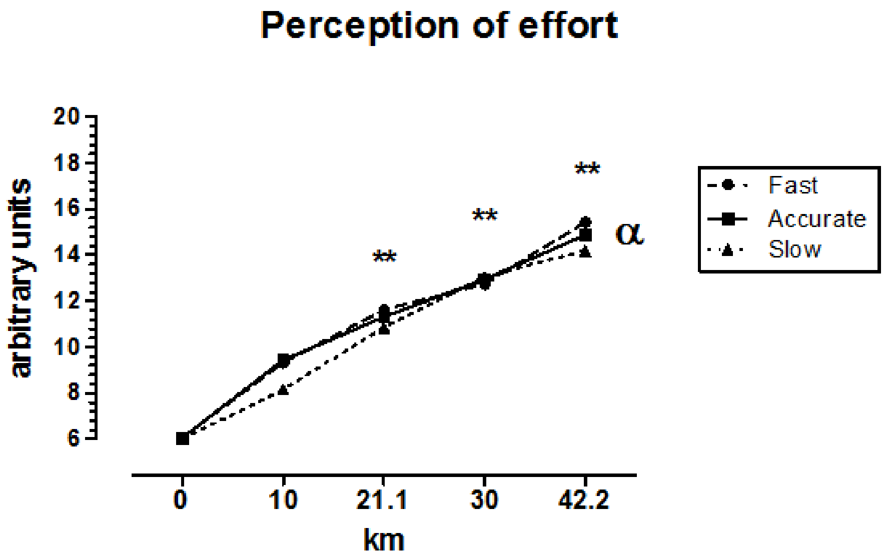

Figure 3.6: Average relative perception of effort scores during the marathon for accurate (n = 16), fast (n = 21) and slow (n = 26) groups.

Significant differences:
α: main effect of time (p = 0.00001)
*** 21.1 km vs. 0 km (p = 0.0003)*
*** 30 km vs. 0 km ((p = 0.0003)*
*** 42.2 km vs. 0 km (p = 0.0003)*

3.3.8 Pacing strategy

Forty-two participants (67%) indicated they adopted a pacing strategy; 21 participants (33%) indicated they did not have a pacing strategy. The predicted and actual pacing strategy of participants in the accurate (n = 9; 21%), fast (n = 15; 36%) and slow (n = 18; 43%) groups are shown in Table 3.6. Two percentage points was considered as a meaningful difference in time. If the participants' actual pacing strategy for the second half of the marathon (21.1 km – 42.2 km) was accurate within two percentage points of the actual pacing strategy for the first half of the marathon (0 km – 21.1 km), it was considered an even pacing strategy. There were no significant differences between groups for pacing strategy chosen. Data are expressed as numbers (n) and percentages (%).

Table 3.5: Pacing strategy for accurate (n = 9), fast (n = 15) and slow (n = 18) groups. Data are expressed as numbers (n).

Pacing strategy	**Accurate n**		**Fast n**		**Slow n**	
	Predicted	Actual	Predicted	Actual	Predicted	Actual
Positive	1	3	1	8	4	10
Negative	3	2	2	4	6	1
Even	3	4	9	3	4	7
Variable	2	0	3	0	4	0

3.3.9 Post-race pain

The post-race pain scores for seven days after the race of participants for accurate, fast and slow groups are shown in Figure 3.7. There were no significant differences between groups. However, there was a significant main effect of time ($F_{(6, 318)} = 44.99$; $p = 0.000001$). Pain scores were significantly increased on day one ($p < 0.00003$), day two ($p < 0.00003$) and day three ($p < 0.002$) after the race.

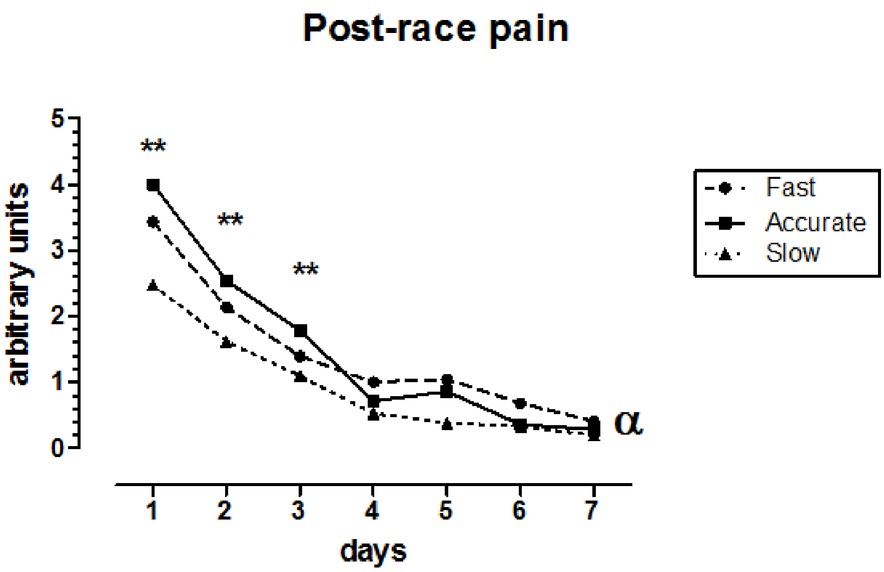

Figure 3.7: Average post-race pain for accurate (n = 16), fast (n = 21) and slow (n = 26) groups.

Significant differences:
α: main effect of time (p = 0.000001).
*** day 1 vs. days 2, 3, 4, 5, 6, and 7 (p < 0.00003)*
*** day 2 vs. days 4, 5, 6, and 7 (p < 0.00003)*
*** day 3 vs. days 6 and 7 (p < 0.002)*

3.3.10 Timing of the first run after the race

There were no significant differences between groups for timing of the first run after the race. The timing of the first run after the race was 4 ± 3 days post-race for the accurate group, 5 ± 3 days post-race for the fast group and 5 ± 4 days post-race for the slow group. The timing of the first run ranged from one to 14 days after the marathon.

3.3.11 Regression analyses

Forward stepwise regression analyses were performed to determine whether any demographic, training and racing history, or race variables were associated with the accuracy of prediction of performance. Six different regression models were used, as described in Section 3.2.5.1 (page 42). The results of the regression analyses are shown in Table 3.7. There were no significant predictive factors for the accuracy of marathon race times.

Table 3.6: Forward stepwise regression analyses using six different models.

Model	**Variable**	**p**
Model 1	Gender	0.61
	Age	0.06
	BMI	0.83
Model 2	Pacing	0.25
	Taper	0.10
	Marathon experience	0.91
Model 3	Frequency of training	0.39
	Duration of training	0.72
	Distance in training	0.41
Model 4	Pre-race training	0.50
	Last long distance run	0.72
Model 5	Delta RPE	0.88
	Delta pain	0.97
Model 6	Flu symptoms	0.78
	Previous injury	0.49
	Sites of pain	0.23

3.3.12 Summary of results

Participants in the slow group were significantly younger, had faster 10 km PB times, and trained at a faster pace compared to participants in the accurate and fast groups. Participants in the slow group also had faster actual and predicted marathon times, compared to participants in the accurate and fast groups. There was a significant positive relationship between actual and predicted marathon times. There were no significant differences between groups in muscle pain and RPE during the race; however there were significant main effects of time for pain and RPE during the race. Muscle pain and RPE were significantly increased at 21 km, 30 km, and 42.2 km, compared to pre-race values. There were no significant differences in post-race pain between groups, but there was a significant main effect of time as muscle pain was significantly elevated for three days after the race. This study was also unable to identify any significant demographic, training and competition history, self-identified pacing strategy, or race factors (muscle pain and RPE) associated with the accuracy of prediction of marathon performance.

3.4 DISCUSSION

Endurance exercise performance is multi-factorial and complex [(1)(5)]. There is a lack of evidence for the role of teleoanticipation on endurance running performance. This study examined endurance running performance from the perspective of accuracy of prediction of performance. This approach allowed for the consideration of the effects of teleoanticipatory factors such as pacing and prior experience on performance. Linear increases in muscle pain and RPE were observed during the race in all groups. However, this study was unable to identify specific factors associated with the accuracy of prediction of running performance during a marathon race. The findings of this study will now be discussed in more detail. The discussion follows the order of the presentation of the results in Section 3.3.

3.4.1 Participants

3.4.1.1 Study sample

The total sample size of this study was 63 participants (Section 3.2.2.3, page 37). Previous studies of factors influencing the accuracy of prediction of endurance running performance had sample sizes of between 23 and 363 participants (2)(3(6)(7)(8)(9)(10)(11)(12)(13). Only three of these studies (7)(10)(11) compared different groups based on either experience or mileage per week. Most of these studies investigated the marathon distance. However, in terms of gender, some investigated only females (6)(10) or only males (2)(8)(9)(11) while only a few investigated both male and female runners (3)(7)(12)(13). All of the previous studies had a low level of evidence of between three and four (96). In addition, there is no uniform definition for an "accurate" marathon time across different studies. The studies defined the participants' "underestimating" or "closely approximating" their estimated times (7), saying that their predicted times were "better correlated" using the correlation coefficient (0.85) (82) or not indicating what an accurate time was at all (2). This allows for limited comparison of findings from different studies. Future studies should clearly define parameters for accuracy of prediction of running performance, particularly as this may be considered as an important indicator of teleoanticipatory factors influencing endurance running performance.

3.4.1.2 Descriptive characteristics

There were no significant differences in the body mass, stature and BMI between the participants in the accurate, slow and fast groups (Section 3.3.2, page 45). Participants in the slow group were significantly younger than participants in the accurate and fast groups. The literature focuses on associations between running experience and not age in relation to the accurate prediction of running performance. Experienced runners were seen to have a better ability to estimate their race time (2)(7)(8)(9)(10). No literature was found indicating that age is an important factor relating to running performance. In previous studies body mass, stature and BMI have not been indicated as the main predictive factors for endurance running performance, which is similar to the findings of this study.

3.4.2 Training characteristics

In this study, there were no significant differences in the 42.2 km PB times between groups. However, participants in the slow group had significantly faster 10 km PB times and marathon times, compared to participants in the accurate and fast groups (Section 3.3.4, page 47 and Section 3.3.5, page 48). McKelvie et al [2] found that marathon prediction time is strongly associated with fastest 10 km time, which suggests that speed may be associated with performance. Training pace was significantly faster in the slow group compared to the accurate and fast groups. This finding differs to the literature where training pace is seen as an important factor for prediction and performance [1][2][6]. The slow group did, however, have significantly faster marathon times than the fast and accurate groups which showed how the slow group, who trained at a high pace, performed better, despite not being accurate in their marathon prediction. Two studies on female marathoners [1][83] showed that the distance covered in training and training pace are important predictors of overall marathon performance.

In this study, there were no significant differences between groups in average training frequency, average training duration and average training distance before the marathon. In a previous study comparing top-class (runners having a PB of less than 131 min for males and 152 min for females for a marathon) and high-level (runners having a PB of less than 136 min for males and 158 min for females for a marathon) marathon runners, the high-level runners ran a greater mileage per week than the top-class runners who ran more than 200 $km.wk^{-1}$ [43]. This implies that at an elite level, distance covered per week may be related to performance. This previous study was based on elite runners, whereas participants in the current study were recreational marathon runners. A previous study of male runners showed that training more than 100 $km.wk^{-1}$ was a good predictor for marathon race time [11]. In this study there was a range of training distances of between 37.6 km and 52.3 $km.wk^{-1}$ three months preceding the marathon. This is low mileage compared to the two previous studies mentioned which described training distances of 200 $km.wk^{-1}$ and 100 $km.wk^{-1}$ respectively. High mileage covered in training positively impacts performance; this is further supported by a study of middle aged and older runners [81]. In a 100 km race, weekly training volume was seen as a good predictor for marathon time [8]. However, a study on the Glasgow marathon on first time marathon runners showed no relationship between average weekly mileage and performance linked to lack of experience [82].

There is no consensus in the literature regarding the ideal training distance covered per week. Previous studies describe first time marathon runners, male marathon runners and elite marathon runners mileage per week, as mentioned above [11][43][81]. These results are varied and are difficult to apply to this study which is based on recreational marathon runners. The type of training in these studies was not recorded. A very detailed training history description was not included in the questionnaire in this study. This may be a limitation to this study, however, the questionnaire needed to be completed quickly at race registration to ensure the recruitment of volunteers.

In contrast to the literature reviewed [(2)(7)(8)(9)(10)], this study did not show that experience influenced the accuracy of prediction of marathon times. This study showed no significant difference between groups for the number of marathons completed. One study supported that years as a runner rather than actual marathons completed predicted performance [(1)]. Other studies suggest that experience is an important factor for predicting marathon or half marathon times [(2)((6)(7)8)]. This is the second time that the Mandela Day marathon has been held and the route profile is very challenging (Section 3.2.3.5, page 40). Despite the participants' experience, this particular marathon may have been more difficult than they anticipated, which could have affected their performance.

3.4.3 Tapering

In this study there was no significance difference in tapering history between groups (Section 3.3.4, page 47). Current literature recommends two weeks [(45)] or between four and 28 days [(44)] as an optimal tapering period. Another study showed that a taper period of between 14 and 21 days showed effects of de-training [(18)]. Despite the inconsistencies regarding an optimal tapering period, there is overall consensus that a taper period has a significant positive effect on performance [(13)(18)(45)(46)(47)(48)]. Training volume and frequency need to be reduced in the taper period [(13)(46)(47)(48)]. In this study, changes in training volume and frequency during the taper period were not recorded. It is recognised that this may have limited the interpretation of the effects of tapering on the accuracy of prediction of marathon performance.

3.4.4 Marathon times

In this study, the slow group had significantly faster marathon times compared to the accurate and fast groups (Section 3.3.5, page 48). There was also a significant positive correlation between actual and predicted marathon race time. To our knowledge, this is the first study that has systematically examined performance during a marathon event based on the accuracy of prediction of performance. One earlier study [(95)] examined the accuracy of prediction of performance during an Ironman triathlon event. In the triathlon study, the main findings were that perception of effort and pain scores increased as the race progressed; improved performance was associated with less training; and that there were no differences in muscle pain between the accurate, fast or slow groups of triathletes after the race and up to seven weeks post-race.

3.4.5 Pain and RPE during the marathon

3.4.5.1 Pain

In this study, there were no significant differences in race pain between groups; however there was a significant main effect of time, with pain increasing as the race distance increased (Section 3.3.7.1, page 49). Although there are no previous studies for the effects of pain on the accuracy of prediction of performance, there is evidence that suggests that pain does affect exercise performance (17)(31). One of the main factors that exacerbate muscle damage are muscle lengthening exercises because they result in a higher load per fibre ratio (31). This follows with an acute loss of strength some days after the muscle lengthening exercises with a decreased ability to produce force which can take up to a week to recover (32)(33). There were no previous studies on the effects of pain during an endurance event on running performance.

Previous studies suggest that exercising for a long duration can lead to muscle damage (17), which results in pain. Similarly, another study found that muscle pain is the most important indicator of EIMD (31). However, the effects of EIMD on endurance running performance are unclear (52). Exercise-induced muscle damage results in decreased muscle power which leads to poor performance, and may also contribute to fatigue during prolonged exercise events (31). However, previous studies have focussed on post-exercise pain rather than pain during the endurance event. From this study, pain increased over the duration of the marathon and was not seen as a predictive variable for the accuracy of prediction of running performance. More research is needed to confirm the role of pain during exercise on endurance running performance.

3.4.5.2 Relative perception of effort

In this study, there were no significant differences in race RPE between groups; however there was a significant main effect of time, with RPE increasing as the race distance increased (Section 3.3.7.2, page 50). Current literature shows that RPE is set in a feed-forward mechanism at the start of the race and rises in a linear manner during the marathon so that it may be completed without causing bodily harm (69)(70). A study of 15 endurance-trained cyclists concluded that the RPE rises in a linear manner for the exercise duration but stops before the body is unable to cope (71). No studies were found regarding changes in RPE during a marathon race and the effects on running performance.

Perception of effort appears to be a regulator of exercise performance and increases in RPE may indicate how close to the end of exercise the athlete is at any time [(62)(69)(70)]. Perception of effort is seen as an important regulator in exercise performance. Athletes pace themselves according to their level of perceived exertion [(69)(52)]. Teleoanticipation may have an inherent ability to be refined by an individual's experience in completing fatiguing tasks. Teleoanticipation alters the motor recruitment patterns to regulate pace to match the planned activity and the resultant afferent input [(48)]. Practice and experience have been shown to improve RPE values as the athlete has shown the ability to increase in exercise intensity [(42)]. Internal clock and teleoanticipatory pacing are supported by the ability of athletes to reproduce identical pacing strategies with exercise of a similar known duration [(42)]. However, in this study there were no significant differences in RPE between groups. It is possible that the route profile, with a significant change in elevation from the start to the finish of the race, may have confounded potential teleoanticipatory pacing. More studies are needed to fully understand this phenomenon, and to determine if RPE may be related to the accuracy of prediction of endurance running performance.

3.4.6 Pacing strategy

Optimal pacing is determined by certain factors such as knowledge of the endpoint, duration of the event, internal clock using scalar timing, and memory of pacing strategy from previous events [(42)]. The pacing strategy begins at the start of exercise, comparing actual with expected fatigue [(38)(43)]. The central governor model proposes that the subconscious brain projects “finishing points”, thereby assisting the regulation of pacing strategy [(48)]. Previous literature supports an even pacing strategy for longer distances [(23)(69)]. However, these studies have predominantly examined pacing strategies over short distances. Lima-Silva et al [(86)] showed that 10 km runners who had a positive pacing strategy performed better than runners using even pacing strategies. In addition, an uneven pace was seen to result in a higher physiological demand for runners on a 30-minute self-paced treadmill run [(87)]. In this study, there were no differences between groups in predicted or actual self-identified pacing strategies (Section 3.3.8, page 50). There was also a strong relationship between predicted and actual marathon times. However, participants were asked about pacing strategies prior to the race, as they completed the medical and training questionnaire. It is possible participants who were unfamiliar with the route profile, which had a significant change in elevation from the start to the finish of the race, may have selected a different predicted pacing strategy if they had prior knowledge of the route. However, familiarity with the route profile was not assessed in this study.

3.4.7 Post-race pain and timing of the first run

In this study, there were no significant differences between the three groups regarding post-race pain; however there was a significant main effect of time (Section 3.3.9, page 51). Post-race pain was significantly elevated for three days after the marathon, but was almost minimal by day seven after the marathon. Previous studies have shown that DOMS may persist for as long as five to seven days after a marathon, even in highly trained individuals [(17)(56)]. There were also no significant differences between groups for timing of the first run after the race. On average, most participants ran for the first time on day four or five after the race. Although post-race pain was no longer significantly elevated, it is possible that runners may still have experienced reductions in muscle power or work capacity. This is supported by a study that monitored recovery of 10 male marathon runners who were allocated to either an active recovery group or a rest group. The rest group had recovered their work capacity after three days while the active recovery group were still impaired by day seven [(57)]. Further studies are needed to accurately determine the timing of recovery of muscle power and work capacity after a marathon.

3.4.8 Factors associated with the accuracy of prediction of performance

This study was also unable to identify any significant demographic, training and competition history, self-identified pacing strategy, or race factors (muscle pain and RPE) associated with the accuracy of prediction of marathon performance (Section 3.3.11, page 52). Previous studies have suggested that experience [(2)(7)(8)]; weekly training mileage [(1)(2)3)(8)(81)]; even or positive pacing strategy [(84)(85)(86)]; or training pace [(2)(6)(23)] are the best predictors for performance in endurance running events. However, these studies did not considered the teleoanticipatory role of the accuracy of prediction of endurance running performance. It is possible that the slow marathon times and the low relative exercise intensity in all groups may have limited the effects of muscle pain and RPE on self-regulated pacing and performance. Future studies should have more stringent inclusion criteria to ensure runners are competing at moderate to high relative exercise intensities. In addition, future studies should carefully consider route profiles to ensure that the race profile does not potentially confound the accuracy of prediction of performance by limiting actual marathon times. More research is needed to determine factors associated with the accurate prediction of marathon running performance.

3.4.9 Limitations of study

The main limitation of this study appears to be the dropout rate. Despite the familiarisation session at registration, participants may have been more committed if they were aware of the study a few weeks before the race. This was attempted with the SMS system but the SMS response was poor. However, there was a short time period between obtaining ethics approval, conducting the feasibility study and needing to recruit participants for the study which prevented earlier recruitment of potential participants. A possible strategy to improve this limitation could be to target running clubs or send out an email to participants ahead of race day. Participants' email addresses were unfortunately not available for this study. More research assistants were needed at the registration and at the finish of the race. This could have increased the number of participants and improved the compliance of participants who completed the race.

This was only the second year the Mandela Day marathon was held, which meant that participants were not necessarily familiar with this route. Further, the route profile had a steep elevation and it would have been difficult for runners to pace themselves accurately. The questionnaire could have asked if the participants had previously run the Mandela Day marathon. This information could have helped with understanding if familiarity of the route impacted on the participants' race prediction. In addition, other forms of exercise undertaken by participants were not recorded which may have influenced race performance.

All participants completing the marathon within the seven-hour cut-off were included in this study. This allowed for slow finishing times, compared to other marathons that normally have a five or five and a half hour cut-off time which meant that participants were running at low maximum efforts if finishing just before the cut-off time. The average marathon personal best times were over four hours for all groups. This implies that although there were experienced runners, the runners were perhaps slower and would not necessarily run the marathon at a high intensity, which was seen with the slow finishing times for the race. Similarly, all the BMIs were quite high for endurance runners, even though they were within the “normal” range, suggesting that the runners were not highly trained.

CHAPTER 4: SUMMARY AND CONCLUSION

The marathon may be considered as one of the most challenging forms of endurance competition [88]. As participation in the marathon distance is becoming more popular, runners want to know how to train and prepare for a marathon to maximise performance [82]. There are a number of physiological and training variables that influence running performance [8]. However, there is a lack of evidence for the role of teleoanticipation on endurance running performance. Previous studies did not consider the role of predicting performance outcomes before competition, and the potential influence of self-regulated pacing and prior experience on running performance [1][5][8][23][24]. The accuracy of prediction of running performance allows for the consideration of the effects of teleoanticipatory factors on performance. More research is needed to determine whether there are any relationships between the accuracy of prediction of performance, and other training- and competition-related factors that may influence performance outcomes**.** Therefore, the overall aim of this study was to determine potential factors associated with the accuracy of prediction of running performance during a marathon race. Based on the evidence provided in this dissertation, the study objectives as described in Section 1.2.2, page 2) may be answered as follows:

> *To determine whether there were differences in training history, pacing, muscle pain and the relative perception of effort (RPE) in three identified groups that accurately predicted race time, performed faster than the predicted time, or performed slower than the predicted time.*

Participants in the slow group were significantly younger, had faster 10 km PB times, and trained at a faster pace compared to participants in the accurate and fast groups. Participants in the slow group also had faster actual and predicted marathon times, compared to participants in the accurate and fast groups. There was a significant positive relationship between actual and predicted marathon times. There were no significant differences between groups in muscle pain and RPE during the race; however there were significant main effects of time for pain and RPE during the race. Muscle pain and RPE were significantly increased at 21 km, 30 km, and 42.2 km, compared to pre-race values. There were no significant differences in post-race pain between groups, but there was a significant main effect of time as muscle pain was significantly elevated for three days after the race.

> *To determine if demographic characteristics, training and competition history, self-identified pacing strategy, muscle pain and the relative perception of effort (RPE) were associated with the accuracy of predicting performance during the marathon.*

This study was unable to identify any significant demographic, training and competition history, self-identified pacing strategy; or race (muscle pain and RPE) factors associated with the accuracy of prediction of marathon performance.

It is possible that the slow marathon times and the low relative exercise intensity in all groups may have limited the effects of muscle pain and RPE on self-regulated pacing and performance. Future studies should have more stringent inclusion criteria to ensure runners are competing at moderate to high relative exercise intensities. In addition, future studies should carefully consider route profiles to ensure that the race profile does not potentially confound the accuracy of prediction of performance by limiting actual marathon times.

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APPENDIX I: RECRUITMENT ADVERTISEMENTS

SMS recruitment advertisement

Mandela Day marathon research study. I am studying my masters in sports physiotherapy examining factors that may influence the accuracy of prediction of time in a marathon performance. It should not affect your race performance. You will be informed about the results of the study and information on pacing and training strategies. Please contact Dawn at dawnnunes@gmail.com if you wish to take part.

Recruitment advertisement letter

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

Mandela Day marathon

Study on accurate prediction of marathon performance and the relationship to training history, muscle pain and relative perception of effort.

Study outline

The study aims to examine factors that may influence the accuracy of prediction of time in a marathon performance.

Testing includes:

- A familiarisation session before the race where you will be briefed regarding details of the study.
- A medical and training questionnaire (before the race).
- Muscle pain and perception of effort ratings during the race.
- Muscle pain recordings via email seven days post-race

Those interested in participating should be:

- Healthy male and female runners.
- Aged 20 to 60 years.
- Taking part in a marathon.

Benefits of participating in the study include:

- There is no remuneration for participating in this study.
- You will be provided with evidence-based information on pacing and training strategies specifically for running.

Deadline for applications: **August 2013**

If you are interested in taking part in the study and would like additional information, please contact:

Dawn Nunes
Telephone: 081 3475605
Email: dawnnunes@gmail.com

APPENDIX II: INFORMED CONSENT AND RACE INFORMATION

Dear Participant

I am a Physiotherapy student at the University of Cape Town and I will be conducting a study to find out what factors might contribute to the accuracy of prediction of your performance in the marathon. I will be looking at factors such as training and racing history, muscle pain, and the relative perception of effort (RPE) or how hard you feel that you are running. Information obtained in the study will enable me to complete my Masters degree in Sports Physiotherapy. The results of this study will contribute to current evidence regarding training history, muscle pain and RPE and how these variables relate to the accuracy of prediction of endurance running performance in a marathon race. This study has been given ethical approval by the University of Cape Town, Faculty of Health Sciences Human Research Ethics Committee (HREC REF 252/2013).

This study will be supervised by Dr Theresa Burgess, a senior lecturer in Physiotherapy at the University of Cape Town, and Professor Mike Lambert of the MRC/UCT Research Unit for Exercise Science and Sports Medicine. Please take time to read this form thoroughly before signing it. If you decide to take part in the study, we will ask you to do the following:

Before race day

You will be asked to attend a familiarisation session one week prior to the race lasting approximately an hour. This appointment will take place at a location that is convenient for you, such as your running club.

You will be asked to fill out a questionnaire regarding personal details, training and racing history, predicted times, tapering (the training you do in the weeks leading up to the race) and pacing (how you change your speed during the race) strategies and general medical history. The data collection procedure during the race will also be explained to you, and you will be given a copy of the muscle pain and RPE scales to become familiar with before the race.

During the race

You will be required to wear a laminated yellow band around your wrist or on the front of your shorts during the race. On this band you will record, using stickers, your muscle pain and RPE scores. You will also be asked to shout out your scores to researchers at 10, 21.1 and 30 kms during the race. You will be warned of upcoming data collection points. The researchers will also be easily identifiable on the day of the race as they will be wearing neon orange t-shirts. You will also be asked to score your muscle pain and RPE at the start and immediately after completing the race as well as a mini verbal questionnaire asking about illness or injury during the race.

After the race we will also ask you some questions about how you felt during the race, and whether you used anything (for example, medication or ice) during the race that could have changed how tired or sore you felt during the race.

The week after the race

You will be asked to rate your muscle pain daily for seven days after the marathon by completing a rating of pain scale.

All information recorded during this study will remain confidential, and you will not be identified by name in any potential publications that may arise from this research. Your email address will not be shared with anybody.

Potential Risks

There are no risks associated with any of the testing procedures in this study. However, on three occasions during the race you will be asked to rate your pain and RPE, which may affect your concentration momentarily. This is unlikely to have any major effect on your performance. There are inherent risks associated with taking part in the marathon race. In addition, safe participation in the marathon is a primary concern. It is recommended that you have a check-up with your general practitioner in the 10 days before the race. You will be excluded from the study if you report any flu-like symptoms 2 weeks prior to the race, and you will be referred to your doctor for further assessment. If you report any other injury or illness in the detailed medical history section of the study questionnaire you will be excluded from the study, and referred for further care.

Benefits

The study aims to establish whether the perceived effort, training history and muscle pain have an impact on your predicted time for the race. The data collected during this study may prove as a useful tool for athletes competing in future events to improve their performance. You will be informed of the results of the study and therefore will gain knowledge which will be of benefit to you regarding future performance in endurance events. You will also receive an information pamphlet regarding pacing and training strategies. Unfortunately you will not be financially compensated for your participation in this study.

Questions or Concerns

You are under no obligation to participate in this study and have the right to withdraw from the study at any time. If at any time you have any questions about the study, please feel free to contact me. You are assured that all enquiries will remain confidential.

Dawn Nunes

Telephone number: 081 3475605

E-mail: dawnnunes@gmail.com

Should you have any further queries, feel free to contact my supervisors:

Dr Theresa Burgess (021 406 6171; theresa.burgess@uct.ac.za)

Professor Mike Lambert (021 650 4558; mike.lambert@uct.ac.za)

If you have any questions or concerns regarding your rights as a research participant, please contact Professor Marc Blockman, Chairperson of the University of Cape Town, Faculty of Health Sciences Human Research Ethics Committee on 021 406 6338.

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

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

______________________	______________________	__________________
Signature of Volunteer	Name (Please Print)	Date
______________________	______________________	__________________
Signature of Investigator	Name (Please Print)	Date

APPENDIX III: MEDICAL AND TRAINING QUESTIONNAIRE

MEDICAL AND TRAINING QUESTIONNAIRE

2013 MANDELA DAY MARATHON

This questionnaire will take approximately 20 - 30 minutes to complete. The completion of the questionnaire is voluntary and all the information will be kept confidential. The information collected will only be used for research purposes.

Instructions

You can complete the questionnaire electronically using Microsoft Word, print the questionnaire and complete it manually or copies will be available at the familiarisation session to complete. Please answer each question by filling in the details in the allocated space or checking one or more of the option boxes.

If you complete the questionnaire and the informed consent form electronically using Microsoft Word, please e-mail the completed forms to dawnnunes@gmail.com.

If you complete the questionnaire and informed consent form manually, please bring the completed forms to the familiarisation session.

Please complete Sections A, B, C, D, E, F, G and H

Section A	Personal Details
Section B	Racing History
Section C	Pacing
Section D	Training history
Section E	Tapering History
Section F	Flexibility History
Section G	General Medical History

Please complete only the relevant questions in the following section:

Section H	Additional Detailed Medical History

Section A: Personal details			
2013 marathon race number			
Surname			
First name			
Postal address			
Postal code		Email address	
Age on race day		Phone (day time)	
Height	_________ cm	Cell phone	
Weight	_________ kg	Gender	Male ☐ Female ☐

Section B: Racing history				
What is your predicted time for the 2013 marathon?	____ hrs: ____ min			
Type of running event	**5km**	**10km**	**21.1km**	**42.2km**
In how many events have you participated in the past 12 months?				
Personal best time	____ hrs: ____ min	____ hrs: ____ min	____ hrs: ____ min	____ hrs: ____ min
Most recent time	____ hrs: ____ min	____ hrs: ____ min	____ hrs: ____ min	____ hrs: ____ min
How many marathon races have you participated in?				
How many days after the marathon would you go on your first training run?				

Section C: Pacing		
Pacing is a competitive strategy in which you change your speed during the race to achieve your performance goal		
Do you use a pacing strategy when you run marathons?	Yes ☐ No ☐	
If yes, please tick the most appropriate description of pacing that you use.	☐ Positive pacing (start fast and progressively slow down) ☐ Negative pacing (start slow and increase in speed) ☐ Even pacing (maintaining relatively the same pace during the race) ☐ Variable pacing (vary between increasing and decreasing throughout the race)	

Section D: Training history			
Please provide your training history in the table below for the specified periods			
Training period	**Training frequency (days/ week)**	**Training duration (hours/week)**	**Training distance (km/ week)**
14 – 11 weeks before marathon			
10 – 6 weeks before marathon			
5 weeks before marathon			
4 weeks before marathon			
3 weeks before marathon			
2 weeks before marathon			
1 week before marathon			

Section E: Tapering history	
Tapering is a period when you decrease your training load prior to your race	
Do you taper before the marathon?	Yes ☐ No ☐
If yes, how long is your tapering period?	_____ months _____ weeks _____ days
What was your training mileage (km's) in the 7-day period before the race?	
What was your average training pace in the 7-day period before the race?	______ min/ km
When did you do your last long slow distance run (> 20km)?	

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

Section G: General medical history	
In this section, you are asked to read through 6 questions about your personal general medical history. If you answer "yes" to any of questions 1, 4 and/or 5, please complete the additional questions at the end of the section (Section H).	
1. In the **6 weeks before this race** (from 21st April) did you suffer from any **symptoms of flu** (fever, sore throat, blocked or runny nose, cough, wheeze, muscle aches and pains)? If you answer "yes", please complete the additional questions in Section H.	Yes ☐ No ☐
2. Have you **ever** in your marathon career suffered from **muscle cramping** during or immediately (within 6 hours) after exercise (in training or competition)?	Yes ☐ No ☐
3. Have you **ever** in your marathon career suffered from **a tendon or ligament injury** (pain, swelling, stiffness) in any tendon (including Achilles tendon, knee tendons, and shoulder tendons) or ligaments (partial or complete tear)?	Yes ☐ No ☐
4. Have you **ever** in your marathon career **used medicines to treat injuries** in the week **before or during a race** – including anti-inflammatory drugs, cortisone (pills or injection) or pain killers? If you answer "yes", please complete the additional questions in Section H.	Yes ☐ No ☐
5. Do you **currently** suffer from any **symptoms of injury** in the muscles, tendons, bones, ligaments or joints? If you answer "yes", please complete the additional questions in Section H.	Yes ☐ No ☐
6. Please tick in which anatomical area you ever had **surgery** performed.	☐ Head ☐ Finger ☐ Neck ☐ Lower back ☐ Face ☐ Hip ☐ Front chest ☐ Thigh ☐ Back chest ☐ Knee ☐ Shoulder ☐ Lower leg ☐ Upper arm ☐ Achilles ☐ Elbow ☐ Ankle ☐ Forearm ☐ Foot ☐ Wrist ☐ Abdomen ☐ Other (Specify: ________________________________)

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

<u>If you have answered **YES** to questions 1, 4, or 5 of the General Medical History questionnaire (Section G) please complete the relevant additional questions that follow in Section H.</u>

Section H: Additional detailed medical history (Please complete all the sections to which you answered "Yes" in the personal general medical history)	
1. Flu symptoms in the last 6 weeks If you answered **YES** to **question 1** in section G, please complete the following two questions related to flu symptoms in the last 6 weeks.	
(1a) Please tick which of these flu symptoms you suffered from **<u>in the last 6 weeks</u>**.	☐ Fever ☐ Cough ☐ Joint pains ☐ Blocked nose ☐ Wheezing ☐ Runny nose ☐ Muscle aches ☐ Any other flu symptoms (Specify: ________________________________)
(1b) Please tick which of these flu symptoms you suffered from **<u>in the last 7 days</u>**.	☐ Fever ☐ Cough ☐ Joint pains ☐ Blocked nose ☐ Wheezing ☐ Runny nose ☐ Muscle aches ☐ Any other flu symptoms (Specify: ________________________________)

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

3. History of any current injury that you suffer from.

If you answered **YES** to **question 5** in section G, please complete the following questions (3a. to 3g.) related to each of your current injury/injuries (Space is provided for two injuries)

Injury 1	
(3a) Is this the first time that you have sustained this injury? If **NO**, when had you <u>originally</u> injured yourself?	Yes ☐ No ☐ Month: ______________ Year: _________
(3b) What was the approximate date when you first became aware of the injury?	Month: ______________ Year: _________
(3c) Please indicate which side of your body is injured. (if applicable)	☐ Right ☐ Left
(3d) Please indicate which anatomical area is currently injured	☐ Head ☐ Elbow ☐ Hamstring ☐ Neck ☐ Forearm ☐ Quadriceps ☐ Face ☐ Wrist ☐ Knee ☐ Front chest ☐ Finger ☐ Shin ☐ Back chest ☐ Lower back ☐ Achilles ☐ Shoulder ☐ Hip ☐ Ankle ☐ Upper arm ☐ Thigh ☐ Foot Other (Specify: ______________________________)
(3e) Please indicate the type of structure that was injured	☐ Muscle ☐ Ligament ☐ Tendon ☐ Joint ☐ Bone Other (Specify: ______________________________)
(3f) Please indicate the severity of the injury. Please only tick one box.	☐ I only experience symptoms after exercise - Grade 1 ☐ I experience symptoms during exercise, but it does not interfere with exercise - Grade 2. ☐ I experience symptoms during exercise that may interfere with my training/competition - Grade 3. ☐ I am so painful that I may not be able to train or compete - Grade 4.
(3g) Please indicate how your injury was treated to date. You can tick more than one box.	☐ Rest ☐ Tablets ☐ Stretches ☐ Physiotherapy ☐ Surgery ☐ Orthotics ☐ Cortisone injection ☐ Other injection ☐ Strengthening exercises ☐ Equipment change Other (Specify: ______________________________)

Injury 2	
(3a) Is this the first time that you have sustained this injury? If **NO**, when had you <u>originally</u> injured yourself?	Yes ☐ No ☐ Month: ______________ Year: _________
(3b) What was the approximate date when you first became aware of the injury?	Month: ______________ Year: _________
(3c) Please indicate which side of your body is injured. (if applicable)	Right ☐ ☐ Left
(3d) Please indicate which anatomical area is currently injured	☐ Head ☐ Elbow ☐ Hamstring ☐ Neck ☐ Forearm ☐ Quadriceps ☐ Face ☐ Wrist ☐ Knee ☐ Front chest ☐ Finger ☐ Shin ☐ Back chest ☐ Lower back ☐ Achilles ☐ Shoulder ☐ Hip ☐ Ankle ☐ Upper arm ☐ Thigh ☐ Foot Other (Specify: ______________________________)
(3e) Please indicate the type of structure that was injured	☐ Muscle ☐ Ligament ☐ Tendon ☐ Joint ☐ Bone Other (Specify: ______________________________)
(3f) Please indicate the severity of the injury. Please only tick one box.	☐ I only experience symptoms after exercise - Grade 1 ☐ I experience symptoms during exercise, but it does not interfere with exercise - Grade 2. ☐ I experience symptoms during exercise that may interfere with my training/competition - Grade 3. ☐ I am so painful that I may not be able to train or compete - Grade 4.
(3g) Please indicate how your injury was treated to date. You can tick more than one box.	☐ Rest ☐ Tablets ☐ Stretches ☐ Physiotherapy ☐ Surgery ☐ Orthotics ☐ Cortisone injection ☐ Other injection ☐ Strengthening exercises ☐ Equipment change Other (Specify: ______________________________)

APPENDIX IV: RACE PERFORMANCE DATA CAPTURING

Race bracelet with VAS and Borg scale

Race poster with VAS and Borg scale

APPENDIX V: POST-RACE COMPLIANCE QUESTIONNAIRE

<table>
<tr><td colspan="3">Participant's Number:</td></tr>
<tr><td>Were you injured during the race today that it affected your running performance?</td><td>Yes</td><td>No</td></tr>
<tr><td>Did you feel physically ill or nauseous that it impacted on your running performance?</td><td>Yes</td><td>No</td></tr>
<tr><td>Have you taken any medication during the race that you would not normally take?</td><td>Yes</td><td>No</td></tr>
<tr><td>If YES, what type of medication? Ring appropriate answer.</td><td colspan="2">Analgesics (panado)
Anti-inflammatories (ibuprofen)
Muscle relaxants</td></tr>
<tr><td>Did you use any type of recovery aid? Ring appropriate answer.</td><td colspan="2">Ice
Massage
Stretching
Creams (e.g. Deep Heat)
Physiotherapy</td></tr>
</table>

APPENDIX VI: ETHICS APPROVAL LETTER

UNIVERSITY OF CAPE TOWN

Faculty of Health Sciences
Faculty of Health Sciences Human Research Ethics Committee
Room E52-24 Groote Schuur Hospital Old Main Building
Observatory 7925
Telephone [021] 406 6338 • **Facsimile** [021] 406 6411
e-mail: sumayah.ariefdien@uct.ac.za
www.health.uct.ac.za/research/humanethics/forms

21 June 2013

HREC REF: 252/2013

Dr T Burgess
Physiotherapy
Health & Rehab
F-45
OMB

Dear Dr Burgess

PROJECT TITLE: ACCURACY OF PREDICTION OF ENDURANCE RUNNING PERFORMANCE: RELATIONSHIP TO TRAINING HISTORY, MUSCLE PAIN AND RELATIVE PERCEPTION OF EFFORT

Thank you for your letter dated 18 June 2013, addressing the issues raised by the Human Research Ethics Committee.

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

Approval is granted for one year till the 28 June 2014.

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.

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

Please quote the REC. REF in all your correspondence.

Yours sincerely

PROFESSOR M BLOCKMAN
CHAIRPERSON, HSF HUMAN ETHICS

Federal Wide Assurance Number: FWA00001637.
Institutional Review Board (IRB) number: IRB00001938

sAriefdien

APPENDIX VII: PARTICIPANT INFORMATION SHEET ON PACING AND TRAINING STRATEGIES

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

Dear participant

Thank you so much for taking the time to be part of my study. Your assistance was invaluable and contributed significantly to our understanding of factors influencing running performance during a marathon. The information in this letter is based on the literature which I reviewed on marathon pacing and training strategies. You will also find the results of my study on the Mandela Day marathon.

If you have any questions or would like more information related to my study, please contact me. Thank you once again for your willingness to be part of my study.

Kind regards

Dawn Nunes

dawnnunes@gmail.com

081 3475605

REVIEW OF LITERATURE

Pacing strategies

The literature suggests a more “even” pace, how fast you run, for long distances. An “even” pace can be described as maintaining relatively the same pace during the race. Experience improves pacing to be more consistent. Your body anticipates the duration of the exercise and then alters your pace accordingly. This change in pacing is improved through experience. The important factor is to train specifically for the race that you are running to improve your pacing strategy. For example, if your race is mainly uphill, then hill training will be an important part of your training. The more you have practised, the more refined your pacing will become.

Training strategies

Weekly training distance, especially two to three months before the race, is an important factor contributing to performance. The studies I reviewed varied in the best distance recommended and this was mainly because they compared elite, novice and recreational runners. One study on elite athletes suggested more than 200 km per week was run by top – class athletes. Another study suggested more than 100 km per week. Also, training pace is important for improving performance. Additionally, the type of training should include both high and low training intensities for optimal performance.

Tapering (the period before the race where you reduce the amount of training load over a period of time) is an important part of training. The literature does not agree on an exact tapering period, however it seems between four days and two weeks is the optimal period with the most benefits. Most studies agree that a reduction in training load is important, between 50% to 70%, while maintaining training intensity (how hard you run) and frequency (how often you run).

Summary

- An “even” pace is the best for long distance running
- Experience improves pacing strategy
- Train specifically for the running event
- Weekly training distance is important
- Include both high and low intensity in your training
- Taper before you race; between four days and two weeks
- Reduce your training load in your taper period, but maintain your training intensity

TRAINING PROGRAM

Here is an example of a basic training program for marathon runners. All entries are for running time in minutes. This may be used as a guideline for your training. More detailed training programs specifically to train for faster marathon times are available in Noakes's “Lore of Running” book.

Tim Noakes's 26-week training program for marathon runners						
Day	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	
1	30	-	-	-	-	
2	-	25	35	20	40	
3	30	40	30	-	20	
4	-	-	-	35	-	
5	35	30	30	-	45	
6	25	25	25	20	20	
7	40	30	50	40	60	
	Week 6	**Week 7**	**Week 8**	**Week 9**	**Week 10**	
1	-	-	-	-	-	
2	40	30	40	50	30	
3	20	50	50	40	55	
4	-	-	-	-	30	
5	50	50	50	60	55	
6	20	20	20	20	-	
7	50	70	60	80	70	
	Week 11	**Week 12**	**Week 13**	**Week 14**	**Week 15**	**Week 16**
1	-	-	-	-	-	-
2	60	65	60	70	70	70
3	35	40	30	40	30	40
4	60	30	50	60	60	70
5	40	40	35	40	35	30
6	-	-	-	-	-	-
7	90	80	100	90	110	100
	Week 17	**Week 18**	**Week 19**	**Week 20**	**Week 21**	
1	-	-	-	-	-	
2	70	85	80	80	85	
3	35	40	45	40	35	
4	70	75	70	75	75	
5	35	40	40	25	20	
6	-	-	-	20	20	
7	120	110	130	120	140	
	Week 22	**Week 23**	**Week 24**	**Week 25**	**Week 26**	
1	40	40	-	40	40	
2	80	90	90	-	20	
3	40	40	40	40	10	
4	40	90	90	-	-	
5	35	40	40	30	-	
6	-	-	-	60	-	
7	130	150	60	20	Race	

Training program from Tim Noakes's book “Lore of Running”.

RESULTS FROM THE MANDELA DAY MARATHON

Accuracy of prediction of endurance running performance: relationship to training history, muscle pain and relative perception of effort

All participants (63) were divided into three groups depending on their accuracy of predicting their marathon time: accurate (16), slow (26) and fast (21) groups. The slow group had significantly faster training pace, 10 km personal best times and average marathon times compared with the accurate and fast groups. All groups felt pain and perception of effort (how hard they felt they were running) at a similar rate during the race. This meant that it did not matter whether they ran fast or slow, everyone experienced similar pain and effort at a similar time which increased as the race progressed. Similarly, for post-race pain, all groups experienced pain at a similar level and the pain decreased at a similar rate. There were no significant factors in this study that were found to accurately predict performance in a marathon.

Descriptive characteristics

The descriptive characteristics are shown in Table 1. The $p < 0.05$ value means that there was a significant difference found between the groups for that variable. The mean is the average for the group and the standard deviation is the range above and below the mean.

Table 1: Descriptive characteristics for accurate (n = 16), fast groups (n = 21) and slow (n = 25) . Data are expressed as mean ± standard deviation (SD).

Variables	Accurate (n = 16)	Fast (n = 21)	Slow (n = 25)	p
Age (years)	48.5 ± 5.9 (n = 16)	48.5 ± 9.2 (n = 21)	42.3 ± 9.2 (n = 25)	0.02*
Body mass (kg)	66.6 ± 11.3 (n = 14)	69.6 ± 13.9 (n = 20)	69.9 ± 9.2 (n = 22)	0.68
Stature (m)	169.1 ± 13.2 (n = 11)	169.2 ± 8.8 (n = 20)	170.9 ± 8.0 (n = 20)	0.82
Body mass index ($kg.m^{-2}$)	23.2 ± 2.8 (n = 11)	24.1 ± 3.1 (n = 20)	24.2 ± 1.9 (n = 20)	0.56

** p < 0.05*

Training characteristics

The training characteristics are shown in Table 2. The p < 0.01 value means that there was a significant difference found between the groups for that variable.

Table 2: Training characteristics for accurate (n = 16), fast (n = 21) and slow groups (n = 26). Data are expressed as mean ± standard deviation (SD).

	Accurate (n = 16)	**Fast (n = 21)**	**Slow (n = 26)**	**p**
10 km PB (min)	53.7 ± 7.7 (n = 7)	60.7 ± 5.2 (n = 10)	43.4 ± 10.1 (n = 12)	0.0002**
42.2 km PB (min)	269.7 ± 28.3 (n = 11)	273.9 ± 52.3 (n = 19)	252.1 ± 56.7 (n = 20)	0.37
Number of marathon races completed	21.8 ± 23.5 (n = 16)	19.2 ± 34.3 (n = 21)	10.4 ± 10.8 (n = 26)	0.26
Training pace ($m.s^{-1}$)	2.6 ± 0.28 (n = 11)	2.5 ± 0.3 (n = 18)	3.1 ± 0.5 (n = 14)	0.0003**
Training mileage 7 days before marathon (km)	29.4 ± 32.3 (n = 12)	31.3 ± 29.1 (n = 20)	19.6 ± 15.5 (n = 18)	0.36
Average training frequency ($days.week^{-1}$)	3.7 ± 1.5 (n = 15)	3.5 ± 1.4 (n = 19)	4 ± 1.1 (n = 25)	0.44
Average training duration ($min.week^{-1}$)	271.7 ± 183.7 (n = 15)	281.6 ± 141.1 (n = 19)	294.3 ± 136.7 (n = 26)	0.89
Average training distance ($km.week^{-1}$)	37.6 ± 24.2 (n = 16)	45.8 ± 19.6 (n = 20)	52.3 ± 30.7 (n = 26)	0.21
Taper length (days)	10.0 ± 4.5 (n = 6)	9.2 ± 4.7 (n = 12)	10.4 ± 4.7 (n = 17)	0.78

*** p < 0.01*

Pacing strategies

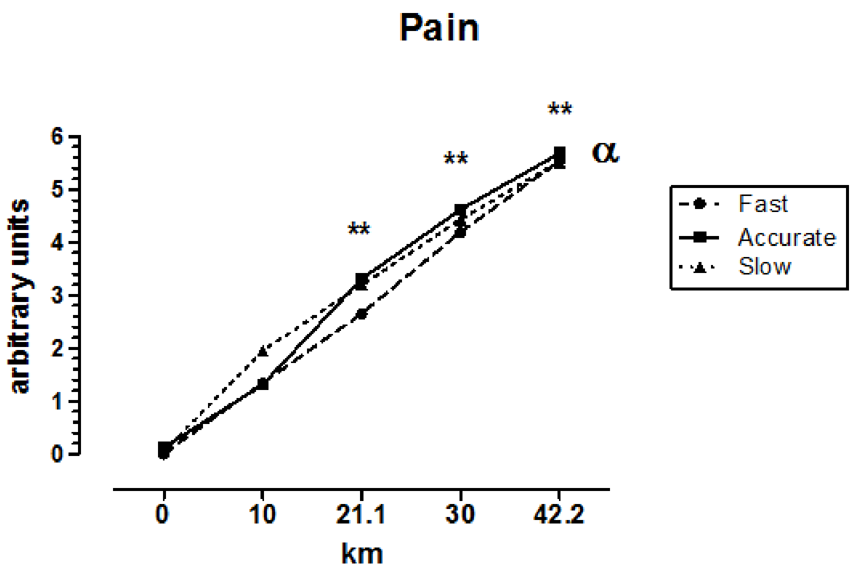
The pacing strategies are shown in Table 3. This table shows the number (and percentages) of participants who predicted their pacing strategy and their actual pacing strategy for the race.

Table 3: Pacing strategy for accurate (n = 9), fast (n = 15) and slow (n = 18) groups. Data are expressed as numbers (n).

Pacing strategy	**Accurate n**		**Fast n**		**Slow n**	
	Predicted	Actual	Predicted	Actual	Predicted	Actual
Positive	1	3	1	8	4	10
Negative	3	2	2	4	6	1
Even	3	4	9	3	4	7
Variable	2	0	3	0	4	0

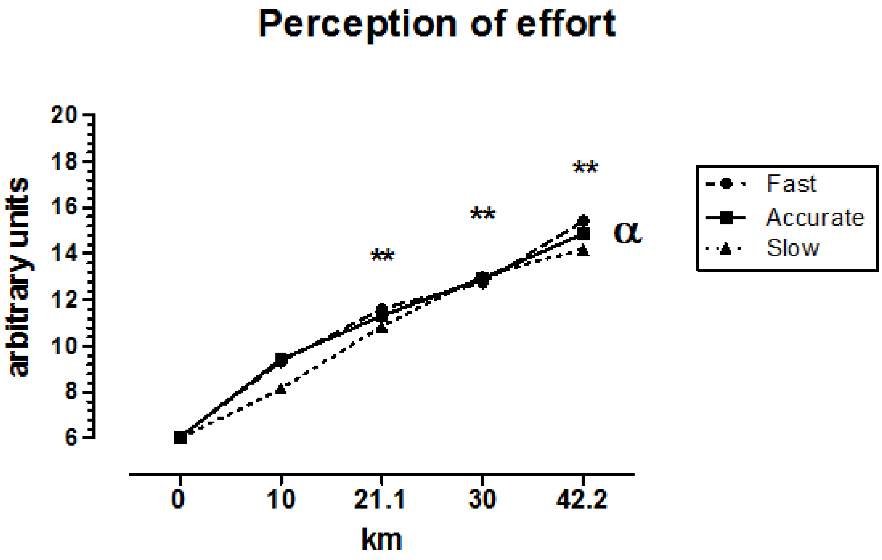
Pain during the marathon

The figure for pain during the marathon for all groups is shown below. From this study, pain increased over the duration of the marathon and was not seen as a predictive variable for performance. Interestingly, all groups experienced pain similarly despite their pace or duration of the race.



Perception of effort

The figure for the perception of effort for all groups is shown below. This figure shows how the relative perception of effort increased similarly for all groups as time progressed in the marathon.



Post-race pain

The figure for post-race pain for all groups is shown below. This study showed participants' pain being almost minimal by day seven after the marathon. In this study there was a lack of differences between groups suggesting that there was no perceived difference in the relative intensity of exercise.