THE IMPACT OF LOAD CARRIAGE ON THE BIOMECHANICAL AND PHYSIOLOGICAL RESPONSES TO SHOD AND UNSHOD RUNNING

BY

DAVID GOBLE

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Department of Human Kinetics and Ergonomics

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ABSTRACT

Repetitive strain injuries among frequent runners have resulted in many athletes seeking medical and orthopedic attention. The main reason for the high injury rate is the highly repetitive and abrupt loading that occurs at stance phase of the running gait. Researchers have therefore recently set out to investigate the shod versus unshod relationship and possible benefits of each, with the majority of the literature focused on differences between electromyography, oxygen consumption and kinematic variables. Findings indicate that unshod running presents a variety of performance benefits, namely; a reduced heart rate, a decreased rate of oxygen consumption as well as lower rates of energy expenditure. These differences have been attributed to alterations in the foot kinematics during stance phase of running, including; foot strike patterns, stride length and stride frequency.

With an increasing prevalence of adventure sports (canoeing and cone portaging) and a limited amount of literature conducted in the area of loaded running, it would be of particular interest to study this relationship (shod versus unshod) and how it is affected by load. The purpose of this study was therefore to investigate the impact of load carriage on the biomechanical, physiological and perceptual responses to shod and unshod running. There were four experimental conditions (two shod and two unshod) each lasting for a total of six minutes. 12 trained Rhodes University runners with an average age of 22 (±1.53) yrs comprised the sample. The experimental conditions required participants to run on a motorized treadmill at a speed of $10km.h^{-1}$, while the loaded conditions utilised a load of 10kg. During experimentation biomechanical, physiological and psychophysical responses were collected. Significant differences were observed in all dependant variables when comparing loaded and unloaded running, with the loaded conditions eliciting higher responses. However, the comparison of shod and unshod running produced significant differences in only the biomechanical variables (stride length and stride frequency). Physiological and perceptual responses were reduced when unshod, indicating the performance benefits of barefoot running. Unshod running proved to be affected to a greater degree by the application of load; therefore, it is recommended that future research employ a greater number of

participants at a variety of speeds, loads and gradients to ascertain whether unshod running continually produces lower responses.

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CHAPTER I
INTRODUCTION

BACKGROUND TO THE STUDY

Running has become increasingly popular over the last 100 years with more and more people running for a variety of reasons, including - sport, recreational activity and health promotion. The health and lifestyle benefits that accompany running have lead to more individuals competing in half and full marathons. However, due to the highly repetitive nature of running and the abrupt lower limb loading, the extent to which running related injuries occur in frequent runners, has lead to many athletes seeking medical and orthopaedic attention. Many of these repetitive stress injuries are sustained in the surrounding muscles, ligaments and tendons that are used in running. Warburton (2001), states that, compared to shod running, running barefoot minimises the risk of associated lower leg and ankle injuries. It is believed that by shifting the way in which the foot comes into contact with the ground, many of the biomechanical and physiological responses of running can be altered (Lieberman *et al.,* 2010).

For this reason much research has focused on the design of various shoes, sole types and compositions. Furthermore, the last decade has given rise to literature that has concentrated specifically on the differences between shod and unshod running, with several researchers proclaiming barefoot running to be more beneficial to the runner than that of shod running (Divert *et al.,* 2005; Divert, *et al.,* 2008; Squadrone and Gallozzi, 2009; Lieberman *et al.,* 2010).

The reasoning behind this theory relates to the biomechanics of the foot and lower limb during the stance phase of running gait. It has been suggested that the manner in which the foot strikes the ground is an imperative mechanism in the ground reaction force at initial contact – thereby affecting the energetics of running as well as the forces placed on the foot and lower limb (Lieberman *et al.,* 2010). Literature indicates that adopting a fore-foot strike (FFS) during running results in a significantly reduced impact transient in comparison to that of a rear-foot strike (RFS) (Lieberman *et al.,* 2010). Barefoot running has been shown to be less costly in terms of oxygen consumption and energy expenditure and hence more beneficial to the runner, resulting in improved running economy. Consequently, most studies have focused on differences such as VO_2, electromyographic (EMG) activity, running kinematics and the effect of shoe mass on the energy costs of running (De Wit *et al.,* 2000; Divert *et al.,* 2005; Divert *et al.,* 2008).

With adventure sports becoming more popular, athletes are now required to run whilst carrying loads. These sports often call for load carriage in the form of backpacks, canoes and bicycles – although only at certain stages of the race. With a limited amount of literature regarding load carriage whilst running, it is necessary to use literature regarding the impact of load on the biomechanical and physiological responses during walking. The application of a load at various walking speeds has shown to affect both the biomechanics as well as the physiology of walking. Studies indicate that the application of a load results in alterations in kinematic variables (increases in ground reaction forces at initial contact, increases in stride frequency and decreases stride length) as well as increases in physiological responses (heart rate and oxygen consumption). Similarly, as the speed of walking increases the degrees to which these alterations take place become larger (Abe *et al.,* 2004; Coombes and Kingswell, 2005; Abe *et al.,* 2008).

Therefore considering the literature on shod versus unshod running, and the limited literature on load carriage during running it would therefore be of particular interest to study this relationship (shod versus unshod) and how it is affected by load. The current study aims to gain insight into the relationship between shod and unshod running and, in addition, looks to determine the impact of load on the biomechanical and physiological responses during a shod and unshod running protocol.

STATEMENT OF THE PROBLEM

Given the higher speeds employed in running and the added combination of load, the effect on the shod versus unshod relationship is unknown. It is however anticipated that this combination will result in alterations in the biomechanical responses which in turn will affect the physiological and perceptual responses.

The purpose of this thesis is therefore to investigate the biomechanical, physiological and psychophysical responses of shod versus unshod running. Further aims include: obtaining an understanding on the effect of load carriage during running - an area of research that has received little to no attention in previous literature – as well as the effect of load on the shod versus unshod relationship. In order to achieve this, a number of variables affected by the selected running style will be the focus of this study. These include: gait alterations (foot strike patterns, stride frequency and stride length), heart rate, oxygen consumption, energy expenditure, and - more importantly - the effects of load upon these variables.

RESEARCH HYPOTHESES

The research hypothesis proposed is that a difference between shod and unshod running will be present as the kinematics at stance phase will be altered by the foot condition and, as a result, this will affect the physiological and psychophysical responses. It is hypothesized that the unshod condition will be affected to a lesser extent than the shod condition. Furthermore, it is proposed that the biomechanical, physiological and psychophysical responses to shod and unshod running will be affected by the application of a load to the running protocol. The additional mass will place the participants under greater biomechanical and physiological stress compared to the unloaded conditions; this in turn will result in a greater perception of exertion. Therefore it is hypothesized that the responses obtained from the loaded condition will be more exaggerated than those obtained from the unloaded conditions.

STATISTICAL HYPOTHESES

The statistical hypotheses proposed are that the results obtained from the shod and unshod condition will be significantly different from each other. In addition, the results obtained from the loaded conditions will be significantly different from those of the unloaded conditions.

Hypothesis 1: The biomechanical, physiological and psychophysical responses are equal for both shod and unshod conditions.

Ho: $\mu pS = \mu pUS$

Ha: $\mu pS \neq \mu pUS$

Where: p = Biomechanical, physiological and psychophysical responses; S = Shod; US = Unshod

Hypothesis 2: The biomechanical, physiological and psychophysical responses will not be affected by the application of a load and will therefore be equal.

Ho: $\mu pL = \mu pUL$

Ha: $\mu pL \neq \mu pUL$

Where: p = Biomechanical, physiological and psychophysical responses; L = Loaded; UL = unloaded.

DELIMITATIONS

This specific research sample was delimited to 12 healthy, active, male Rhodes University students, who were all well trained in road running and ran a minimum of 20km per week. This was done to ensure a group of trained athletes were employed in the study, thus reducing the variability between participants and increasing the validity of the results obtained through the experimentation process. In addition, it was ensured that no participants at the time of study had any form of running related injury that may have affected the results.

The age range of the selected sample was delimited to ages between 20-26; however the sample was not delimited for stature or mass. By ensuring sufficient testing time to reach a level of steady state, the results obtained will be more valid and hence reliable. Shoe mass of the shod condition was delimited to a mass between 0.5 and 0.8kg. This was done to limit the effect of shoe mass on biomechanical and physiological responses. Moreover, the shoe type employed to mimic barefoot running was delimited to the Vibram FiveFingers KSO model (a barefoot technology which mimics barefoot running and lacks arch support and cushioning). The controlled running speed, load and load position ensured that each individual who was tested was subjected to similar stress and hence differences that presented themselves could be attributed to variations in experimental conditions.

Participants were required to attend a habituation session to gain an understanding and familiarisation of the testing apparatus and protocol employed in the study. In an attempt to reduce order and learning effects a permutation table was constructed which ensured the order of testing was randomised. The testing conditions and procedures were standardised for each subject, contributing to the reliability of the study. Lastly, experimentation occurred under controlled laboratory conditions throughout the day, negating the effect of ambient factors such as temperature. In this environment, it was possible to standardise methodological factors.

LIMITATIONS

Meticulous efforts were required to reduce the likelihood of extraneous variables, and therefore to control as many as possible; however it must be noted that it is often impossible to completely control all impinging influences. Therefore, when analysing the data the following limitations had to be considered.

The experimental protocol and design were limited by the following factors; the small sample size – which suited the nature of this specific study - may have limited the relevance of the data found. This combined with the limited age range of the participants may make the sample selected not fully representative of the running population. What is more, the fact that only male participants were used in this study may, also limit the relevance of these data. In addition, the short habituation session that was provided may contribute as a limitation to the present study. If a greater period for habituation was allowed, the differences obtained between shod and unshod running may have been more marked; due to time limitations this was not possible. A further limiting factor may have been the environmental conditions within the laboratory setting. Laboratory conditions may not have been fully representative of the running environment, given that the laboratory was cooler than the outside temperature. The fact that the surface was controlled - through the use of a treadmill - may have limited the data obtained. This can be said as the surface type in outdoor running would be much more uneven and may require greater energy expenditure in order to stabilize the joints and muscles involved at the level of the foot and ankle. A further limitation to this study was shoe size. Limited funding only allowed for shoe sizes ranging from 9-11 (UK sizing) to be purchased; as a result, only participants within this size range could be tested. Shoe mass should also be noted as a limitation, as the mass of the shoe has been shown to effect physiological variables (Divert *et al*., 2008).

CHAPTER II
REVIEW OF RELATED LITERATURE

INTRODUCTION

The recent interest in the shod and unshod relationship has resulted in a handful of papers being composed and published. Most of this literature has focused on the biomechanical and physiological alterations between shod and unshod. The recent literature has presented arguments that tend to favor unshod running over that of shod running. These arguments have been justified with the aid of physiological data; reports indicate that unshod running results in a decrease in the cost of running, reductions in oxygen consumption as well as a reduced heart rate (Squadrone and Gallozzi, 2009; Lieberman *et al.,* 2010). It has been contended that the decreased physiological responses that accompany unshod running are a result of altered foot kinematics at the initial contact of stance phase.

This paper serves to further investigate the relationship between shod and unshod running. It further intends to investigate the relationship between load carriage and running as well as the effects of load on this previously established relationship. As a result the literature referred to is centered on the recent findings regarding shod and unshod running. Furthermore, given the limited amount of literature regarding load carriage during running, a reliance on literature concerning load carriage during walking was required.

BIOMECHANICS OF RUNNING

Gait Cycle

According to Novacheck (1998), the gait cycle (GC) is the basic measurement with regards to gait analysis. It should be noted that the GC for walking differs to that of running. One GC is defined as the period of time from initial contact (IC) of one foot to the IC of the same foot again (Perry, 1992). The GC of walking can be broken down into two phases, that of stance and swing. In stance phase, both feet are in contact with the ground. The swing phase is characterised by the beginning of toe-off and ends at IC of the foot (Perry, 1992). The stance phase of walking comprises 60% of one GC, where two periods of double support (DS) – when both feet are on the ground – are present, one at the beginning and end of stance. Conversely, in the running GC, there is no period when both the feet are in contact with the ground (Novacheck, 1998). Rather DS is replaced by two periods known as float, where the feet are completely airborne, one period occurring before swing and the other after swing. It should be noted that the amount of time spent in stance decreases as the speed of running increases, thereby increasing the time spent in double float (Novacheck, 1998).

Models of locomotion

Walking involves the theory of the inverted pendulum, whereby the centre of mass (COM) is vaulted over an extended stationary foot (Bramble and Lieberman, 2004). This results in a change in vertical displacement, hence resulting in an increase in potential energy. This energy is then converted back to kinetic energy as the body falls to the ground. Therefore, walking involves a reciprocal exchange of potential and kinetic energy which is out of phase in every step (Bramble and Lieberman 2004).

Running, on the other hand employs the mechanical mass-spring system that exchanges potential and kinetic energy very differently (Carrier, 1984). This mass-spring mechanism makes use of collagen-rich tendons and ligaments in the legs (springs), which store elastic-strain energy during the initial breaking part of the cycle. Therefore, as the foot comes into contact with the ground, joint motion at the ankle, knee and hip lowers the body's COM, representing absorption of energy and compression of the spring (Bishop *et al.,* 2006). The energy is then released by a recoil mechanism in the consecutive propulsive phase of running (Bramble and Lieberman 2004; Bishop *et al.,* 2006). Running therefore uses these springs in order to conserve what little energy can be preserved in this system. In order to use these springs effectively, the legs flex more during running compared to that of walking. Where exchanges in potential and kinetic energy during walking are out of phase, the exchange of these energies in running is in phase. Furthermore Novacheck (1998), states that as a result of the exchange of potential and kinetic energy in running being in phase, running efficiency is maintained in two ways. Firstly, it is maintained through the storage of elastic potential energy by the stretch of elastic tissues. Secondly, running efficiency is maintained by transfer of energy from one body segment to another through the use of biarticular muscles.

Shod vs. unshod running

There is much controversy in respect to which running style is more beneficial to the athlete, shod or unshod. On the one hand running with shoes has been presented as having many advantages – rear foot control, cushioning, shock distribution as well as heel stabilization (Divert *et al.,* 2008). On the other hand, a variety of researchers state that barefoot running results in a decreased prevalence of injury (Warburton, 2001; Lieberman *et al.,* 2010) as well as decreased energy costs (Warburton, 2001; Divert *et al.,* 2005; Divert, *et al.,* 2008; Squadrone and Gallozzi, 2009). Reasons why such differences have been found have been explained by the varying effects that the running shoe has on running gait and the mechanical characteristics of the foot and lower limb (Divert *et al.,* 2005; Divert, *et al.,* 2008). These differences present themselves through; variations in foot strike patterns, kinematic changes as well as biomechanical alterations.

FOOT STRIKE PATTERNS

A foot strike pattern refers to the way in which the foot comes into contact with the striking surface. The three main foot striking patterns as identified by Lieberman *et al.* (2010) are rear-foot strike (RFS), mid-foot strike (MFS) and fore-foot strike (FFS). A RFS is identified as landing on the rear third of the foot (i.e. the heel), a MFS as landing simultaneously on the heel and ball of the foot and a FFS as landing on the front third of the foot (ball of the foot). Novacheck (1998) proposed that approximately 75 - 80% of shod endurance runners tend to RFS with the remaining percentage landing in that of a MFS or FFS. Furthermore, Novacheck contends that as an individual’s running orientation changes from jogging to sprinting, so the foot striking pattern at initial contact also changes, with sprinters adopting a complete FFS. This notion was confirmed by Keller *et al.* (1996), finding that 86% of participants adopted a FFS at speeds above 6 $m.s^{-1}$ (21.5 $km.h^{-1}$). Lieberman *et al.* (2010) further states that habitually shod runners (individuals who grew up using shoes) predominantly RFS during shod running as well as when barefoot running; however, when running barefoot, the foot strike is altered to that of a flatter foot placement by dorsiflexing the ankle 7-10^0 less. In contrast, habitually barefoot runners tend to adopt a FFS during both shod and unshod running.

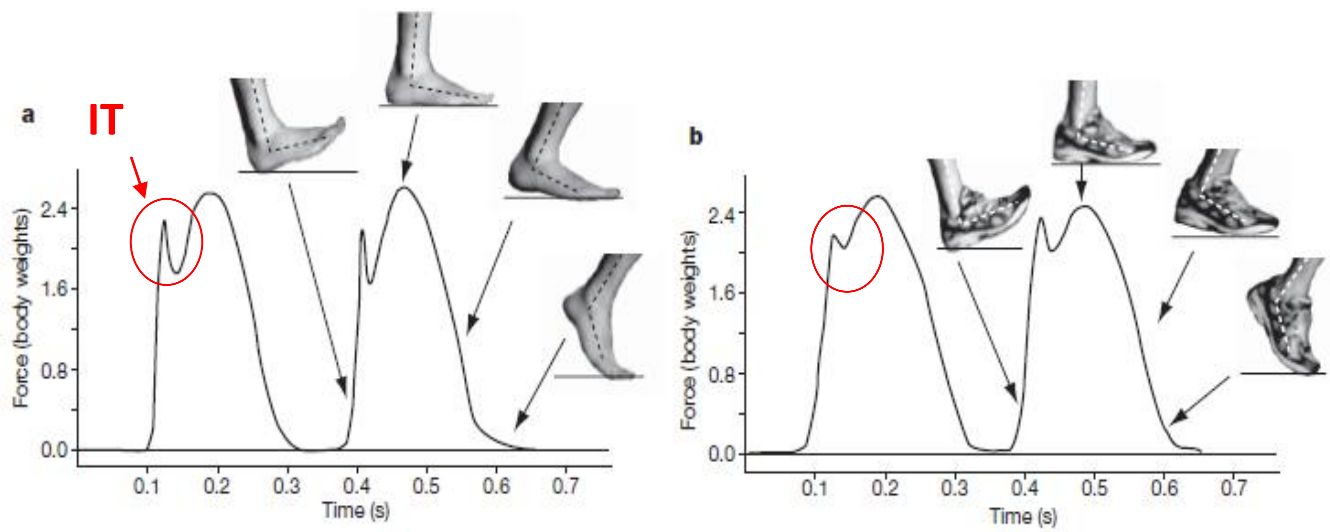
In a study conducted by Bishop *et al.* (2006), leg stiffness and running kinematics were evaluated in both shod and unshod running conditions. It was found that the running shoe altered the way in which the foot strikes the ground. The study indicated that shod running induces more dorsiflexion at the ankle compared to that of unshod running, resulting in that of a RFS. In contrast barefoot runners from this study landed with the foot in a more plantar flexed position adopting that of a MFS or FFS.

KINETIC VARIABLES

GROUND REACTION FORCES

There are a number of ground reaction forces (GRF) that the foot, lower limb and body are subjected to whilst running. At initial contact the foot is loaded abruptly and is simultaneously subjected to anteroposterior, mediolateral and vertical force components (Cavanga and Lafortune, 1980). The vertical GRF has been of most interest in past studies, and is dependent on a variety of external factors – namely - the subject’s body mass, loading rate, running speed, running style, area of foot in contact with the ground as well as the mechanical properties of the foot, shoe and running surface involved (Keller *et al.,* 1996).

The impact transient (IT) – a component of the vertical GRF - is the initial force acting on the foot and lower limb during the loading response of the running gait cycle. A variety of researchers (Novacheck, 1998; Squadrone and Gallozzi, 2009; Lieberman *et al*., 2010) state that a RFS results in a higher impact transient (1.5 – 3 times body weight in the first 50 milliseconds) in comparison to that of a FFS or MFS. A result of the greater impact transient is a larger ground reaction force – in terms of rate of loading and magnitude - being placed on the foot and lower limbs, with forces travelling up from the foot to the limbs. A reason for the decreased impact transient during FFS running is primarily due to a more plantar flexed foot with increased ankle compliance during landing, decreasing the effective mass of the body as it collides with the ground (Lieberman *et al.,* 2010). It must however be stated that the impact of barefoot running is dependent on a number of factors, the main factor being the way in which the foot strikes the ground. What this implies is that a barefoot runner who strikes the ground with a RFS is at far more risk of developing a repetitive strain injury in comparison to a

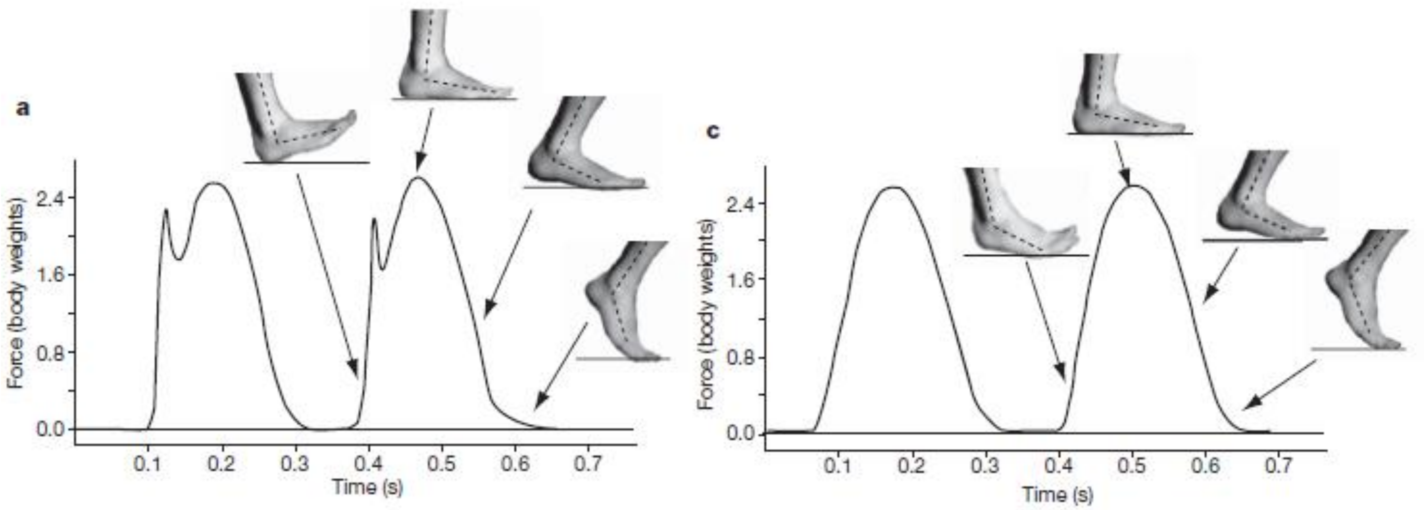


shod RFS runner (**Figure 1**).

Figure 1: Comparison of a RFS between unshod and shod running from the same individual. a) indicating that a RFS in an unshod condition results in the greatest IT.

(Adapted from Lieberman *et al.,* 2010)

In contrast, a barefoot runner striking the ground with a FFS is at lesser risk of injury compared to a shod RFS runner. Lieberman *et al*. (2010), found that the highest impact transient was elicited in barefoot runners who RFS in comparison to shod runners who RFS. This finding is largely contributed to the shock absorbing nature of the modern day running shoe, which slows the transient's rate of loading and therefore lowers the magnitude of force. It was further noticed that when running barefoot, the impact transient was almost completely reduced when adopting a FFS, with the magnitude of force being approximately three times lower than runners who RFS shod or unshod (**Figure 2**). A further finding was that the average rate of impact loading was similar between barefoot FFS and shod RFS runners, 64.6 (±70.1) and 69.7 (±28.7) body weights per second respectively. However these results were seven times lower when compared to the results obtained for the unshod RFS runners, 463.1 (±141.0) body



weights per second (Lieberman *et al*., 2010).

Figure 2: Comparison of a RFS and a FFS in an unshod condition from the same individual. a) confirms that a RFS when unshod or shod (Figure 1b) results in a significantly larger IT in comparison to an unshod FFS.

(Adapted from Lieberman *et al.,* 2010)

Squadrone and Gallozzi (2009) – although not controlling the foot strike pattern - found that the impact transient when shod was significantly higher in comparison to both barefoot running and running with the Vibram FiveFingers (VFF). These higher impact transients have been said to contribute to a high incidence of running-related injuries (Lieberman *et al*., 2010). Divert *et al.* (2005), found similar results, indicating that both the passive and active GRF were significantly higher in the shod condition compared to that of the unshod condition. It must be noted that for this specific study, Divert controlled both the shod and unshod running conditions in terms of RFS. The results of the studies carried out by Divert *et al.,* (2005) and Lieberman *et al.,* (2010) conflict in terms of GRF and unshod RFS running.

In contrast to the results obtained by Divert *et al.* (2005) and Lieberman *et al*. (2010), De Wit *et al.* (2000) argue that the GRF at initial contact was higher in the barefoot runners compared to that of shod runners. Furthermore it was stated that the initial rate of loading was significantly higher for barefoot runners than in the shod condition. However, these authors fail to mention whether the participants adopted a FFS or RFS running gait, a key determinant of the GRF. Moreover it should be noted that none of the participants were habitual barefoot runners; this could have contributed to the higher rate of loading and increased GRF during barefoot running. These results may therefore not contradict that of Lieberman *et al.* (2010) when comparing shod and unshod running in terms of RFS.

ANKLE STIFFNESS

Two biomechanical factors contribute to a decreased impact transient accompanying the FFS, namely the point of contact and ankle stiffness (Lieberman *et al.*, 2010). In a FFS, initial contact takes place at the front of the foot, which causes the ankle to dorsiflex as the heel drops under the control of triceps surae. Lieberman *et al.* (2010) states, the GRF during a FFS torques the foot around the ankle and converts the translational kinetic energy at the lower limb into rotational kinetic energy, in turn decreasing the effective mass of the body - this is especially noted in FFS with low ankle stiffness. On the other hand, the impact during a RFS occurs just below the ankle. As a result, the entire centre of mass of the leg and foot is loaded just below the ankle. This, accompanied with variable plantarflexion, results in little conversion of translational energy into rotational energy (Lieberman *et al.,* 2010). Consequently, this results in a loss of energy within the system and an increase in the effective mass. Bishop *et al.* (2006), states that ankle stiffness increases when running shod. In contrast, barefoot running allows for a more compliant ankle, resulting in the absorption and conversion of energy at initial contact.

LEG STIFFNESS AND COMPLIANCE

Leg compliance can be defined as the drop in the body's COM relative to the vertical force during initial contact (impact) and results from a series of motions at the ankle, knee and hip. It has been stated that vertical leg compliance is greater during FFS running compared to that of RFS running. Moreover, Lieberman *et al.* (2010) expresses that running with a more compliant limb during a FFS results in a lower rate of loading on the foot and lower limb. Bishop *et al.* (2006) contends that if leg stiffness during running is invariant, the running efficiency of the individual can greatly decreased. A reason for the decreased efficiency is the continuous oscillation of the COM in a vertical direction. Furthermore, Bishop states that the stiffness of the leg shares an inverse relationship with the terrain on which the individual runs. A harder surface will result in running with a more compliant limb, whereas if an individual was running on a softer surface (such as gravel or sand) the limb would become stiffer and less compliant.

SPATIO-TEMPORAL VARIABLES

CONTACT TIME

Many studies have indicated that contact time is a key factor affecting both the energetics and mechanics of running (Morin *et al.,* 2007). Contact time is defined as the length of time the foot is in contact with the ground during stance phase of the gait cycle (Perry, 1992). The literature regarding contact time during shod and unshod running is unanimous, stating that contact time is reduced in the unshod condition and higher during shod running (De Wit *et al.,* 2000; Divert *et al.,* 2005; Divert *et al.,* 2008; Lieberman *et al*., 2010). In addition, De Wit *et al.* (2000), indicate that contact time was higher in all shod conditions irrespective of running speed, eliciting results of 0.251s and 0.239s at 12.6km.h^{-1}; 0.219s and 0.200s at 16.2km.h^{-1} and 0.193s and 0.175s at 19.8km.h^{-1} respectively for shod and unshod running. Subsequently, it can be seen from these results that as speed of running increases so contact time decreases. When comparing a variety of shoes to barefoot running, Divert *et al.* (2008) found that between the various types of shoes contact time remained fairly constant. However, when compared to barefoot running, contact time was significant higher in the shod condition 34.2 (±0 2.5) s and 32.2 (± 2.7) s respectively.

It has been found that the soft cushioning systems of shoes and the various sole properties allow for an increased contact time, by distributing the forces across a larger area of the plantar surface, thereby making RFS running more comfortable (Verdejo & Mills, 2004).

STRIDE FREQUENCY AND STRIDE LENGTH

Other biomechanical changes accompanying the reduced contact time in the unshod condition are, an increase in stride frequency, a decrease in stride length and decreased flight time (De Wit *et al.,* 2000; Divert *et al.,* 2005; Divert *et al.,* 2008; Squadrone and Gallozzi, 2009; Lieberman *et al*., 2010). The results of De Wit *et al.* (2000) indicate that stride frequency was significantly higher in the barefoot condition throughout all speeds, with the average stride frequency for each condition amounting to 79 and 82 st.min^{-1} at 12.6km.h^{-1}; 82 and 86 st.min^{-1} at 16.2km.h^{-1} and 85 and 90 st.min^{-1} at 19.8km.h^{-1} respectively for shod and unshod conditions. Stride length was higher in the shod condition in the same study throughout all conditions, however these differences were not considered significant. In addition, it was noted that as the speed of running increased, so increases in stride length and stride frequency were found (De Wit *et al.,* 2000).

It has been hypothesised (Burkett *et al.,* 1985) that this decreased stride length contributes in reducing the initial impact forces which should be absorbed by the musculoskeletal system at each step. Furthermore, Divert *et al.* (2008) states that the decrease in stride frequency during the shod condition was a result of the shoe and mass effect, rather than an outright kinematic change by the subject. With regards to shod running, literature indicates that contact time was higher and was accompanied by an increase in flight time, decreased stride frequency and increased stride length (De

Wit *et al.,* 2000; Divert *et al.,* 2005; Divert *et al.,* 2008; Squadrone and Gallozzi, 2009; Lieberman *et al*., 2010).

PHYSIOLOGY OF RUNNING

Physiological costs

It has been generally accepted that during treadmill running the relationship between running speed and oxygen consumption (VO_2) is linear throughout the entire aerobic running range – 8-24km.h^{-1} (Mayhew, 1977). However, when this relationship was investigated on the track the relationship was found to be somewhat curvilinear (Mayhew, 1977). Mayhew found that the oxygen cost of running increased as running speed increased, demonstrating an increase in VO_2 of 30.1 (±2.7) ml.kg $^{-1}$.min^{-1} to 41.4 (±3.4) ml.kg $^{-1}$.min^{-1} and 54.1 (±4.0) ml.kg $^{-1}$.min^{-1} in the 10, 13 and 16 km.h^{-1} speeds respectively. Furthermore, energy expenditure during running also increased in a linear fashion, with results indicating 0.17, 0.2 and 0.25 Kcal.Kg^{-1}.min^{-1} at speeds of 10, 12 and 15km.h^{-1} (Mayhew, 1977). It can therefore be observed that a monotonic relationship exists between running speed and physiological demands placed on the body.

Due to limited literature regarding the physiological costs of shod and unshod running, there seems to be no significant difference in terms of energy expenditure. Squadrone and Gallozzi (2009) observed - when adopting a preferred foot striking technique - that there was no significant difference in VO_2 between shod and unshod running. It was however noted that the energy cost of running decreased by 1.3% when running barefoot in comparison to standard running shoes (Squadrone and Gallozzi, 2009). When comparing standard running shoes to the VFF, significant differences in VO_2 were observed. In addition, running with the VFF in comparison to a standard running shoe elicited a significant decrease in VO_2 (2.8%) and hence a reduction in the energy cost of running. A similar finding (Warburton, 2001) was that the energy cost of running is reduced by approximately 4% when the feet are unshod, however this author also, fails to mention which foot striking technique was employed. In terms of heart rate (HR), Squadrone and Gallozzi (2009) observed no significant differences between the shod, VFF and unshod protocols.

Several authors (Frederick, 1984; Martin 1985; Divert *et al.,* 2008;) contend that the increase in the physiological costs that accompany shod running are largely due to the mass effect of the shoe. Frederick (1984) found a 1% increase in the metabolic cost of running whilst shod. Similarly Martin (1985) stated that increasing the mass of the foot by 0.5 and 1kg respectively, resulted in significant increases in $VO_{2,}$ suggesting that the added weight of the shoe does in fact correlate to increases in the mechanical work of the foot. Furthermore, Burkett *et al.* (1985) found that the VO_2 during running increased as the mass that was added to the foot increased. This weight amounted to an increase of 1% body weight and effectively increased VO_2 by 3.1%. Similarly when running with a ~ 700g pair of shoes, opposed to barefoot, Flaherty (1994), found an increase in VO_2 of 4.7%. It can therefore be seen that the mass of the shoe does in fact have an effect on the energy costs of running. It must however be noted that the mass effect of the shoe is not the only contributing factor to increased physiological costs; others factors include ground reaction forces and foot striking patterns.

This point illustrates that the application of a load – even a very small load - to a running protocol results in significant increases in the physiological responses of running. Therefore a study implementing a heavier load whilst running may have even greater effects on the biomechanics and physiology of running.

SHOE DESIGN

The highly repetitive abrupt loading that accompanies running has warranted a variety of shoe designs, which aim to provide protection to the foot and lower aspects of the limb. The design of shoes has focused on a variety of mechanisms to promote foot control, increased stability, shock distribution as well as protection, thereby making running more comfortable and less injurious.

Given the various types of foot strikes that have become apparent over the last years, a variety of shoe designs to cater exactly for these differences have been designed and produced. A major contributing factor as to why 75 - 80% of runners RFS, is due to the large cushioned sole of modern day running shoes, which cushion the heel at heel strike (Lieberman *et al.,* 2010). Furthermore, current cushioning technologies in running shoes are designed to elevate the heel in comparison to the fore-foot (Kerrigan *et al.,* 2009). As a result the sole is thickest just below the heel and is said to dorsiflex the foot approximately 5^0 less, allowing the runner to RFS more comfortably. In contrast, a shoe sole that is of a flatter nature – i.e. a racing flat – may promote the individual to adopt more of a FFS whilst running. Therefore a running shoe that has a flatter sole orientation and has less of a heel may be more beneficial to habitually barefoot runners, who FFS when unshod as well as when shod. It can therefore be said that the design of the shoe can facilitate different striking patterns.

However, with the latest studies indicating that the mass of the shoe has a significant effect on running and running economy (Divert *et al.,* 2005; Divert *et al.,* 2008), the majority of manufacturers have adopted new types of light weight materials (Ethylene-vinyl acetate – EVA – is the most commonly used) to decrease the weight of the shoe, but at the same time retain the shoe's protection, stabilisation and control (Wallden, 2009). The main functions of the running shoe include shock absorption at the foot, protection against ground surface at stance phase and to align the foot to achieve a uniform distribution of force (Novacheck, 1998). These functions are achieved by designing shoes with stiffer heel counters, lacing systems, fibreglass midsole plates and varying densities and types of materials in the shoe's midsole.

RUNNING RELATED INJURIES

Running has been proven to promote immediate and substantial health benefits (Kerrigan *et al.,* 2009). However there is no clinical evidence to support the fact that modern running footwear is most favourable in promoting long-term health in runners (Richards *et al.,* 2008). Moreover, as stated earlier, the design of modern running shoes promotes athletes to RFS more often and more comfortably. Several authors have previously stated that the repetitive nature of running, combined with the abrupt loading of the foot and lower limb are two mechanisms which are responsible for the development and continual incidence of running related injuries (Novacheck, 1998; Divert *et al.,* 2005; Bishop *et al.,* 2006; Divert *et al.,* 2008; Kerrigan *et al.,* 2009; Lieberman *et al.,* 2010). Therefore the alteration of the foot strike pattern to more of a RFS – as a direct result of the shoe effect - may result in an increased prevalence of running related injuries in comparison to that of a FFS – a foot strike pattern that often accompanies unshod running.

The various injuries that may present themselves as a result of running may be classified as either acute or chronic. Acute injuries refer to any form of injury arising from an accident whilst running and include incidents such as ankle sprains, with inversion sprains accounting for 90-95% of all sprains (Warburton, 2001). In contrast, chronic injuries occur as a result of continual exposure to running and can persist for months at a time. Frequent chronic injuries can be attributed to excessive pronation supination and the shock of loading the limbs abruptly. These include; shin splints, illio-tibial band syndrome, peri-patellar pain as well as plantar fasciitis (Siff and Verkhoshansky, 1999).

OPTIMUM PERFORMANCE

The in phase nature of potential energy exchange that occurs during running requires the human body to have various mechanisms by which energy can be stored and transferred. Therefore the efficiency with which this can be done and the amount of energy that is lost during running are factors affecting optimum performance. As a result, optimal performance can be achieved by improving economy of motion and running economy.

Economy of motion

It has been accepted that one of the most important determining factors of the manner in which the individual moves is to maximise efficiency (Novacheck, 1998; Bramble and Lieberman, 2004). It is well established that a curvilinear relationship exists for walking as the speed increases, with an optimal speed of walking occurring between 2 and 5km.h^{-1} depending on inter-individual variability (Carrier, 1984; Novacheck, 1998; Bramble and Lieberman, 2004). In contrast, no such relationship exists for running speed and energy cost, and oxygen consumption (VO_2), change very slightly over a wide range of walking speeds. Economy of motion during running is therefore elusively maintained with certain mechanisms, including choices of stride frequency, muscle shortening and velocity and by sources of mechanical output (Novacheck, 1998). A result of the exchange of energy during running being in phase requires biarticular muscles to store elastic strain energy and later return this energy through the use of the active springs within the leg. Kram and Taylor (1990) contend that the economy of running has little to do with the work done against the environment but rather it is two-fold – firstly, it involves the efficiency with which an individual can continually produce the work required by the muscles and tendons to lift and accelerate the body and limbs and secondly it involves an inverse relationship to stride frequency, in that the faster or quicker the stride frequency the less efficiently that individual will be running.

Running economy

Running economy may be expressed as the steady state sub-maximal VO_2 at a given running speed (Larsen, 2003). It is further stated that the lower an individual's $VO_{2,}$ at any given sub-maximal running speed, the better the running economy. Running economy can be expressed in many ways, including; kcal.kg^{-1}.min^{-1}, kj.hr^{-1} or in terms of VO_2 (ml. kg^{-1}.min^{-1}).

LOAD CARRIAGE

Load carriage is an integral part of many modern day occupations and sports. Therefore, the impact load has on the biomechanics and physiology of individuals during these activities is imperative. In the past, literature has mainly focused on the biomechanical and physiological costs of load carriage during walking, with little interest into the relationship between load carriage and running. Research has indicated that certain factors may alter the relationship between load and the biomechanical and physiological responses. These factors include increases in load (body weight and external load), load position/distribution, walking speed and gradient as well as terrain type (Knapik *et al.,* 1996; Abe *et al.,* 2004; Abe *et al.,* 2008a; Abe *et al.,* 2008b).

Biomechanical aspects of load carriage

EFFECT OF LOAD ON GAIT

When introducing a load during walking, it can be expected that the usual gait pattern of an individual will change. Literature states that the stance phase of gait is not affected by loads that are less than approximately 50% of body weight; however the swing phase of the GC is affected when walking speeds are relatively fast – ~ 6.5 $km.h^{-1}$ (Knapik *et al.,* 1996; LaFiandra *et al.,* 2003). Moreover, it is the duration of swing phase that decreases in response to the application of load (Hong & Brueggemann, 2000). The result of a reduced swing phase is an increase in periods of DS, increased stride frequency and decreased stride length (Knapik *et al.,* 1996; Hong & Brueggemann, 2000; LaFiandra *et al.,* 2003).

LaFiandra *et al.* (2003) observed that the average stride length at a speed of approximately 5.5$km.h^{-1}$ was 1.48m (loaded) and 1.55m (unloaded) respectively. At the same speed, stride frequency was higher in the loaded condition compared to that of the unloaded condition, 1.08 and 1.04 $st.sec^{-1}$ respectively. A reason for the shorter stride length has been proposed as a mechanism to maintain normal walking patterns; however this finding is subject to individual variability. LaFiandra *et al.* (2003) contends that the shorter stride length during load carriage is due to a decrease in transverse pelvic rotation. It can therefore be seen that in order to maintain a constant speed under conditions of load carriage, the individual must either increase hip excursion in the sagittal plane – thereby increasing stride length - or increase stride frequency. A further biomechanical change that results from an increased load is an increase in GRFs in the downward, forward, rearward and lateral directions (Knapik *et al.,* 1996).

EFFECT OF SPEED ON GAIT

Studies conducted into load carriage indicate that as walking speed in an unloaded condition increases both stride length and stride frequency increase to roughly the same degree. Reasons as to why this is apparent lie in the literature presented by LaFiandra *et al.* (2003). These researchers state that as speed increases, pelvic and thoracic rotation becomes less in phase which leads to variability in stride length and stride frequency – a theory that is likewise supported by Wagenaar and van Emmerik, (2000). Furthermore as the speed increases, the biomechanical changes between loaded and unloaded conditions become more evident, resulting in much larger differences being elicited by the loaded condition. Other mechanical measures that may change as speed of walking increases include; percentage of DS per stride, lateral and vertical impact transients per stride, breaking impulse as well as peak and average breaking (LaFiandra *et al.* (2003).

Physiological aspects of load carriage

ENERGY COST OF LOAD CARRIAGE

It has been well documented that the implementation of a load whilst walking results in an increase in physiological responses such as VO_2 and HR (Datta and Ramanathan, 1971; Lloyd and Cooke, 2000; Coombes and Kingswell, 2005). Literature regarding the relationship between VO_2 and the speed of walking is undisputed, describing the relationship to be curvilinear and u-shaped in nature. However, the literature regarding load carriage during walking is controversial, with previous studies indicating that the metabolic demand of walking whilst carrying a load increases linearly with the carrying weight (Abe *et al.,* 2004). On the other hand, reports indicate that the metabolic cost whilst walking with loads did not change unless the load was 20% of the subject's body weight or higher (Keren *et al.,* 1981; Charteris *et al.,* 1989; Abe *et al.,* 2008a; Abe *et al.,* 2008b), a situation coined as the *free-ride* hypothesis.

Holewjin and Meeuesen (2000) conducted a study into the physiological strain associated with load carriage whilst walking. These researchers reported changes in VO_2 as load increased, eliciting increases in VO_2 of 3.3% when increasing load from 5.4kg to 10.4kg – loads representative of 7.4% and 10.4% of mean subject body weight. Furthermore, these researchers found that HR was significantly lower in the control condition (unloaded) when compared to the loaded conditions. A finding similar to this was observed by Hong & Brueggemann, (2000), in that HR increased significantly from the control condition (unloaded) compared to that of the loaded conditions. Furthermore, HR increased as the load applied increased (10%-15%-20% BW) with the highest HR elicited in the 20% body weight condition. It must be noted that no significant differences in HR were found between the loaded conditions; the authors attribute this to participants reaching a fairly steady exercise state by the 5^{th} minute (Hong & Brueggemann, 2000).

LOAD DISTRIBUTION

A study conducted by Abe *et al.* (2004), illustrated that when the load position was altered, the cost of walking changed. More specifically it was found that when carrying a load conventionally - in a backpack, in this case – the lowest cost of walking was elicited. The next highest cost of walking was found in when carrying a load in the hands and the highest cost of walking was found whilst placing a load on the legs. In scientific terms it is most efficient to carry a load as close to the body's COM as possible, this has been shown extensively with physiological studies (Datta and Ramanathan, 1971; Lloyd and Cooke, 2000; Coombes and Kingswell, 2005; Abe *et al.,* 2008a; Abe *et al.,* 2008b; Birrell & Haslam, 2010), providing reason as to why the backpack elicited the lowest cost of walking.

LOAD CARRIAGE AND RUNNING

The only piece of literature that was found regarding load carriage and running was conducted by Myers and Steudel (1985), who observed that when imposing a mass of 3.7kg during running a 3.7% increase in VO_2 resulted. Therefore, with little literature focused on load carriage whilst running, it can only be expected that the biomechanical and physiological changes associated with load carriage during walking will be exacerbated due to the increased speed that accompanies running.

Thus, the main aim of this study is to investigate the relationship between shod and unshod running, but more specifically to observe how the biomechanical and physiological variables that accompany this relationship are altered by the application of a load to a running protocol.

CHAPTER III
METHODOLOGY

INTRODUCTION

Shod versus unshod running has received much attention over the last decade, with most studies investigating differences in VO_2, electromyographic (EMG) activity, running kinematics and the effect of shoe mass on the energy costs of running. The use of varying methodologies has lead to dissenting results being obtained, although the majority of studies proclaim barefoot running to be more beneficial (in terms of energy expenditure and forces acting on the foot and limbs) to the runner (Divert et al., 2005; Divert, et al., 2008, Squadrone and Gallozzi, 2009, Lieberman *et al*., 2010).

Previous shod versus unshod methodologies have controlled for age, training status, speed, foot strike patterns as well as shoe type. However the literature regarding load carriage during running is almost nonexistent. Subsequently this study requires a different range of controls, compared to past literature. Therefore important methodological considerations include the speed of running, the load imposed whilst running, and the manner in which the load will be carried by the participants as well as the shoe type employed in the shod condition. Each of these factors has the ability to affect experimental responses, it is therefore of great importance that these variables are controlled, thereby producing results that will be accurate and reliable.

The current study aims to gain insight into the relationship between shod and unshod running but more specifically this study looks to determine the impact of load on the biomechanical and physiological responses during a shod and unshod running protocol.

PILOT STUDY WORKS

In order to determine the viability and logistical working of this research project, pilot investigations were performed in the Department of Human Kinetics and Ergonomics at

Rhodes University. Two pilot sessions were conducted, wherein conditions of the intended testing protocol were administered using two participants who filled the required criteria. The purpose of these pilot sessions was to refine the testing procedure, eliminate any potential methodological flaws, ensure the correct use of the testing equipment, and for the author to gain an understanding of the proposed outcomes.

Speed and load selection

It has been well documented that as running speed increases so the cost of running increases in a linear fashion (Mayhew, 1977; Bramble and Lieberman, 2004). In addition, studies conducted on load carriage during walking have shown that as the speed of walking increases, changes in gait patterns and increases in physiological responses become more apparent. Therefore it is pertinent that an appropriate speed and load combination is selected, thereby allowing participants to run comfortably whilst at the same time providing validity and reliability to the results.

Previous literature into the relationship between shod and unshod running have employed running speeds ranging from 12 – 20 $km.h^{-1}$ (De Wit *et al.,* 2000; Divert *et al.,* 2005; Divert *et al.,* 2008; Squadrone and Gallozzi, 2009; Lieberman *et al.,* 2010). It has been found that at the higher running speeds (20$km.h^{-1}$), the foot strike pattern changes to more of a FFS orientation (Novacheck, 1998). Moreover, accompanying this, are increases in both stride length and stride frequency. At moderate speeds (12$km.h^{-1}$), differences between stride length and stride frequency were more apparent; furthermore at such speeds it is unlikely that the foot strike pattern will be as exaggerated, and as a result a moderate intensity running gait will be utilised by the subject. In addition, adventure sports and canoe portaging usually adopt speeds much slower than the aforementioned speeds. Therefore utilising moderate running speeds (i.e. 10 - 12$km.h^{-1}$) may make the experimental condition employed more applicable to real world scenarios.

It can therefore be seen that if the running speed selected for this study is too fast, it may result in exaggerated alterations to stride length and stride frequency and the foot strike pattern. In addition, a speed that is too fast may result in the onset of fatigue during the testing protocol; this too may exaggerate the gait pattern and physiological responses. Therefore by adopting a moderate running speed, the subject may feel more comfortable whilst running and as a result, the data that will be collected and analysed may be more representative of the research question.

With the limited amount of literature regarding load carriage during running, the information with regards to an appropriate load to carry whilst running is not yet established; however the selection of an appropriate load to carry whilst running is of great importance. This is due to the fact that load has a large impact on the biomechanical and physiological responses whilst walking, and therefore likely to have an even greater effect during running. The load implemented should be heavy enough in order to avoid a *free-ride* phenomenon but light enough to not cause severe fatigue or injury whilst testing. Moreover the fact that the *free-ride* phenomenon has not been established whilst running makes the selection of an appropriate load an ever greater task.

The limited literature regarding load carriage and running required a reliance on literature pertaining to load carriage during walking. This literature indicates that when walking, loads below 20% body weight incur a phenomenon termed *free-ride* (Keren *et al.,* 1981; Charteris *et al.,* 1989; Abe *et al*., 2004; Abe *et al.,* 2008a; Abe *et al.,* 2008b); however a load that is above 20% body weight will result in an increase in the cost of walking as well as increases in HR and VO_2. Given the fact that this study is focused on running and given that the speed of testing will be far greater than that of walking, it would have been unrealistic to ask participants to run with a load equal to 20% body weight or higher. If this were the case it would be likely that participants would experience a certain degree of fatigue, and this may impact the results negatively, decreasing the reliability and validity of the study.

Adventure sports, such as canoeing, often require the athlete to carry the boat through certain stages of a race – a term called portaging (Mars and Gomes, 2005). The average weight of a K1 – single person canoe – is ± 12kg, therefore it would be ideal to simulate this load as it is sport specific and light enough to not cause fatigue at the higher speeds associated with running. However in a study conducted by Joiner (2007), on the effects of preferred and non-preferred canoe shoulder carriage, it was found that the shape and length of the canoe resulted in increased trunk stiffness whilst running – in order to stabilize the body and canoe. This increase in trunk activation (stiffness) resulted in a degree of fatigue, hence affecting the energy cost of running. Therefore for the purpose of this study it was decided that the load would be carried in the form of a backpack with three loads (8, 10 and 12kg) being implemented during two pilot studies in order to ascertain what an appropriate load to carry whilst running would be.

For the purpose of the first pilot, a 21 year-old male participant who was relatively well trained and ran on a regular basis was used to investigate the effect of load whilst running. The three loads were tested at a speed of $12km.h^{-1}$ in order to determine the physiological demand placed on the subject whilst running. Results indicated that load had a substantial effect on both heart rate and oxygen consumption. It was found that the combination of load to a running protocol elicited results in excess of 80% of HR_{max} in all of the respective conditions (86, 92 and 93% of HR_{max} for respective loads). These calculations were based on the age predicted maximum heart rate method. Moreover it was noticed that whilst running at this speed and carrying the 12kg load, the subject ran less confidently and tended to deviate from the centre of the treadmill's running belt. This indicated that perhaps the speed of running that was utilised was too fast or perhaps that the load was too heavy; as a result a further pilot investigation was conducted with the same loads, at a reduced running speed.

A second pilot was conducted to ascertain the effect of the various loads at a reduced running speed. This pilot utilised a 23 year-old male, who averaged 10 – 15km of road running per week, as the subject. The three loads were employed to determine which load would be appropriate to carry whilst running at a speed of $10km.h^{-1}$. The results indicated that the highest load elicited a response well above 80% of HR_{max} (92% of the age predicted maximum) whilst the 8 and 10kg load elicited responses between 70% and 85% of the age predicted HR maximum (74% and 83% respectively).

Finalization of load and running speed

The pilot studies indicated that a speed of 12km.h^{-1} was too fast and that a load of 12kg was too heavy to employ during a running protocol of this nature. It was therefore decided that a load of 10kg would be an appropriate load to apply at a running speed of 10km.h^{-1}.

EXPERIMENTAL DESIGN

The majority of findings regarding the shod versus unshod relationship indicate an increase in stride frequency combined with reduced stride length, contact time, HR and VO_2 accompanying barefoot running with the inverse occurring with shod running.

Similarly the effect of load on walking gait patterns and physiological costs have been extensively revised, with the majority of literature stating that applying loads above 20% of body weight will result in increases in physiological responses as well as biomechanical changes (increases in GRF and stride frequency with reductions in stride length) during the stance phase of walking. When utilising loads below this benchmark, a phenomenon termed *free-ride* occurs, wherein the metabolic cost of walking does not necessarily increase despite an increase in speed (Abe *et al*., 2004; Abe *et al*., 2008a; Abe *et al*., 2008b).

Conversely, the impact of load carriage on running has received little to no attention. Nevertheless, given the increasing prevalence of adventure sports in South Africa, there is a need to establish the impact of load carriage during running. Furthermore, although the responses to shod and unshod running have been researched, the impact of load on this relationship is unknown.

Increases in the speed of walking have shown to influence both the biomechanics (increased stride frequency and reduced stride length) physiology (increased HR and VO_2) and perceptual responses (ratings of perceived exertion and body discomfort) of load carriage. Conversely, increases in running speed have shown to decrease stride frequency and increase in stride length, HR and VO_2. Given the differing biomechanical physiological and perceptual responses that accompany load carriage whilst walking and the increased speed of running, it can be anticipated that when combining these two aspects, the relationship between shod versus unshod running may be affected. It is therefore anticipated that the application of load to a running protocol will alter the expected shod versus unshod relationship and provide valuable information into the effect of load carriage during running.

Therefore this study employs a two-by-two design matrix, which allows comparison between shod and unshod conditions as well as the loaded and unloaded condition (Table I). Further the design allows for an investigation of the interaction of the two independent variables.

Table I: Design Matrix

	Shod	Unshod
Unloaded	X	X
Loaded	X	X

The dependent variables that were investigated in this study included stride length, stride frequency, oxygen consumption, energy expenditure, heart rate, ratings of perceived exertion (RPE) as well as body discomfort. Furthermore the independent variables that were studied were that of load and shod/unshod conditions.

Selection of load

Due to consultation of this literature and with the aid of pilot studies, a load of 10kg was deemed to be appropriate to implement during the loaded running conditions.

Selection of running speed

The addition of a load to a running protocol establishes load as a key factor in the selection of running speed. Therefore this study consulted literature with regards to shod versus unshod running and employed the use of pilot studies, both of which confirmed that a speed of $10km.h^{-1}$ would be an appropriate speed to conduct a loaded running protocol. Moreover, given the fact that the participants in the study were moderately trained runners, it is believed that this speed was appropriate.

Selection of backpack

Backpack selection was also of great importance, as previous studies have identified that variations in backpacks as well as the location of backpacks affect the energy expenditure associated with load carriage (Knapik *et* al., 1996; Abe *et al.,* 2008b; Birrell and Haslam, 2010). In terms of load distribution, locating the load as close as possible to the COM of the body appears to result in the lowest energy cost.

For the purpose of this investigation, a backpack was set at a comfortable height, at a relatively mid-back position (Figure 3). This was done to ensure the backpack was located as close to the COM as possible and so that it did not restrict movement. The backpack employed in this study was a Targus TEB01 Campus Backpack ©. It was selected for this study as it has a 3D contoured air-mesh back padding which helps alleviate excessive stress and strain on the back. Moreover this specific model contains a hip strap, which distributes the load evenly on the hips, thereby reducing unnecessary strain on the back. Furthermore, the Targus TEB01 has adjustable shoulder straps, which allow the load to be moved either superiorly or inferiorly to allow a more comfortable back position to be attained.

Figure 3:Illustration of backpack employed in the study and relative back position.

Selection of shoe type.

Vibram's FiveFinger footwear technology was employed in this study and represented the barefoot condition. This was done as it has been stated that the VFF mimic barefoot running, in that they promote a mid-foot/fore-foot strike and result in more energetically efficient running in comparison to that of shod running (Warburton, 2001 and Wallden, 2009). For this specific study the KSO model of the VFF were utilised as the unshod condition.

Selection of time frame

When considering appropriate condition times, both steady state and experimentation time were considered as key factors in making this decision. Steady state has been defined as the condition of a system or physiological function that remains at a relatively constant (steady) value (Tortora and Grabowski, 2005). After approximately three to four minutes of submaximal exercise, a person reaches a steady state in which heart rate and rate of oxygen consumption tend to remain constant or at a constant rate of work (McArdle *et al.,* 2001). Furthermore, to allow adequate time for experimentation, a period of two minutes was used. Therefore a total test time of six minutes was employed in this study. This amount of time would allow for sufficient experimentation time as well as time to ensure that a steady state exercise level was attained in each condition (a statistical comparison between minute four and six would reveal this).

MEASUREMENT AND EQUIPMENT PROTOCOL

Initial experimentation involved obtaining anthropometric data from each participant in the sample. With regards to experimentation, responses recorded included: biomechanical (stride length and stride frequency), physiological (VO_2 and HR) and psychophysical (ratings of perceived exertion and body discomfort). These data were collected by employing the use of a response counter, Quark b^2 ergospirometer, ratings of perceived exertion (RPE) and body discomfort scales for the respective biomechanical, physiological and psychophysical responses.

Anthropometric Data

The anthropometric data collected included stature, mass and leg length. These data were recorded in the habituation session and were recorded with the use of a stadiometer, scale and anthropometer.

STATURE

Stature is the vertical distance from the floor to the subject's vertex and was measured in the habituation session using a Harpenden Stadiometer - this allowed for stature to be recorded to the nearest millimeter. In order to ensure standardisation, each subject was requested to remove any objects from their pockets as well as to remove their shoes. The measuring process required participants to stand in an upright position with heels, shoulders and backs against the stadiometer, whilst ensuring their eyes were facing forward and the head in the Frankfort horizontal plane.

BODY MASS

A Toledo© electronic scale was used to record participants' body masses in the habituation session of the testing protocol. Each subject's mass was recorded to the nearest 0.01kg. Participants were request to remove all non-essential clothing, shoes and jewellery. To ensure standardisation, participants were instructed to take a deep breath and to exhale before standing on the middle of the measuring device. Furthermore participants were asked to stand still with their arms pendent and their heads in the Frankfort horizontal plane until the display had clearly indicated the mass. Body mass was recorded in order to relativise and compare oxygen consumption and energy expenditure.

LEG LENGTH

Each subject's leg length was recorded in the introductory session of the experimental design. Measurement employed the use of a Holtain anthropometer and was considered to be the distance from the floor to that of greater trochanter of the femur. A reason for calculating leg length is that a longer leg length may correspond to the subject's ability to produce an increased stride length. This increased stride length may further effect gait adaptations, in that an increased stride length may result in a decreased stride frequency.

Biomechanical Measures

STRIDE FREQUENCY (SF)

Stride frequency was determined by counting the number of steps taken during the data collection period of the experimental procedure (minutes 3-4 and 5-6); the data collected from these two minutes were averaged to obtain mean stride frequency. The instrument used to measure stride frequency was a response counter. A stride is defined as the distance covered from heel strike of one foot to the following heel strike of that same foot again. Therefore one stride was counted each time the right foot came into contact with the treadmill.

STRIDE LENGTH (SL)

Stride length can be defined as the distance between the initial contact of one foot and the next initial contact of the same foot. It is therefore the sum of the right and left step lengths and the distance traversed in one complete gait cycle (Perry, 1992). Stride length will be calculated mathematically using the following equation:

Speed = SF x SL . . . . Equation 1

Therefore by reworking the equation, stride length can become the variable of choice to calculate.

SL = Speed / SF . . . . Equation 2

By determining stride length and stride frequency in each of the conditions, it allowed for interpretation of gait alterations resulting from the shod or unshod condition or from the application of load in each of these conditions.

Physiological Measures

HEART RATE (HR)

HR was recorded to allow interpretation to be gained regarding the effect of each of the four experimental conditions. The Quark b^2 is an open circuit ergospirometry system whose stable turbine sensors, easy operation and integrated HR telemetry system show its advantages over other conventional stationary methods of experimentation. Components of this device include a central processing unit (responsible for subject information and collection of data), HR monitor cord and face mask with sampling tube. The Quark b^2 allows for breath-by-breath analysis and provides all data needed for a complete function analysis of the lungs, heart, circulation and metabolism under varying testing conditions. The Quark b^2 provided a light weight non-invasive alternative for measuring the physiological taxing of the heart during each condition and recorded HR in $bt.min^{-1}$. To ensure greater conductivity of the signal, water was placed on the sensors of the telemetry strap before it was attached to the subject. The strap was placed with the electrode at the level of the xiphoid process of the sternum, with the watch on the subject's left arm. This was done to ensure that the watch could detect the signal sent by the electrode, and that no disturbances in the signal were present.

OXYGEN CONSUMPTION (VO2) AND ENERGY EXPENDITURE

VO_2 and EE were recorded using the Quark b^2 ergospirometer and was measured in $ml.kg^{-1}.min^{-1}$ and $kcal.min^{-1}$ respectively. Collecting data in terms of VO_2 ($ml.kg^{-1}.min^{-1}$) allowed for the comparison of energy expenditure and the cost of running ($ml.kg^{-1}.km^{-1}$) between the various conditions. This clearly indicated which condition was more metabolically/physiologically taxing and to what extent.

Before each experimental session the Quark b^2 was calibrated. This included room-air, gas and turbine calibration. Room-air calibration was done via the sampling tube. Furthermore, gas sensors were calibrated with a gas mixture consisting of 2.9% carbon dioxide, 16.09% oxygen, with the remainder consisting of nitrogen. Finally, turbine calibration was completed with a three litre syringe and involved forcing air through the turbine ten times. Using the Quark b^2 ergospirometer may be viewed as quite invasive by some, as the mask surrounds the majority of the mouth and nose, however in order to keep participants as comfortable as possible, the researcher demonstrated the use of the mask during the habituation session. Moreover during testing the researcher conversed with participants as the mask was fitted – in an attempt to make participants more comfortable whilst fitting the mask.

Psychophysical Measures

RATING OF PERCEIVED EXERTION (RPE)

Each subject was requested to rate perceived exertion (RPE) at minute four and six of the experimental procedure. Exertion is based on the physical sensations a person experiences during physical activity including: increased heart rate, increased respiration or breathing rate, increased sweating, and muscle fatigue. Local RPE – perceived exertion of the muscles - was used in order to ascertain differences in exertion between loaded and unloaded conditions. In order to achieve this, the Borg scale (Appendix C) was utilised in this study - this scale rates exertion on a level from six to twenty (Borg, 1982). Level six on the scale represents very low exertion at all whilst 20 constitutes complete exhaustion - so much so that the test would have to be terminated. Although this is a subjective measure, a person's exertion rating may provide a fairly good estimate of the actual heart rate or muscle fatigue during physical activity (Borg, 1982).

BODY DISCOMFORT MAP AND RATING SCALE

The body discomfort (BD) scale - Appendix C - was developed by Corlett and Bishop (1976), and is considered an important psychophysical measure of perceived discomfort elicited by the experimental protocol. The map illustrates anterior and posterior views of human body, which is further divided into 28 segments, representative of specific muscle groups. Participants are required to select three areas as illustrated on the map that are perceived to be feeling the most discomfort. Further the subject must rate the feeling of perceived discomfort on the accompanying scale from one to ten. One representing the subject sitting in a relaxed manner and ten constituting a state of excruciating discomfort which would force the individual to stop the experimental protocol. The BD scale can be implemented to indicate sites that may be fatiguing and could therefore result in the concern for injury. Additionally, this scale proved to be beneficial as it allowed for a psychophysical comparison of discomfort between the loaded and unloaded conditions.

Additional equipment

QUINTON 611 INCREMENTAL TREADMILL

In order to control the speed of running as well as the environmental testing conditions, the Quinton 611 – an incremental treadmill – was used for each of the running conditions. This treadmill supports a variety of functions, including the implementation of a variety of speeds and gradients. However, for the purpose of this study the treadmill was set at a level gradient and to a speed of $10km.h^{-1}$.

SONY HANDYCAM© DIGITAL VIDEO CAMERA RECORDER

Video recordings were taken during minute four and six of the experimental procedure, using the Sony handycam digital video camera recorder. The footage acquired by the use of this digital video recorder allowed for the interpretation of footstrike patterns for each individual in each condition.

TARGUS TEB01 CAMPUS BACKPACK©

In order to carry the load in a comfortable and safe manner, the Targus TEB01 Campus Backpack© was used. This specific backpack boasts the following features: 3D contoured air-mesh back padding, detachable hip/waist strap and adjustable shoulder straps. The total weight of the pack was 1.32 kg and the dimensions (breadth, width and length) were 26.7 x 4.2 x 38.7cm respectively.

EXPERIMENTAL PROCEDURES

The experimental testing of all participants was carried out for approximately two weeks. Each subject was required to attend three sessions – each of 30 minutes duration; an introductory session followed by two testing sessions occurring on different days. The two testing sessions comprised two conditions selected at random, lasting six minutes in duration. Participants were allowed sufficient resting time between conditions to allow heart rate to return within five percent baseline measures.

Introductory session

Upon arrival at the physiology laboratory at the Department of Human Kinetics and Ergonomics, participants were briefed on the purpose and aims of the study as well as the details of each testing procedure. Following the explanation of the purpose and aims, participants were given the opportunity to ask any questions concerning the study. Thereafter, participants were introduced to the equipment that was to be utilised during experimentation, and were informed about what each device measured and how it was measured. A letter of information regarding the study was issued to each subject - this was done to ensure that each subject fully understood the testing procedure and what was required of them. Once the letter was read and understood, participants were asked to sign an informed consent form giving permission for the author to use the subject's data in the project. Following this, a heart rate monitor telemetry strap was fitted to each subject and resting heart rate (RHR) was recorded in the supine position. Thereafter, stature, mass and leg length were recorded. Participants were then required to have a brief habituation session on the treadmill; this ensured each subject was familiar with the treadmill speed, load and running within a confined space. Moreover participants were allowed to familiarise themselves with the different experimental conditions until they felt comfortable, thus allowing for a thorough habituation. The introductory session was not longer than 30 minutes.

Experimental sessions

Participants returned for the experimental sessions within a week of the introductory session. Participants were reminded of the purpose and testing procedure before the fitment of the Quark b^2 mask and HR telemetry strap. Participants were allocated six minutes to warm-up and stretch, with three minutes allotted for each. The first testing protocol required participants to complete two of the four experimental conditions - each of six minutes in duration and in a random order (see Appendix C). A rest interval - allowing HR to return within 5% of RHR - was implemented between conditions, thereby making total test time for equipment fitment and testing approximately 30 minutes for each experimental session. Two of the four allotted conditions involved running at a speed of $10km.h^{-1}$ in a shod and unshod state. The two remaining conditions were conducted in exactly the same fashion as previously stated; however a backpack with a load of 10kg was employed in unison with a shod and unshod condition.

The first four minutes of each condition allowed for a steady state exercise level (a state where all bodily responses approximate a relatively unchanging level) to be achieved with the last two minutes of testing ensuring a steady state exercise level had been achieved. Data was recorded at the fourth and sixth minute of testing. Oxygen consumption, energy expenditure, heart rate, foot strike patterns, stride length, stride frequency, local RPE as well as body discomfort were the variables under investigation and were recorded with the Quark b^2 ergospirometer, heart rate monitor and response counter respectively. During all testing protocols, standardised testing conditions were adhered to for all participants.

SUBJECT CHARACTERISTICS

This test protocol involved testing 12 male participants, with the mean age of participants being 22 (±1.53) years of age. (Table II) represents subject characteristics for the respective measurements. Inclusion criteria included a minimum of 20km of road running per week, as well as no form of running related injury at the time of study. This benchmark was set to ensure that the sample tested was of a moderate training status and had some form of experience in running. Furthermore the criterion pertaining to injury ensured no unnecessary gait alterations resulting from pain due to a running related injury. A further exclusion criterion for this study was shoe size. This study required participants to have a foot size between to that of a size nine and eleven (United Kingdom sizing). This exclusion criterion was instated due to limited funding, which resulted in only a certain number of shoes being purchased. This size is commonly regarded as average among male athletes.

Table II: Anthropometric data of participants (n = 12)

ANTHROPOMETRIC CHARACTERISTICS	Mean (±SD)	CV (%)
RHR (bt.min^{-1})	63 (±7.3)	11.43
Age (yrs)	22 (±1.53)	7.00
Stature (mm)	1803.58 (±61.22)	3.39
Mass (kg)	75.33 (±9.70)	13.43
Leg length (mm)	91.21 (±3.29)	3.60
Shoe mass (kg)	0.66 (±0.09)	14.39

STATISTICS

Statistical procedures were analyzed using STATISTICA (version 9.1). Initially a Shapiro-Wilks W test was carried out to establish whether the data obtained was normally distributed. The test indicated that 27 of the 32 cases were normally distributed. The five cases that were not normally distributed can be attributed to outliers within the data. The fact that these outliers were not from the same subject did not warrant for the exclusion of participants from the study. Moreover, by reducing the already small sample size may have decreased the validity of the results. Descriptive statistics were performed in order to determine the means, standard deviations and coefficient of variation from the respective conditions. In order to be able to compare the results obtained from each condition, a two-way ANOVA was used to assess significance between conditions and where these differences lay within the results. Statistical responses were assessed using a confidence interval of 95%; therefore a $p \leq 0.05$ was set.

CHAPTER IV
RESULTS

INTRODUCTION

For the purpose of this study the main dependent variables that were investigated included stride length (SL), stride frequency (SF), heart rate (HR), oxygen consumption (VO_2), energy expenditure (EE) as well as local ratings of perceived exertion (RPE) and body discomfort (BD). The data were statistically analysed in order to ascertain significance between both shod and unshod conditions as well as in terms of load. The results will be presented in terms of the impact of foot condition and load condition on the biomechanical, physiological and lastly the psychophysical variables. The results obtained provide insight into the effects of load on the shod versus unshod running relationship and further indicate concordance with the already established shod and unshod relationship.

BIOMECHANICAL IMPACT

Foot strike patterns

Results of the video analysis of foot strike patterns (Table III), established that the majority of participants adopted a RFS during shod running (83.33%). However for the unshod conditions, a greater percentage (58%) of the participants demonstrated a MFS or a FFS. When participants were required to run with a load, the majority of the participants (83.33% and 75%) reverted to a RFS when shod and unshod.

Table III: Footstrike patterns (*N* = 12), illustrating the differences between foot condition and the impact of load. (SUL = shod unloaded; USUL = unshod unloaded; SL = shod loaded and USL = unshod loaded)

Footstrike	SUL	USUL	SL	USL
FFS	1	2	0	1
MFS	1	5	2	2
RFS	10	5	10	9
	12	**12**	**12**	**12**

It was noted that in the unshod condition that there was a majority of MFS and FFS techniques employed (accounting for 58.33% of participants); however with the application of load it was found that the majority of participants reverted to a RFS. Furthermore, Figure 4 depicts the footstrike patterns of each subject (a different colour block representing each subject) for each of the experimental conditions, indicating whether or not the subject maintained a consistent footstrike pattern.

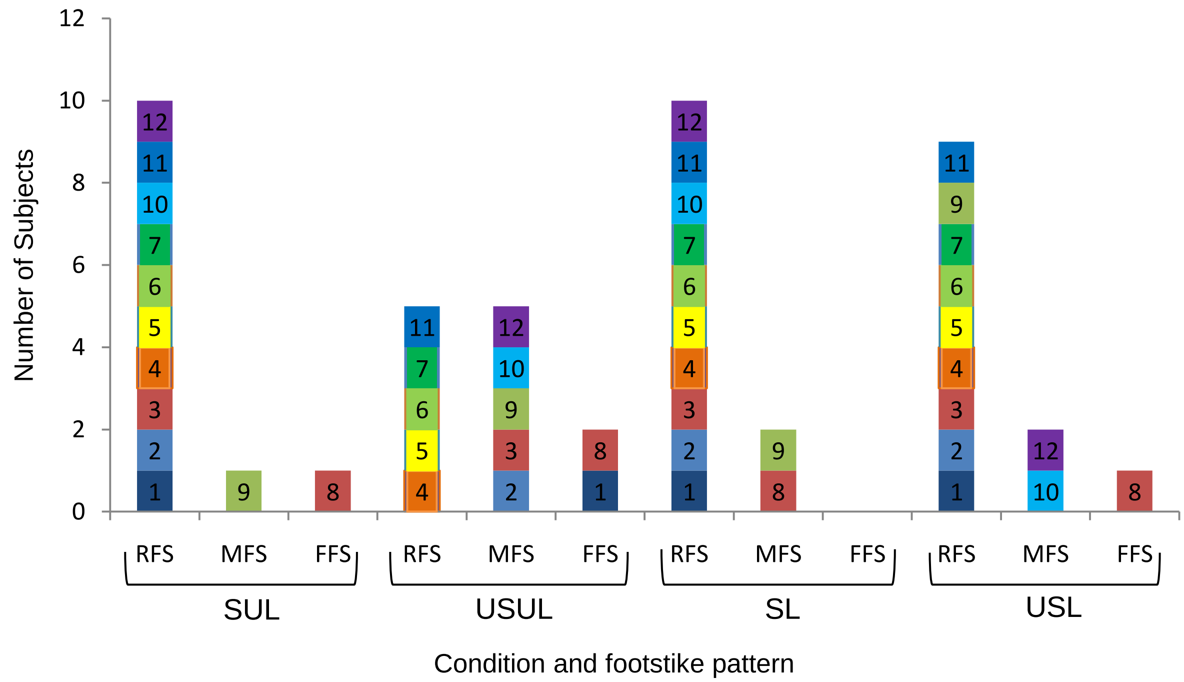


Figure 4: Individual comparison of footstrike results, indicating the frequency of patterns amongst the respective conditions. (SUL = shod unloaded; USUL = unshod unloaded; SL = shod loaded and USL = unshod loaded)

The above Figure **4** - illustrates that in the shod conditions all participants maintained the same foot strike pattern - irrespective of load - with the majority (10) adopting a RFS. Of the two participants that did not adopt a RFS, only one (subject 8) adopted an alternative foot strike pattern with the application of load. The unloaded conditions produced greater variability, with seven participants opting for either a MFS or FFS. The application of load to the unshod conditions resulted in five participants reverting to a RFS.

Stride length and stride frequency

Analysis of stride frequency (SF) data revealed that the unshod condition resulted in a higher SF when compared to the shod condition. It was observed that when running with a load, SF increased, with the highest result elicited in the unshod condition (Table IV). Stride length (SL) on the other hand adopted an inverse relationship in comparison to SF, with the shortest SL being observed in the unshod condition. Furthermore, the application of a load further decreased SL, with the lowest SL being found in the unshod condition.

Table IV: Mean, standard deviation and coefficient of variation values for SF and SL for each respective condition.

N = 12 10 km.h^{-1}		Unloaded		Loaded	
		Unshod	Shod	Unshod	Shod
SF (st.min^{-1})	Mean	79	78	81	79
	SD	(4.48)	(5.20)	(4.81)	(3.92)
	CV (%)	5.68	6.71	5.92	4.94
		└──────┘		└──────┘	
SL (m)	Mean	2.12	2.15	2.05	2.1
	SD	(0.127)	(0.142)	(0.126)	(0.107)
	CV (%)	6.01	6.57	6.12	5.10
		└──────┘		└──────┘	

└──┘ Significance ($p < 0.05$)

IMPACT OF LOAD

The impact of load on SF and SL produced significant effects for both variables for the respective loaded and unloaded conditions. As seen in Figure 5, the application of a load to shod and unshod running resulted in significant decreases in SL. It is evident that loaded unshod running resulted in the shortest SL 2.05 (±0.126) m while loaded shod running elicited a significantly larger SL 2.10 (±0.107) m.

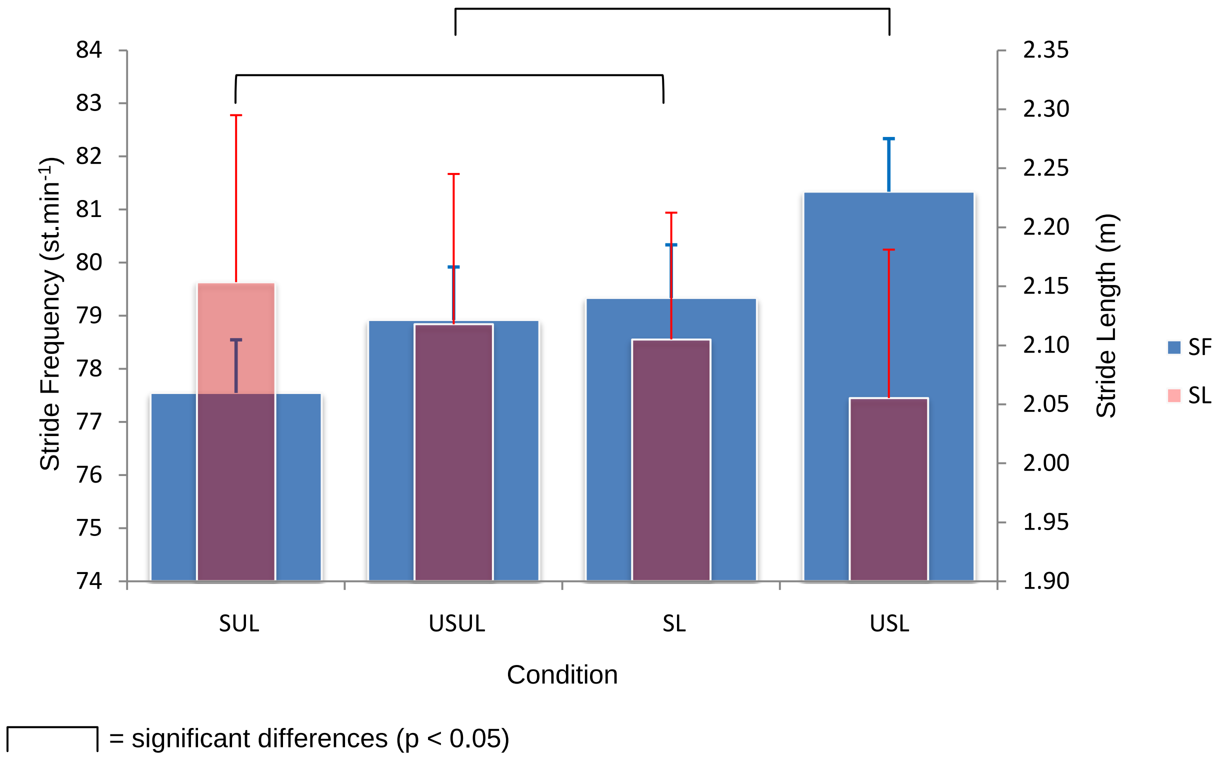


Figure 5: Stride frequency and stride length with the concurrent effect on the shod versus unshod relationship.

When considering the impact of load on SF (Figure 5), it was established that SF increased significantly in the loaded conditions. The higher SF demonstrated in the unshod condition 81 (±4.81) st.min^{-1}, compared to that of the shod condition 79 (±3.92) st.min^{-1}, illustrates that the previously established shod versus unshod relationship was not altered by the application of a load. It can however be seen that the unshod condition was affected to a greater degree by the application of a load, eliciting a 2.5% increase in SF in the unshod conditions compared to 1.3% increase in the shod conditions. Likewise, unshod running resulted in a 3.3% decrease in SL compared to a 2.3%decrease during shod running. It is evident from these data is that the biomechanics of shod and unshod running were significantly affected by the application of load.

SHOD VERSUS UNSHOD

When comparing the two unloaded conditions it was ascertained that when shod, SL was greater compared to that of unshod running, eliciting values of 2.15 (±0.142) m and 2.12 (±0.127) m respectively. What is more, accompanying the increased SL was a reduced SF 78 (±5.2) $st.min^{-1}$ while shod, and 79 (±4.48) $st.min^{-1}$ in the unshod condition (Figure 5). It is evident from these data that the variability between participants was relatively similar across all conditions.

PHYSIOLOGICAL IMPACT

Heart rate

The analysis of HR revealed that unshod running consistently produced lower HR responses in comparison to that of the shod running (Table V). The lowest HR response was observed during unloaded running in the unshod condition. Shod running whilst loaded resulted in the greatest demand being placed on the heart; however this value was only marginally higher than loaded running whilst unshod.

Table V: Heart rate responses elicited from foot condition and impact of load.

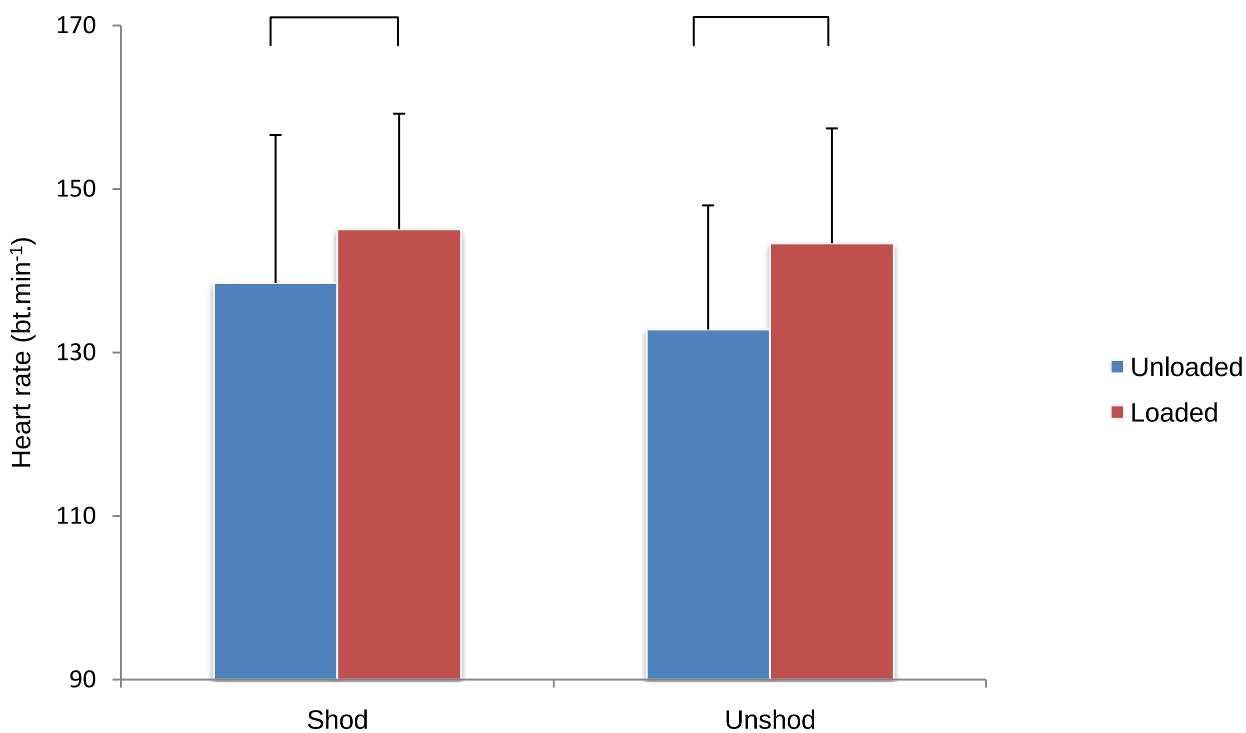
N = 12 10 $km.h^{-1}$		**Unloaded**		**Loaded**	
		Unshod	Shod	Unshod	Shod
HR ($bt.min^{-1}$)	Mean	133	138	143	145
	SD	(15.18)	(18.10)	(14.05)	(14.12)
	CV (%)	11.43	13.07	9.80	9.73

IMPACT OF LOAD

Table V illustrates that when loaded, heart rate was significantly elevated in comparison to the unloaded conditions, demonstrating a 10 $bt.min^{-1}$ increase from unloaded barefoot condition to unshod loaded, or from conditions with no load to the loaded condition, 133 (±15.18) $bt.min^{-1}$ and 143 (±14.05) $bt.min^{-1}$ respectively. Correspondingly heart rate rose by a similar margin when comparing the shod conditions, 138 (±18.10) bt.min^{-1}, versus 145 (±14.12) bt.min^{-1}. Figure 6 depicts these findings and summarises the data concerning the impact of load on HR with respect to the shod and unshod conditions.

SHOD VERSUS UNSHOD

When comparing HR between shod and unshod running, it was noted that the shod condition elicited higher heart rate responses in comparison to the unshod condition, 138 (±18.10) bt.min^{-1} and 133 (±15.18) bt.min^{-1} respectively (Figure 6). It should be noted that the variability between participants was greater when unshod. Furthermore, the unloaded conditions produced a higher variability in comparison to the loaded condition.



= significant differences ($p < 0.05$)

Figure 6: Comparison of average heart rate between shod and unshod conditions, demonstrating the effect of load on this relationship.

Oxygen consumption

Examination of VO_2 indicated that the shod conditions incurred a greater rate of oxygen consumption in comparison to the unshod conditions. It was observed that the unloaded running produced the lowest VO_2 with the lowest rate of oxygen consumption elicited in the unshod condition.

Table VI: VO_2 illustrating differences in foot condition as well as the impact of load.

N = 12 10 km.h^{-1}		Unloaded		Loaded	
		Unshod	Shod	Unshod	Shod
VO_2 (ml.kg^{-1}.min^{-1})	Mean	34.69	37.01	38.53	39.34
	SD	(7.36)	(4.28)	(6.74)	(8.73)
	CV (%)	21.22	11.57	17.50	21.57
VO_2 (ml.kg^{-1}.km^{-1})	Mean	208.15	220.57	231.16	235.76
	SD	(44.16)	(25.04)	(40.46)	(50.85)
	CV (%)	21.22	11.35	17.50	21.57

IMPACT OF LOAD

A comparison of the loaded and unloaded conditions revealed significant differences between conditions, with the consumption of oxygen highest in the loaded conditions. Furthermore, it was observed that oxygen consumption was 2.1% greater when shod compared to unshod, reaching values of 39.34 (±8.73) ml.kg^{-1}.min^{-1} and 38.53 (±6.74) ml.kg^{-1}.min^{-1} for shod and unshod respectively (Table VI). Figure 7 exemplifies the oxygen consumption responses in relation to the loaded and unloaded conditions. A significant increase of 13.4% in oxygen consumption was observed when comparing the unshod unloaded condition to that of unshod loaded. Furthermore the shod loaded condition demonstrated a 4.1% higher oxygen consumption rate compared to that of the shod unloaded protocol. In both the loaded and unloaded conditions, the unshod running style required less consumption of oxygen in comparison to shod running. It should be noted that there is a great deal of variability between conditions, especially in both unshod conditions. Moreover the variability in the shod loaded condition was markedly higher in comparison to unloaded shod running.

SHOD VERSUS UNSHOD

Oxygen consumption followed a similar trend to that of heart rate, with the highest response occurring whilst shod 37.01 (±4.28) $ml.kg^{-1}.min^{-1}$, compared to 34.69 (±7.36) $ml.kg^{-1}.min^{-1}$ when unshod. This difference amounted to a reduction in oxygen consumption of 6.68% for the unshod condition. The variability between shod and unshod running was higher in the unloaded conditions, with the highest variability within loaded shod running.

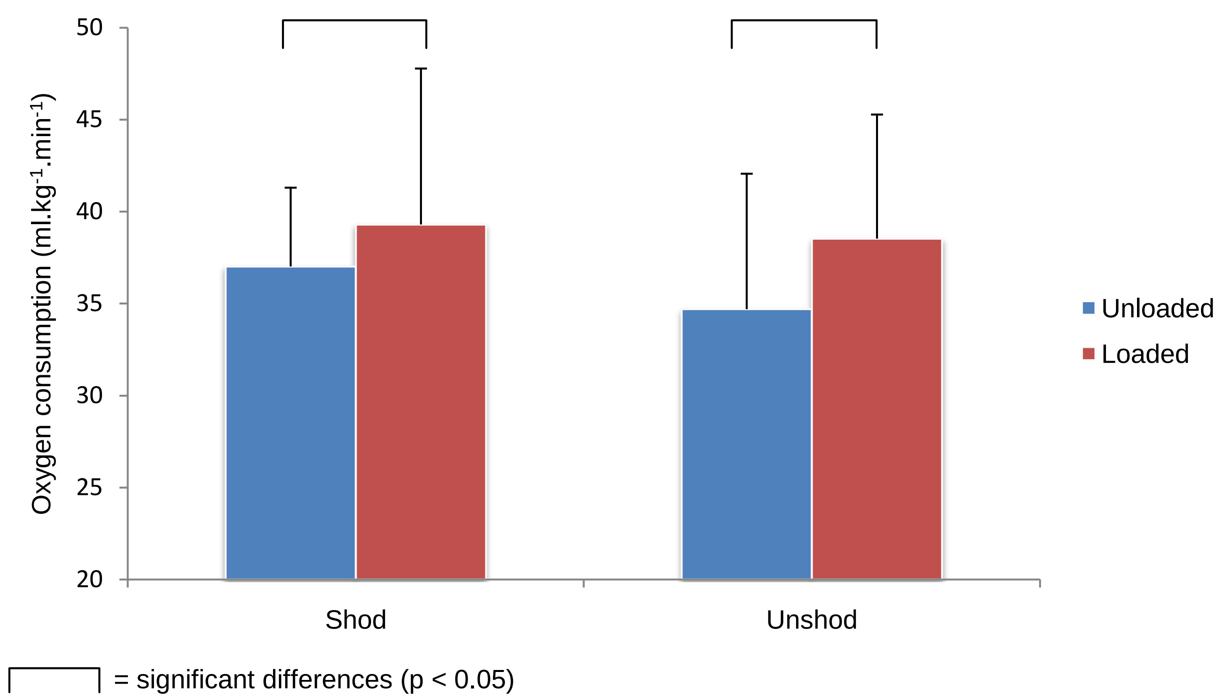


Figure 7: Oxygen consumption responses to shod and unshod running, in both loaded and unloaded conditions.

Energy expenditure

The Quark b^2 analysed EE in a number of ways, allowing comparison in terms of $kcal.min^{-1}$, $kJ.min^{-1}$, $kcal.hr^{-1}$ as well as in terms of power output (PO).

IMPACT OF LOAD

When considering the impact of load on EE (Table VII), it was established that the loaded conditions elicited significantly higher EE rates when compared to the unloaded conditions. The results obtained for the loaded conditions indicated an expenditure rate of 0.197 (±0.04) $kcal.kg^{-1}.min^{-1}$ for the unshod condition and 0.204 (±0.04) $kcal.kg^{-1}.min^{-1}$ whilst running shod – rendering a 3.56% increase in EE. In comparison to the unloaded conditions, the impact of load resulted in an increase in EE of 10.65% in the unshod conditions and 12.25% in the shod conditions.

Table VII: Comparison of EE rates for shod and unshod running. Furthermore, comparison of unloaded to loaded conditions can be observed.

N = 12 10 $km.h^{-1}$		Unloaded		Loaded	
		Unshod	Shod	Unshod	Shod
EE ($kcal.kg^{-1}.min^{-1}$)	Mean	0.176	0.179	0.197	0.204
	SD	(0.03)	(0.02)	(0.04)	(0.04)
	CV (%)	16.75	12.13	20.37	17.22
EE ($kcal.min^{-1}$)	Mean	13.32	13.43	14.76	15.29
	SD	(2.63)	(2.16)	(3.20)	(2.86)
	CV (%)	19.74	16.08	21.68	18.71
EE ($Kj.min^{-1}$)	Mean	55.78	56.25	61.8	64.04
	SD	(11.03)	(9.07)	(13.43)	(12.08)
	CV (%)	19.77	16.12	21.73	18.86
EE ($kcal.hr^{-1}$)	Mean	799.45	806.37	885.85	917.98
	SD	(158.08)	(130.05)	(192.55)	(172.11)
	CV (%)	19.77	16.13	21.74	18.75
PO (watts)	Mean	929.59	937.63	1030.1	1067.41
	SD	(183.81)	(151.22)	(223.90)	(200.13)
	CV (%)	19.77	16.13	21.74	18.75

Furthermore, Table VII presents EE in its various units of measurement. Interestingly noted, the application of a load to a running protocol did not alter the previously established shod versus unshod relationship. This can be said as all the physiological responses under study were reduced in the unshod conditions and higher in the shod conditions. As noted with oxygen consumption, there is a great deal of variability between conditions for all forms of EE, with the greatest deal of variability in the loaded conditions.

SHOD VERSUS UNSHOD

No significant differences were found between shod and unshod conditions; however, it should be noted that the shod condition did elicit higher responses compared to that of the unshod condition, 0.179 (±0.02) $kcal.kg^{-1}.min^{-1}$ and 0.176 (±0.03) $kcal.kg^{-1}.min^{-1}$ respectively, suggesting that it is more efficient to run unshod (Figure 8).

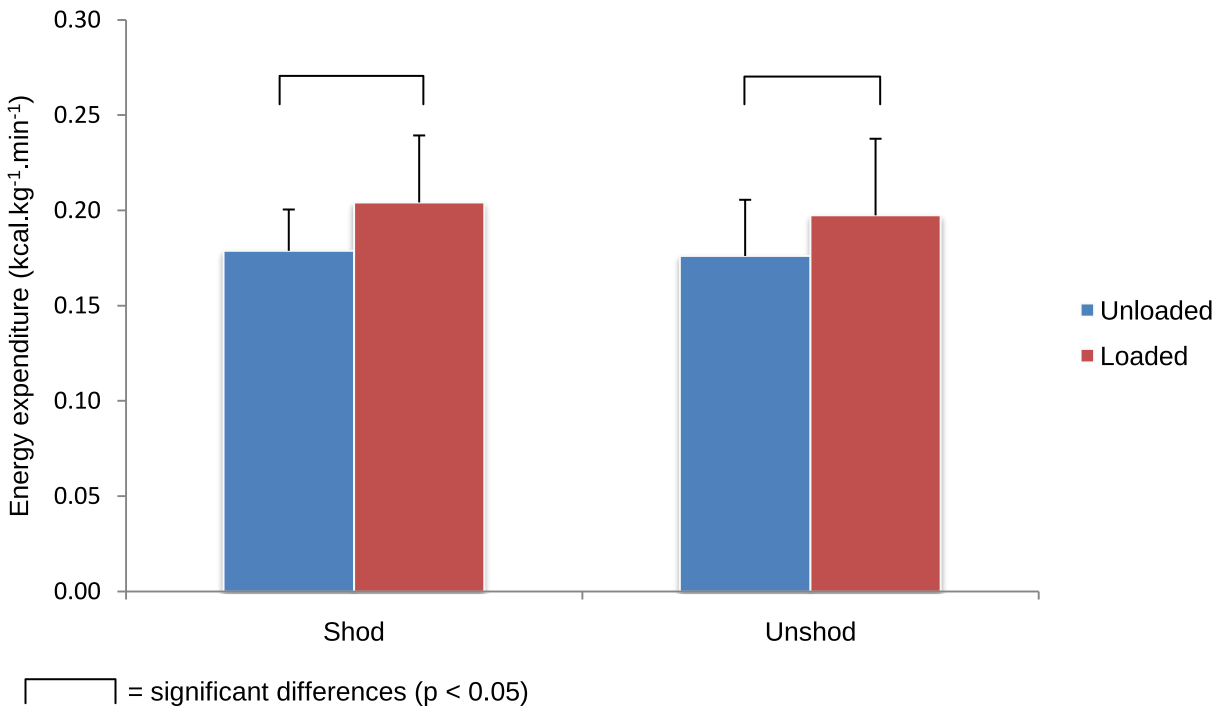


Figure 8: Comparison of EE between shod and unshod and the concurrent impact of load.

The impact of load on the physiological responses whilst running produced significant differences in all three of the physiological variables under study, thereby illustrating the impact that load application has on the physiological system.

PSYCHOPHYSICAL IMPACT

Analysis of psychophysical responses in order to gain a holistic analysis of the perceptual subsystem revealed that the loaded conditions incurred higher ratings of perceived exertion as well as body discomfort. In terms of RPE, no differences were found in the average ratings between shod and unshod. Moreover, there were more body discomfort sightings for unshod running in both loaded and unloaded conditions.

IMPACT OF LOAD

The application of load to shod and unshod running resulted in a significant increase in ratings of perceived exertion, with scores of 12 (±1.54) while unshod and 12 (±1.53) when shod. It can therefore be stated that participants perceived the leg muscles to be under greater demand whilst loaded, when compared to the unloaded conditions. With respect to body discomfort, it can be seen (Table VIII) that the number of sightings increased substantially when a load was applied to the running protocol. The most frequently occurring areas of discomfort whilst loaded include the shoulders (3 and 4), lower back (11 and 12) and the gastrocnemius complex (23 and 24).

Table VIII: Body Discomfort locations and perceived rating of discomfort for shod and unshod running and the effects of load.

Unloaded				**Loaded**			
Condition	**Area**	**Sightings**	**Mean Rating**	**Condition**	**Area**	**Sightings**	**Mean Rating**
Shod	19 20 A	1	4	**Shod**	2P	1	4
	21 22 A	2	2.5		3 4 P	2	4
	23 24 P	4	3.25		5P	3	3.67
					11 12 P	2	3.5
					21 22 A	2	4
					23 24 P	5	4.6
Unshod	23 24 P	6	2.5	**Unshod**	2P	2	3.5
	27 28 P	2	2.5		3 4 P	2	3.5
					5P	1	1
					11 12 P	2	5
					21 22 A	1	5
					23 24 P	4	3.75
					25 26 A+P	1	3
					27 28 P	1	3

A = Anterior side of body; P = Posterior side of body

SHOD VERSUS UNSHOD

Local ratings of perceived exertion did not show as much variation in responses in comparison to what was noted in the biomechanical and physiological variables. For both the shod and unshod conditions the RPE responses were 10 (±1.91) and 10 (±1.92) respectively (Figure 9). With regards to body discomfort, it was noted that there was a relatively similar amount of discomfort sightings in both shod and unshod. It was found that the majority of discomfort complaints related to area 23 and 24, representing that of the gastrocnemius complex, with unshod running accounting for the greater number of sightings. Within the shod condition there were fewer sightings; however the sightings that were made incurred a higher average score in comparison to the unshod rating.

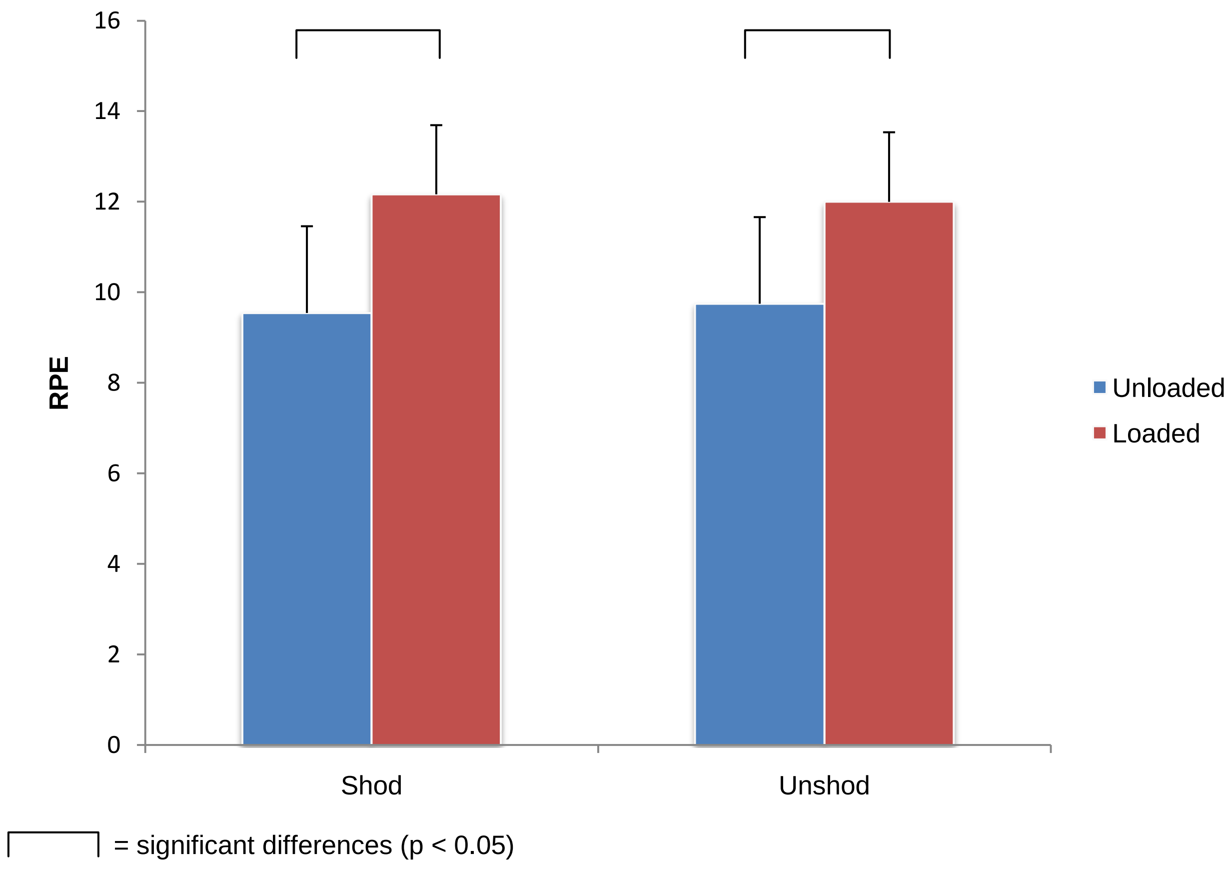


Figure 9: Ratings of perceived exertion of the leg muscles during each condition.

CHAPTER V
DISCUSSION

INTRODUCTION

The aim of this study was to investigate the shod versus unshod relationship whilst concurrently ascertaining the impact that load application had on this relationship. The protocol employed in this study was of a similar nature to previous studies within this field of research. It was however, unique as the impact of load has not been studied during a running protocol.

BIOMECHANICAL IMPACT

Foot strike patterns

Although the foot strike pattern of individuals were not controlled in this study, the way in which the foot came into contact with the running surface was analysed and was used as a co-variable. The vast majority, 83% of participants adopted a RFS in both shod conditions, with the remainder being evenly split between MFS and FFS. This finding is similar to that of Novacheck (1998), who states that 75-80% of runners tend to adopt RFS running gaits when shod. With regard to the unshod conditions, it was observed that whilst unloaded 58% of participants landed in a MFS or FFS. This finding is in accordance with Lieberman *et al.* (2010), who states that barefoot running results in a flatter foot placement due to dorsiflexing the ankle 7-10% less, and therefore as a result tend to land in a FFS or MFS. Exact percentages of FFS patterns were not however measured in Lieberman's study.

With no literature investigating the effects of load on foot strike patterns, interestingly the application of load whilst unshod resulted in individuals reverting to a RFS, with 75% of participants preferring this foot striking pattern. What this illustrates is that the added effect of load in both shod and unshod conditions does in fact alter the individual foot strike patterns. It can therefore be assumed that a loaded RFS will result in greater chance of running related injuries in comparison to an unloaded FFS, based on the arguments presented by Divert *et al.* (2005) and Lieberman *et al.* (2010). This can be argued as it has been found that a shod RFS results in an increased impact transient compared to an unshod FFS, furthermore, a RFS while unshod results in the highest impact transient. This coupled with the additional mass will result in a higher ground reaction force and impact transient – two factors which actively contribute to the prevalence of running related injuries. As noted, the application of load in the unshod condition resulted in 75% of participants reverting to a RFS. Therefore, when loaded it may be detrimental to run unshod or in the VFF, as this may result in a greater preponderance of running related injuries; however, analysis of ground reaction forces would be needed to clarify this argument. Novacheck (1998) contends that as the speed of running increases so the running orientation changes to toe-heel running. Based on this, perhaps if the running speed had been faster, it may have been found that a greater percentage of individuals would have adopted a MFS or FFS running gait. Further investigation is needed.

Stride length and stride frequency

The results obtained relating to SF and SL are in agreement with previous literature regarding the shod and unshod relationship (De Wit *et al.,* 2000; Divert *et al.,* 2005; Divert *et al.,* 2008; Squadrone and Gallozzi, 2009; Lieberman *et al*., 2010). The increased SF and reduced SL that accompanies the unshod condition are indicative of the reduced sole of the VFF. Similarly the larger sole and greater cushioning found in standard trainers allows the individual to strike the ground with a reduced impact transient (in comparison to an unshod RFS), hence reducing the SF and allowing for a greater SL.

Loaded running whilst shod elicited a greater SL and a reduced SF. Conversely the unshod condition produced a shorter SL and an increased cadence. The increased cadence observed while unshod and in the loaded conditions resulted in a decreased contact time and therefore affected the energetics and mechanics of running (Morin *et al.,* 2007). Similarly it can be inferred that an increased contact time accompanied the unloaded and shod conditions. The loaded conditions resulted in significantly lower SL values and significantly higher SF values when compared to the unloaded conditions. These results indicate that the previously established relationship between shod and unshod running in terms of SL and SF (De Wit *et al.,* 2000; Divert *et al.,* 2005; Divert *et al.,* 2008) was not altered by the application of load. However, it does illustrate that the application of load resulted in participants opting for a reduced SL and increased SF.

Two possible explanations for the higher SF and reduced SL during the loaded conditions may become evident when observing the VO_2 and EE values. Firstly, VO_2 and EE may have increased purely as a consequence of the added mass which resulted in an increase in the amount of work done. Secondly, there was an increase in SF in order to maintain balance and stabilization during the required running style, and as a result increases in VO_2 and EE were observed. Therefore, future research investigating a variety of loads and EMG patterns may confirm these theories; however this is beyond the scope of the current study.

Hong & Brueggemann, (2000) postulate that when walking with a load the duration of swing phase decreases and as a result increases in periods of DS are noted. Furthermore, accompanying this decreased swing phase are increases in stride frequency and decreases in stride length (Knapik et al., 1996; Hong & Brueggemann, 2000; LaFiandra et al., 2003). During running there are no periods when both the feet are in contact with the ground (Novacheck, 1998). Rather DS is replaced by two periods known as float. Therefore, the application of load during running must reduce these float periods and in turn increase the SF and reduce the SL.

PHYSIOLOGICAL IMPACT

HR, VO_2 and EE responses have not been extensively studied in shod and unshod running, due to the nature of the methodologies employed. Most of the methodologies made use of runways instead of treadmills and as a result did not acquire continuous data collection with regard to these physiological variables (De Wit *et al.,* 2000, Lieberman *et al.,* 2010). Studies that have considered physiological responses have focused on the oxygen consumption responses, with little data available regarding the heart rate responses. Studies that did employ the use of a treadmill (Divert et al., 2005; Divert et al., 2008), did not however measure heart rate, as the main focus was on VO_2. The nature of this study allowed for the constant monitoring of these variables over a six minute period.

Heart rate

There were no significant differences between shod and unshod conditions in terms of HR, similar to the findings of Squadrone and Gallozzi, (2009). The HR responses obtained from this study were 138 (±18.10) $bt.min^{-1}$ when shod and 133 (±15.18) $bt.min^{-1}$ while unshod. Results presented by Squadrone and Gallozzi, (2009) when running at a speed of $12km.h^{-1}$were 129 (±4) $bt.min^{-1}$ when wearing the VFF and 130 (±5) $bt.min^{-1}$ when running shod. Given the higher speed employed it would be expected that HR responses obtained by Squadrone and Gallozzi, (2009) would be higher; however this was not the case. This can be attributed to the vastly different samples employed in the studies. The participants utilised by Squadrone and Gallozzi, (2009) were experienced barefoot runners of a substantially higher age 32 (±5) years. Furthermore, these participants appeared to be of a more highly trained status, obtaining a mean 10km race time of 40.3 (±4 min), translating to 4.03min/km. These results indicate how differences in training status and the added effect of being a habitual barefoot runner may affect the results obtained. However, and most importantly, this study observed no significant differences between shod and unshod conditions.

When calculating average HR according to the age predicted maximum, during the unloaded conditions, participants were performing at 70% and 67% for shod and unshod conditions respectively. What this illustrates is that the demand placed on the cardiovascular system is approximately within the endurance range of performance, therefore suggesting the demands of the experimental conditions utilised were similar to that of an endurance event.

The impact of load produced significant increases in HR compared to that of the unloaded conditions. The higher HR elicited in the shod condition 143 (±14.05) $bt.min^{-1}$ produced a 3.5% increase in HR compared to the unloaded condition. Similarly, a 5% increase in HR was observed when comparing the unshod conditions in terms of unloaded and loaded running. Subsequently, according to the age predicted HR method, participants were exercising at 72 and 73% for unshod and shod respectively.

Oxygen Consumption

When comparing shod and unshod running in terms of $VO_{2,}$ the unshod condition elicited lower oxygen consumption rates. Although not statistically significant, these findings may have practical significance for performance at an elite level. Squadrone and Gallozzi, (2009) observed a significant decrease in VO_2 (2.8%) and hence a reduction in the energy cost of unshod running. The results from this investigation demonstrated a non-significant decrease (6.68%) in VO_2 when comparing shod to unshod conditions. The fact that Squadrone and Gallozzi, (2009) found a 2.8% decrease in VO_2 to be significant, whereas the 6.68% decrease in this study was not significant may be attributed to variations in samples employed. The participants used in this study were of a lesser trained status and were not frequent barefoot runners, and as a result a larger variability was observed in conditions. This demonstrates how various samples utilised can affect the results.

Running economy may be expressed as the steady state sub-maximal VO_2 at a given running speed (Larsen, 2003). In terms of running economy the unshod condition elicited values of 208.15 (±44.16) $ml.kg^{-1}.km^{-1}$ compared to 220.57 (±25.04) $ml.kg^{-1}.km^{-1}$ while shod (Figure 10). This increased efficiency implies that for the same relative intensity an individual who runs unshod will require approximately 5.63% less oxygen; this has obvious benefits for overall performance. Furthermore, this increased efficiency could be the difference between winning and losing a race, therefore, further indicating the performance implications of this finding.

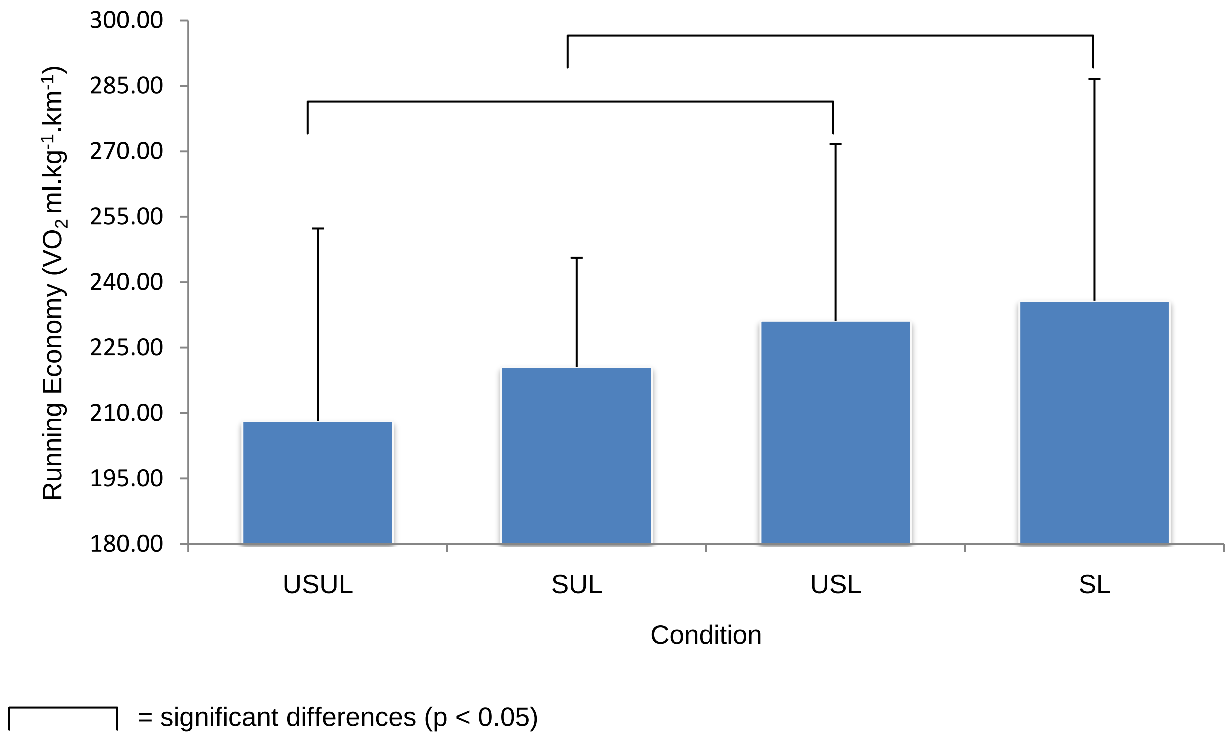


Figure 10: Running economy of each respective condition (USUL = unshod unloaded; SUL = shod unloaded; USL = unshod loaded and SL = shod loaded).

It should be however be noted that there was significant variability 21% within the unshod condition (bar 1). Meticulous analysis of the unloaded conditions revealed that four participants incurred an increase in VO_2 in the unshod condition. In addition to this, three of these participants adopted a RFS with the other participant landing in a MFS (Table IX). However, all participants who adopted a FFS when unshod demonstrated a decrease in VO_2; it can therefore be argued that the increased variability may be attributed to the foot strike pattern. Therefore, further investigation into the number of subjects that actually FFS when barefoot would be necessary, as it would appear that the advantages of barefoot running are only apparent when the footstrike pattern changes. It would be interesting therefore to establish if there is a habituation process, whereby subjects gradually adjust the foot strike pattern from a predominately RFS to FFS when first exposed to barefoot running.

Table IX: Comparison of unloaded conditions (shod and unshod) in terms of oxygen consumption. (RFS = rear foot strike, MFS = mid-foot strike and FFS = fore-foot strike).

SUL		USUL	
RFS	202.06	164.90	MFS
RFS	209.68	119.49	RFS
RFS	204.12	209.67	RFS
RFS	234.86	256.73	RFS
RFS	198.08	189.07	RFS
RFS	216.27	215.03	RFS
RFS	283.13	291.73	RFS
FFS	250.54	244.89	FFS
MFS	221.63	210.56	RFS
RFS	209.29	211.83	MFS
RFS	218.82	197.75	RFS
RFS	198.35	186.15	RFS
Mean	**220.57**	**208.15**	**Mean**
SD	**25.04**	**44.16**	**SD**

Analysis of the loaded conditions revealed similar results, with the unshod condition eliciting a lower VO_2 rate. Comparison of unloaded and loaded conditions demonstrated significant increases in VO_2 for both shod and unshod running. This shows that the application of a load has a significant effect on the rate of oxygen consumption for both foot conditions. Similarly, Myers and Steudel, (1985) observed that imposing a load of 3.7kg during shod running resulted in a 3.7% increase in VO_2. Interestingly, the results from this investigation illustrate that the degree to which VO_2 rose from unloaded to loaded was greater in the unshod condition, increasing by 13% in comparison to 4% in the shod condition. What is clear is that the load had a far greater impact on the unshod conditions than that of the shod conditions. Therefore, this is a key consideration and needs to be taken into account when running with loads. This is of great importance when competing in sports that require load carriage. For example, in races such as the Dusi canoe marathon - where a substantial portion (18-26km dependent on race strategy) of the race is comprised of portaging – using the VFF instead of the traditional running shoes may prove to be more beneficial in terms of performance, and may be the difference between first and second place.

Kram and Taylor (1990) contend that the economy of running has little to do with the work done against the environment but rather it is two-fold. Firstly it involves the efficiency with which an individual can continually produce the work required by the muscles and tendons to lift and accelerate the body and limbs. Secondly it involves an inverse relationship to stride frequency, in that the faster or quicker the stride frequency the less efficiently that individual will be running. This was not the case in this investigation, as SF was significantly higher in the unshod conditions, however the VO_2 – and hence economy – was reduced in these conditions. It could therefore be suggested that the finding by Kram and Taylor does not apply to unshod running but only to shod running.

Energy expenditure

EE was analysed in a number of ways, allowing comparison in terms of $kcal.min^{-1}$, $kJ.min^{-1}$, $kcal.hr^{-1}$ as well as in terms of power output (PO). Since EE is a derivative of VO_2 it was expected that EE would be higher in the shod conditions for both loaded and unloaded running. This was the case in this investigation, with the highest EE observed during loaded running in the shod condition. The lowest rate of EE was demonstrated when unloaded and unshod. Analysis of EE in the unloaded conditions in terms of $kj.min^{-1}$ elicited values of 55.78 (±11.03) while unshod and 56.25 (±9.07) for the shod condition. Squadrone and Gallozzi, (2009) obtained a decrease of 1.3% in EE when running barefoot in comparison to standard running shoes. The results from this study produced similar responses, recording a decrease in EE of 1.68% when running unshod.

EE values rose significantly when running with a load, amounting to increases of 10.7% and 12.3% for unshod and shod running respectively. It can therefore be seen that the rate of EE is higher for the shod conditions and even greater when required to run with a load. As with VO_2, running economy can also be expressed in terms of EE. Results indicated that unshod running results in a reduced rate of EE and hence allows an individual to exercise more economically thus having implications on performance. This becomes evident when considering PO, the rate at which the body converts chemical stored energy to that of mechanical energy and heat (Zoladz *et al.,* 1995). The required rate at which the body converts chemical to mechanical energy was lower in the unshod conditions, illustrating that the demand placed on the body to convert chemical energy to mechanical energy was to fuel exercise was less compared to shod running. The relatively large variance within conditions could possibly be attributed to the fact that individuals were not accustomed to running with a load, and perhaps if a longer habituation period were instated, this variability may have been reduced, hence resulting in more marked differences.

Table X: Subject masses and loads as a function of body mass

	Mass (kg)	Load (%BW)
Subject 1	76.27	13.11
Subject 2	75.14	13.31
Subject 3	88.98	11.24
Subject 4	69.36	14.42
Subject 5	66.32	15.08
Subject 6	68.84	14.53
Subject 7	66.8	14.97
Subject 8	84.16	11.88
Subject 9	84.6	11.82
Subject 10	75.6	13.23
Subject 11	74.18	13.48
Subject 12	73.66	13.58
Mean	**75.33**	**13.39**
SD	**7.31**	**1.25**
CV (%)	**9.70**	**9.35**

A variety of authors (Keren et al., 1981; Charteris et al., 1989; Abe et al., 2008a; Abe et al., 2008b) contend that the metabolic cost whilst walking with loads does not change unless the load is 20% of the subject’s body weight or greater, a situation coined as the *free-ride* hypothesis. Interestingly, it seems that no *free-ride* occurred in either of the loaded conditions while running. This is exemplified by the fact that the load that was applied was less than 20% of body weight for all individuals tested (Table X). However, significant differences were observed in EE and other physiological variables when comparing loaded to the unloaded conditions. It can therefore be argued that the *free-ride* hypothesis does not apply to running as it does to walking. This however, calls for further investigation, possibly investigating the effect of a variety of loads during running at different speeds and gradients.

PSYCHOPHYSICAL IMPACT

In an attempt to gain a holistic approach with regard to this study, psychophysical data was collected in the form of RPE (Borg, 1982) and body discomfort (Corlett and Bishop, 1976). This allowed for an investigation into the perceptual subsystem of each individual.

Ratings of perceived exertion

Each subject rated the local perceived exertion of the musculature that was mostly affected by the imposed task. It was observed that no differences in RPE were obtained between shod 10 (±1.92) and unshod 10 (±1.92) for unloaded conditions. There was however a significant difference in the level of rating between loaded and unloaded, with the loaded conditions eliciting values of 12 (±1.53) while shod and 12 (±1.54) for unshod. Participants therefore did perceive the loaded condition to be more taxing on the musculature. A possible limitation to this finding is the fact that individuals may not have been completely competent in using this scale; as for most individuals it was the first time that it had been used. Regardless of this fact, RPE is still a beneficial measure of subjective exertion and therefore provides valuable information to the study.

Body discomfort

Ratings of body discomfort were relatively similar for both shod and unshod running whilst unloaded, incurring 7 and 8 sightings respectively. Interestingly, the most frequently occurring area of discomfort while unshod was that of the gastrocnemius complex (23 and 24). A possible reason as to why this is the case could correspond to the increased prevalence of FFS and MFS while unshod. This may have therefore have required a greater activation of this group of muscles (triceps surae). This may be explained by the argument presented by Lieberman *et al.* (2010) in that during a FFS initial contact takes place at the front of the foot, this causes the ankle to dorsiflex as the heel drops under the control of triceps surae. This illustrates that co-activation of triceps surae occurs during a FFS. Furthermore, given the fact that none of the participants were habitual barefoot runners, and hence were not accustomed to FFS running, this increased activation may have been perceived as discomfort. Electromyographic analysis of this muscle group in future studies could confirm this.

Whilst loaded the number of sightings increased substantially with the shod condition recording a larger number of sightings (15) in comparison to that of unshod (14). The most frequently occurring areas of discomfort were perceived in the shoulders (3 and 4), lower back (11 and 12) and the gastrocnemius complex (23 and 24). Furthermore, a comparison of the mean rating of discomfort between loaded and unloaded revealed that the discomfort within the gastrocnemius complex was elevated in the loaded conditions, demonstrating that the muscles were possibly more taxed when running with a load. The increase in body discomfort in the shoulders and lower back can be attributed to the application of load, as no sightings in this area were recorded when unloaded. As with RPE, body discomfort ratings may be limited by the fact that individuals may not have fully understood the rating procedure.

CONCLUSION

It can be concluded that the foot condition (shod and unshod) as well as the added effect of the load, resulted in alterations to kinematic variables. The changes in foot strike patterns increased SF and reduced SL contributed to changes in the physiological and psychophysical variables. In addition, physiological and psychophysical increases may have been purely as an effect of the additional mass employed in the loaded conditions.

The lower HR observed in the unshod conditions can be a direct result of individuals adopting a FFS, a factor that has shown to decrease physiological responses (Squadrone and Gallozzi, 2009; Lieberman *et al.,* 2010). Furthermore, it has been found that barefoot running allows for a more compliant ankle, resulting in the absorption and conversion of energy at initial contact, (Bishop *et al.,* 2006). This too may have contributed to the reduced demand on the heart. The significant increase in HR observed in the loaded conditions may be attributed to the additional mass that individuals were required to carry. It could be argued that the increased mass required greater muscle activation and hence an increased demand on the cardiovascular system.

With 83% of individuals adopting a RFS during both loaded conditions, it can be expected that any benefits of the barefoot condition evidenced unloaded (Squadrone and Gallozzi, 2009; Lieberman *et al.,* 2010) would be lost when running with a load. Results indicate that when loaded participants were operating at 73% and 72% of the age predicted maximum, interestingly the increases in HR during the loaded conditions were higher for the unshod condition (5.05%) compared to only 3.54% in the shod conditions suggesting that even though HR is lower in the unshod condition it is perhaps better to run shod when loaded. It must however been noted that HR is subject to great variability as it is affected by many different factors, therefore VO_2 may be a better indicator of this.

Surprisingly, the results from this investigation illustrate that the degree to which VO_2 rose from unloaded to loaded was greater in the unshod condition, increasing by 13% in comparison to 4% in the shod conditions. What is clear is that the load had a far greater impact on the unshod conditions than that of the shod conditions. This finding combined with similar findings in terms of HR suggests that it is perhaps better to run shod while loaded. In spite of this, the results infer that it is still more efficient to run unshod whilst loaded. Therefore, this is a key consideration and needs to be taken into account when running with loads. There is a need to establish HR responses at a greater number of speeds and loads, as conditions may exist where unshod running is in fact worse than shod running.

It can therefore be seen that kinematic changes have the ability to influence both physiological and psychophysical responses to shod and unshod running. In addition the application of load to a running protocol also has the ability to affect the biomechanics of shod and unshod running, thus in turn affecting the physiological and perceptual responses.

CHAPTER VI
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

Running has become increasingly popular over the last century with more and more people running for sporting, recreation or health reasons. However due to the highly repetitive nature of running and the abrupt lower limb loading, the magnitude of running related injuries that present themselves in frequent runners, has lead to many athletes seeking medical and orthopaedic attention (Warbuton, 2001). In order to compete and excel in sport, the athlete is required to have the necessary equipment that accompanies the sport. The same is true for running; having a pair of suitable running shoes allows the athlete to run comfortably and efficiently. However, given the increased prevalence of running related injuries associated with shod running, and the recently established benefits that accompany barefoot running it is believed that athletes can now compete at elite levels without the added expense of running shoes. This is of great importance in a South African context since there is a population of athletes who lack the funding to regularly replace their trainers. Other benefits that accompany unshod running include a decrease in heart rate, oxygen consumption and EE. Therefore, the significance of these reduced responses is of great importance when competing at an elite level.

Load carriage has shown to bring about increases in the physiological and perceptual responses when walking. Given this finding and the higher speeds employed during running, the effects of loaded running are still to be established. Furthermore, with sports such as canoeing with portaging and other adventure sports becoming more popular there is an increasing need to investigate the implications of load carriage during running and whether or not the added benefits that accompany unshod running are applicable to a load carriage scenario. Therefore, the purpose of this investigation was to ascertain the impact of load carriage on the biomechanics and physiology of shod and unshod running. The independent variables were therefore foot condition and load, while the main dependant variables were that of stride length and stride frequency, heart rate, oxygen consumption and EE. These variables were assessed in four experimental conditions each of six minutes in duration.

SUMMARY OF PROCEDURES

The test protocol involved testing 12 male participants, with the mean age of 22 (±1.53) years. Inclusion criteria included a minimum of 15km of road running per week, as well as no form of running related injury at the time of the study. This benchmark was set to ensure that the sample tested was at least of a moderate training status and had some form of experience in running. Furthermore, the criterion ensured no unnecessary gait alterations resulted from pain due to a running related injury. A further exclusion criterion - as a result of limited funding - for this study was shoe size between 9 and 11(UK sizing). Each subject was required to attend three sessions, each of approximately 30 minutes in duration; an introductory session followed by two testing sessions occurring on different days. Four experimental conditions (two shod and two unshod) each lasting for a total of six minutes, were performed in the testing sessions. The experimental conditions required participants to run on a motorized treadmill at a speed of $10km.h^{-1}$, while the loaded conditions utilised a load of 10kg. The barefoot condition was represented by the use of VFF, a modern day barefoot technology that is said to mimic barefoot running.

The introductory and habituation session informed participants of the purpose and aims of the study as well as the details of each testing procedure. Thereafter, participants were introduced to the equipment utilised during experimentation, and were informed about what each device measured and how it was measured. A letter of information regarding the study was issued to each subject - this was done to ensure that each subject fully understood the testing procedure and what was required of them. Once the letter was read and understood, participants were asked to sign an informed consent form giving permission for the author to use the subject’s data in the project. Following this, resting heart rate (RHR) was recorded in the supine position followed by stature

(Harpenden stadiometer), mass (Taledo© scale) and leg length (Holtain anthropometer). Participants were then required to have a brief habituation session on the treadmill; this ensured each subject was familiarised to running with the Vibram Five Fingers, the treadmill speed, the load as well as running within a confined space. The habituation session to the different experimental conditions was carried out until participants felt comfortable, thus allowing for a thorough habituation. The experimental sessions commenced within a week of the introductory session. Participants were allocated a total of six minutes to warm-up and stretch, with three minutes allotted for each. A rest interval allowing HR to return within 5% of RHR was implemented between conditions, thereby making total test time for equipment fitment and testing approximately 30minutes for each experimental session.

A time frame of six minutes was instated, which allowed for a steady state exercise level to be achieved. Moreover, data were recorded at the fourth and sixth minute of testing and included measurement of VO_2, EE, HR, foot strike patterns, SL, SF, local RPE as well as BD. These variables were recorded by employing the use of the Quark b^2 ergospirometer, heart rate monitor and response counter respectively. During all testing protocols standardised testing conditions were adhered to for all participants.

SUMMARY OF RESULTS

Due to the number of variables under experimentation, the results obtained were divided into biomechanical, physiological and psychophysical variables. This was done in order to investigate the effect of foot condition and load on each of these variables, thereby making interpretation more manageable.

Biomechanical Impact

FOOT STRIKE PATTERNS

Analysis of foot strike patterns indicated that while shod 83% of participants adopted a RFS in both the unloaded and loaded conditions. When running in the VFF with no load 58% of the participants opted for a FFS or MFS with the remainder adopting a RFS when unloaded. Interestingly when load was added, 75% of the participants reverted from a FFS to a RFS.

STRIDE LENGTH

SL demonstrated significant differences ($p<0.05$) between foot condition and between loads. SL was significantly higher in the shod condition increasing from 2.12 (±0.127) m during unshod to 2.15 (±0.142) m when shod. These values were significantly reduced with the introduction of load to 2.05 (±0.126) m and 2.10 (±0.107) m for shod and unshod respectively.

STRIDE FREQUENCY

SF produced similar results to that of SL with significant differences observed between shod and unshod as well as with the application of load. The unshod condition recorded a less frequent stride rate 78 (±5.2) st.min^{-1} when compared to the shod condition 79 (±4.48) st.min^{-1}. The application of load resulted in a significant ($p < 0.05$) increase in SF, eliciting a mean value of 81 (±4.81) st.min^{-1} in the unshod condition. SF in the shod condition while loaded was lower than the unshod condition, demonstrating a rate of 79 (±3.92) st.min^{-1}.

Physiological Impact

HEART RATE

The demand placed on the cardiovascular system showed significant differences ($p < 0.05$) when comparing unloaded conditions to those of the loaded trials. Unshod running consistently produced lower HR responses throughout conditions, eliciting a response of 133 (±15.18) bt.min^{-1} when unloaded; a 5 bt.min^{-1} decrease when compared to shod running 138 (±18.10) bt.min^{-1}; although there was no significant difference. Conversely the loaded conditions elicited significant increases of 7% (unshod) and 4.8% (shod) in HR when compared the unloaded conditions.

OXYGEN CONSUMPTION

Examination of VO_2 illustrated that the rate of oxygen consumption was lower in the unshod condition, coinciding with the reduced HR. Further analysis indicated that VO_2 was 6.7% higher when running shod. In terms of running economy, VO_2 while unshod 208.15 (±44.16) $ml.kg^{-1}.km^{-1}$ amounted to a 5.6% reduction in comparison to the VO_2 value obtained in the shod condition 220.57 (±22.04) $ml.kg^{-1}.km^{-1}$, thus illustrating the performance benefits associated with unshod running. Analysis of shod and unshod running whilst loaded produced significant differences ($p < 0.05$) in comparison to unloaded running, with a 13.4% increase in VO_2 while unshod and an increase of 4.1% when in the shod condition.

ENERGY EXPENDITURE

The rate at which energy was expended was reduced when running unshod however this finding was not significant ($p \leq 0.05$). Results indicated that the shod condition elicited a response of 0.179 (±0.02) $kcal.kg^{-1}.min^{-1}$ compared to 0.176 (±0.03) $kcal.kg^{-1}.min^{-1}$ while unshod. The application of a load resulted in significant increases ($p<0.05$) in the rate of EE, with the shod condition incurring the highest rate of expenditure, eliciting a value of 0.204 (±0.04) $kcal.kg^{-1}.min^{-1}$. This finding was 3.43 % higher than the value obtained in the unshod condition while loaded 0.197 (±0.04) $kcal.kg^{-1}.min^{-1}$. The significant difference obtained between loaded and unload conditions applies to all forms of EE ($kcal.min^{-1}$, $kJ.min^{-1}$, $kcal.hr^{-1}$ as well as in terms of power output).

Psychophysical Impact

Analysis of perceptual responses allowed for a subjective interpretation how the body was affected by foot condition and the application of load. This provided important information with regard to how each individual coped with the various experimental conditions.

RPE

Results indicated that participants perceived no differences between the shod and unshod conditions in terms of unloaded running. Shod running elicited a response of 10 (±1.92) while unshod running produced a similar result of 10 (±1.91). A comparable finding was observed when comparing loaded conditions with the shod and unshod conditions, eliciting similar perceptions of exertion, 12 (±1.54) and 12 (±1.53) for shod and unshod respectively. This indicates that although participants did not perceive changes in footwear to have an impact on the task demands, the inclusion of a load resulted in a statistically significant increase in RPE.

BODY DISCOMFORT

Ratings of body discomfort were relatively similar for both shod and unshod running whilst unloaded, incurring 7 and 8 sightings respectively. The most frequently occurring area of discomfort while unshod was that of the gastrocnemius complex. Whilst loaded the number of sightings increased substantially with the shod condition recording a larger number of sightings (15) in comparison to that of unshod (14). The most frequently occurring areas of discomfort were perceived in the shoulders, lower back and the gastrocnemius complex.

HYPOTHESES

Two statistical hypotheses were proposed for the current study; firstly that there would be no difference between the shod and unshod conditions in terms of the biomechanical, physiological and psychophysical responses. Secondly, the results obtained from the unloaded conditions will be equal to that of the loaded conditions in terms of the biomechanical, physiological and psychophysical responses.

Statistical analysis of the biomechanical, physiological and psychophysical responses indicated that the results of the shod and unshod condition elicited mixed responses. Statistical significance was found in terms of the biomechanical responses between shod and unshod running, therefore the null hypothesis: Ho: $\mu pS = \mu pUS$ can be rejected in terms of the biomechanical responses. (p = Biomechanical responses; S = Shod; US = Unshod). However, in terms of physiological and perceptual responses, the null hypothesis: Ho: µpS = µpUS must be tentatively accepted, as no significant differences were observed between shod and unshod running (p = Physiological and perceptual responses; S = Shod; US = Unshod).

Further statistical analysis of the loaded conditions in terms of shod and unshod running, demonstrated significant differences in all three variables; biomechanical, physiological as well as psychophysical. Therefore the null hypothesis: Ho: µpL = µpUL can be rejected (p = Biomechanical, physiological and psychophysical responses; L = Loaded; UL = unloaded).

CONCLUSIONS

Previous literature demonstrated significant differences between shod and unshod running (Warburton, 2001; Divert et al., 2005; Divert, et al., 2008; Squadrone and Gallozzi, 2009); however, the results obtained in this study do not support previous outcomes. The results indicate that unshod running significantly altered the kinematics of the foot at stance phase and as a result produced changes in the cardiovascular and perceptual subsystems. This ultimately resulted in a more economical form of running gait and therefore has implications for improved performance. Future research into this could prove beneficial to the body of sports science knowledge.

Foot condition was found to have had a significant effect on the biomechanical responses; this however, was not the case for the physiological and psychophysical responses. Based on the results, conclusions can be drawn that foot condition has the potential to alter the foot kinematics at initial contact and hence cause subsequent changes to the physiological and psychophysical responses. A variety of authors (Divert et al., 2005; Divert, et al., 2008; Squadrone and Gallozzi, 2009) observed significant decreases in the physiological responses associated with barefoot running. These studies however employed longer habituation periods, or participants that were accustomed to barefoot running. It could be argued that, if a longer habituation period had been instated or if a larger sample (more accustomed to barefoot running) was utilised within this study, the variance between participants may have been reduced and in turn significant differences in physiological responses may have been noted. In spite of this, the decreases in HR, VO_2 and EE observed in the unshod condition and in previous literature suggest that it is more economical to run barefoot. It can therefore be concluded that unshod running proves to be beneficial in many respects.

Load carriage during a running protocol had a significant effect on the biomechanics of shod and unshod running, and thus resulted in significant alterations to the physiological and psychophysical responses compared to the unloaded conditions. The application of load resulted in increases in HR, VO_2, EE, RPE as well as body discomfort. The increases in responses can be attributed to the added mass and hence increased work required to perform the experimental conditions. Based on the results obtained, the application of load did not alter the shod versus unshod relationship – in that unshod running consistently produced lower responses. It is however noteworthy that the application of load did in fact alter the foot strike pattern, with 75% of participants reverting from a FFS in the USUL condition to a RFS when running unshod with a load. The implications associated with this change, may result in a higher ground reaction force, which may contribute to increased physiological costs as well as increased prevalence of running related injuries; future research into the effect of load on ground reaction forces may clarify this argument.

Although unshod running produced lower physiological and perceptual responses on a consistent basis, the degree to which load affected the unshod responses was far greater than that of shod running. For example the application of load produced a 13.4% increase in VO_2 and EE in the unshod conditions, compared to a 4.1% increase when shod. Therefore, under different circumstances (i.e. a greater load, faster speed or a gradient effect), the changes in unshod running may become more marked, and in turn may result in shod running being more beneficial. Investigations into the effect of different loads, speeds and perhaps gradients may therefore result in an alteration to the shod versus unshod relationship. As a result future research into this area may provide a more comprehensive understanding into the effects of load carriage on the shod and unshod relationship. However, based on the methodology employed in this study, it can be concluded that it is more beneficial - in terms of performance - to run unshod in comparison to shod.

RECOMMENDATIONS

A result of the relatively small sample employed in this study means that the extrapolation of results may not fully represent the entire running population, however the meticulous efforts made to reduce extraneous variables and therefore inter-subject variability signifies that the results obtained are valid as well as reliable.

The added benefits that accompany unshod running are apparent. Furthermore, the performance benefits arising from barefoot running suggest that it would be beneficial for athletes to train for and run marathons while unshod. It is however recommended that thorough training and habituation to barefoot running is employed before setting out and running a marathon unshod. Training on a grass track would be the best place to start barefoot running, and as the feet begin to adapt and harden to this nature of running, only then should the athlete progress to tar and harder surfaces. It is recommended that while progressing from shod to barefoot running, that an intermediary such as the VFF, a barefoot technology, be used to train and compete with. This shoe has shown to present the added benefits of unshod running, whilst at the same time negating the negative aspects of barefoot running (i.e. danger of injury – puncture wounds), thereby providing protection to the plantar fascia.

In terms of running while loaded, the same benefits that accompany unshod running apply, however these are to a lesser extent (this is evident in the results obtained for VO_2). As previously mentioned, the degree to which load affects unshod running, is greater than that of shod running. As load is applied, the margin to which shod and unshod running differ begins to reduce, resulting in unshod running approximating that of shod running. Consequently, it can be argued that at a higher load or higher speed the margin between shod and unshod running will be further reduced, possibly resulting in shod running producing lower responses than that of unshod running. Accordingly, it is recommended that further studies employ a variety of loads, speeds and gradients in order to ascertain if an alteration in the shod and unshod relationship does occur. Furthermore, if an alteration in this relationship were to take place, it would be beneficial to ascertain at what speed, load or gradient this change materialises. This is of great importance when extrapolating data to adventure racing, as a heavier load my in fact result in shod running being more beneficial, therefore providing invaluable information to adventure athletes.

Given the harsh environmental conditions that accompany adventure racing and the adverse ground terrain, the practicality of barefoot running is limited. This combined with the loads that athletes are required to carry requires extra precaution, as the added mass may result in a greater chance of repetitive stress injuries to the foot and lower limbs. It is therefore recommended that minimal footwear (i.e. VFF) be worn whilst running loaded, as this may reduce the chances of puncture wounds from foreign objects, but at the same time, provide the additional benefits of unshod running. Furthermore, it is recommended that a similar habituation process be implemented when training for loaded running.

It is recommended that future research investigate the effect of different loads at different speeds, to ascertain if the *free-ride* hypothesis holds true for running. Outcomes from this study indicate that the *free-ride* hypothesis during running was not present. All participants utilised in this study were required to carry a load that was well below 20% of body weight 13.39 (±1.25) %. However, physiological responses were significantly higher in the loaded condition compared to that of the unloaded protocol, illustrating that the *free-ride* did not occur. It could therefore be contended that the *free-ride* hypothesis applies to walking and not to running. Additionally, investigations in this area may allow for a more thorough analysis of the shod and unshod relationship ascertaining whether shod running may be better when loaded.

It is recommended that future research be centered on the effects of load on ground reaction forces and the concurrent prevalence of running related injuries. This area of research may help identify precursors for repetitive stress injuries. Additionally, studies focusing specifically on the prevalence of running related injuries between shod and unshod running may aid in a more comprehensive understanding of this relationship. In addition, electromyographic analysis of loaded running while shod and unshod may be advantageous to sports scientists and adventure sport enthusiasts. Future studies should include a larger number of participants, incorporate longer periods of habituation and should specifically look to determine biomechanical and physiological responses between habitually barefoot runners and conventionally shod runners. By ensuring this, it can be expected that the variability between participants will be reduced, and in turn will result in greater validity and reliability within the results.

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APPENDICES

APPENDIX A: GENERAL INFORMATION

EXPERIMENTAL SCHEDULE

LETTER OF INFORMATION

SUBJECT INFORMEND CONSENT

APPENDIX B: DATA COLLECTION

PRE-TEST INSTRUCTIONS

DEMOGRAPHIC AND ANTHROPOMETRIC INFORMTION COLLECTON FORMS

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APPENDIX C: OTHER INFORMATION

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RATINGS OF PERCEIVED EXERTION SCALE

BODY DISCOMFORT MAP AND RATING SCALE

APPENDIX A: GENERAL INFORMATION

Experimental Schedule

Pre-test

- Ensure computer is on and functioning
- Ensure all equipment is available for use
  - Polar HR monitor
  - Backpack (including load)
  - Response counter
  - Video camera
  - Anthropometer
- Ensure Quark b^2 is calibrated

Habituation

- Welcome and introduction (introduce assistants and relevant people).
- Attach HR monitor (water).
- Explanation of all testing equipment
- Seat subject.
- Issue letter of information and allow time to read.
- Verbal introduction to:
  - Research
  - Experimental conditions
  - Equipment.
- Questions.
- Subject informed consent.
- Record reference HR value.
- Demographic and anthropometric measures.
  - Stature

    - Mass
    - Leg length
- Opportunity to practice protocols.
- Treadmill and Quark b^2 setup.
    - Attach face mask
    - Attach HR telemetry unit
    - Apply load if necessary

Test-session 1

Pre arrival

- Ensure equipment is all on and accounted for
    - Polar HR monitor
    - Backpack (including secured load)
    - Response counter
    - Video camera
    - Quark b^2
- Enter subject data into Quark b^2 software

Arrival

- Welcome and thanks.
- Attach HR monitor telemetry strap (water needed).
- Assign condition sequence
- Re-inform subject of test conditions, and conditions to be completed in this session
- Warm up (3minute stretch, 3min run)
- Quark b^2 setup.
    - Attach face mask (try to breathe normally and not to exaggerate your breathing)
    - Attach HR telemetry unit

    - Attach HR monitor to treadmill railing
- Start testing
    - Data collection at minute 4 and 6
        - VO_2 , HR (Quark b^2)
        - SF (response counter)
    - During rest period
        - Remove backpack if loaded condition employed
        - Seat subject
        - Export data to excel and save
        - Wait until HR with 5% of resting HR

Test-session 2

- **Repeat of test session 1; however the remainder of the experimental conditions is to be implemented.**

Letter of information

Dear: ________________________________

Thank you for participating as a subject in my honors project entitled, "Impact of load carriage on the biomechanical and physiological responses to shod and unshod running", your time and effort is much appreciated and is invaluable to me as a researcher.

The purpose of this project is to investigate the differences (both biomechanical and physiological – changes in running motion and heart and lung function) between running with shoes (shod) and running without shoes (unshod). The main objective is to determine the effect of load (in the form of a backpack loaded to 10kg) on this relationship, and whether or not load further alters this relationship. A further investigation attempts to determine if there are differences in terms of the energy cost of running between shod and unshod. The information gathered during the testing protocol will be used to determine these objectives.

PROCEDURES

You will be required to attend three sessions; the first being a basic measurement and habituation session. Firstly an explanation of the testing procedure and what the study aims to achieve will be given to you. Thereafter you will be asked to sign an informed consent form – giving me permission to use you as a subject. Following this stature (height), mass, leg length and resting heart rate will be recorded – this session should be no longer than 30minutes. The second and third sessions involve the actual testing protocol.

The testing protocol requires you to complete four experimental conditions of six minutes each which will be completed in a random order. Two conditions will be implemented in the first test session, with the remaining two experimental conditions being employed in the follow up session. A rest interval allowing heart rate to return to normal will be implemented between conditions, thereby making total test time for equipment fitment and testing approximately 30 minutes per session. Two conditions involve running at a speed of $10km.h^{-1}$ in a shod and unshod state. The other two of the four conditions will be conducted in exactly the same fashion as previously stated; however a backpack with a load of 10kg will accompany the shod and unshod condition. The first three to four minutes of each condition allow for a steady state exercise level (a state where all bodily responses approximate a relatively unchanging level) to be achieved, the remaining two minutes of testing being allocated to data collection.

Oxygen consumption, heart rate, stride length and stride frequency will be the variables under investigation and will be recorded with the Quark b^2 ergospirometer (a piece of equipment that records heart rate, EE, oxygen consumption and many other physiological variables) and response counter respectively. Using the Quark b^2 ergospirometer may be seen to be quite invasive by some, as the mask is fitted to your mouth, however in order to keep you as comfortable as possible, I will converse with you as it is fitted.

Upon completion of the experimentation and interpretation, I will willingly discuss the results of my project with you, thereby sharing the knowledge gained with you, the subject. Please note that any information obtained in both sessions will be kept confidential and at no stage or time will any of your personal information be used or publicised. The data that will be collected during the testing protocol will be used only for statistical analysis. Moreover one copy of the data will be kept in the Human Kinetics and Ergonomics department and may be used for teaching or research purposes, however anonymity is still insured.

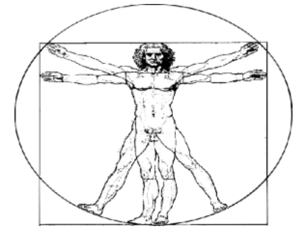
If at any time that you feel you cannot continue with the protocol, please feel free to withdraw from the protocol. Furthermore should you feel you cannot continue with the study, you may by all means withdraw at anytime, this will not result in you being questioned for any reason. If there are any queries that you may have, feel free to contact me in the Human Kinetics and Ergonomics department.

If there are any queries that you may have, feel free to contact me in the Human Kinetics and Ergonomics department.

Yours sincerely

David Goble

(BSc Honours student – Department of Human Kinetics and Ergonomics)



Subject informed consent

RHODES UNIVERSITY

DEPRTMENT OF HUMN KINETICS AND ERGONOMICS

I, ………………………………………… have been fully informed of the research project entitled:

IMPACT OF LOAD CARRIAGE ON THE BIOMECHANICAL AND PHYSIOLOGICAL RESPONSES TO SHOD AND UNSHOD RUNNING.

I have read the information sheet and understand the testing procedure that will take place. I have been told about the risks as well as benefits involved, as well as what will be expected of me as a subject. I understand that all information gained from this project will be treated confidentially, that I will remain anonymous at all times and that data obtained may be used and published for statistical or scientific purposes. All testing procedures, associated risks and the benefits from partaking in this study have been verbally explained to me as well in writing. I have had ample opportunity to ask questions and to clarify any concerns or misunderstandings. I am satisfied that these have been answered satisfactorily.

In light of this, and in agreeing to participate in this study, I accept joint responsibility together with the Human Kinetics and Ergonomics Department, in that should any accident or injury occur as a direct result of the protocols being performed during the study, the Human Kinetics and Ergonomics Department will be liable for any costs with may ensure and will reimburse the subject to the full amount. I.e. doctors consultation, medication etc. The department will, however, waiver any legal recourse against the researchers of Rhodes University, from any and all claims resulting from personal injuries sustained whilst partaking in the investigation due negligence on the part of the subject or from injuries not directly related to the study itself. This waiver shall be binding upon my heirs and personal representatives.

I have read and understood the above information, as well as the information provided in the letter accompanying this form. ***I therefore consent to voluntarily participate in this research project.***

SUBJECT (OR LEGAL REPRESENTATIVE):

_________________________ _________________________ _________________________

(Print name) (Signed) (Date)

PERSON ADMINISTERING INFORMED CONSENT:

_________________________ _________________________ _________________________

(Print name) (Signed) (Date)

WITNESS:

_________________________ _________________________ _________________________

(Print name) (Signed) (Date)

APPENDIX B: DATA COLLECTION

Pre-test instructions

Please inform the researcher of any factors that you think may influence your results on the day of testing, for example if you are taking prescription medication, are asthmatic or are ill. Please note that if you are currently carry any form of injury or have any lower limb problems, as it is advised that you do not participate in the study if this is the case. In order for my results to be accurate, I require that you follow the following instructions before completing the test.

FOR 24 HOURS PRIOR TO TESTING:

- DO NOT DRINK ALCOHOL
- DO NOT PARTICIPATE IN ANY STRENUOUS EXERCISE
- DO NOT TAKE MEDICATION (SUCH AS PAINKILLERS, ASPRIN, FLU TABLETS OR OVER THE COUNTER MEDICATION ETC).
- TRY TO GET AT LEAST 8 HOURS OF SLEEP THE NIGHT BEFORE THE TEST.

ON THE DAY OF TESTING

- EAT A SUBSTANTIAL MEAL APPROXIMATELY 2 HOURS PRIOR TO TESTING
- DO NOT EAT ANYTHING 1.5 HOURS PRIOR TO TESTING
- WEAR COMFORTABLE RUNNING GEAR THAT YOU WOULD GENERALLY WEAR DURIONG A RACE.
- PLEASE BRING ALONG WITH YOU, A SWEAT TOWEL AND WATER BOTTLE.

Please as far as you can, try to comply with the above instructions as this will help me greatly in my data collection. Your cooperation is much appreciated.

Demographic and anthropometric information collection forms

Name:___________________________ Order of testing:____________________________

Age (years):_______________________ Subject Code:______________________________

Body Mass:________________________

Anthropometric Data

VARIABLE	
Stature (mm)	
Mass (kg)	
Leg Length (mm)	
Shoe Size	
Shoe Mass (kg)	

Running History:

____

____

____

____

____

DATA COLLECTION FORMS

Subject Code: ______________________________

Reference HR: ______________________________

Condition:

MIN 3-4

VO_2 ($ml.kg^{-1}.min^{-1}$)	HR ($bt.min^{-1}$)	SF ($st.min^{-1}$)	SL (m)	Local RPE	Body discomfort	

Comments:

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MIN 5-6

VO_2 ($ml.kg^{-1}.min^{-1}$)	HR ($bt.min^{-1}$)	SF ($st.min^{-1}$)	SL (m)	Local RPE	Body discomfort	

Comments:

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APPENDIX C: OTHER INFORMATION
Permutation table

	SESSION 1		SESSION 2	
	CONDITION	CONDITION	CONDITION	CONDITION
SUBJECT 1	1	4	2	3
SUBJECT 2	2	3	1	4
SUBJECT 3	3	2	4	1
SUBJECT 4	4	1	3	2
SUBJECT 5	1	2	3	4
SUBJECT 6	2	4	1	3
SUBJECT 7	3	1	4	2
SUBJECT 8	4	3	2	1
SUBJECT 9	1	3	2	4
SUBJECT 10	2	1	4	3
SUBJECT 11	3	4	1	2
SUBJECT 12	4	2	3	1

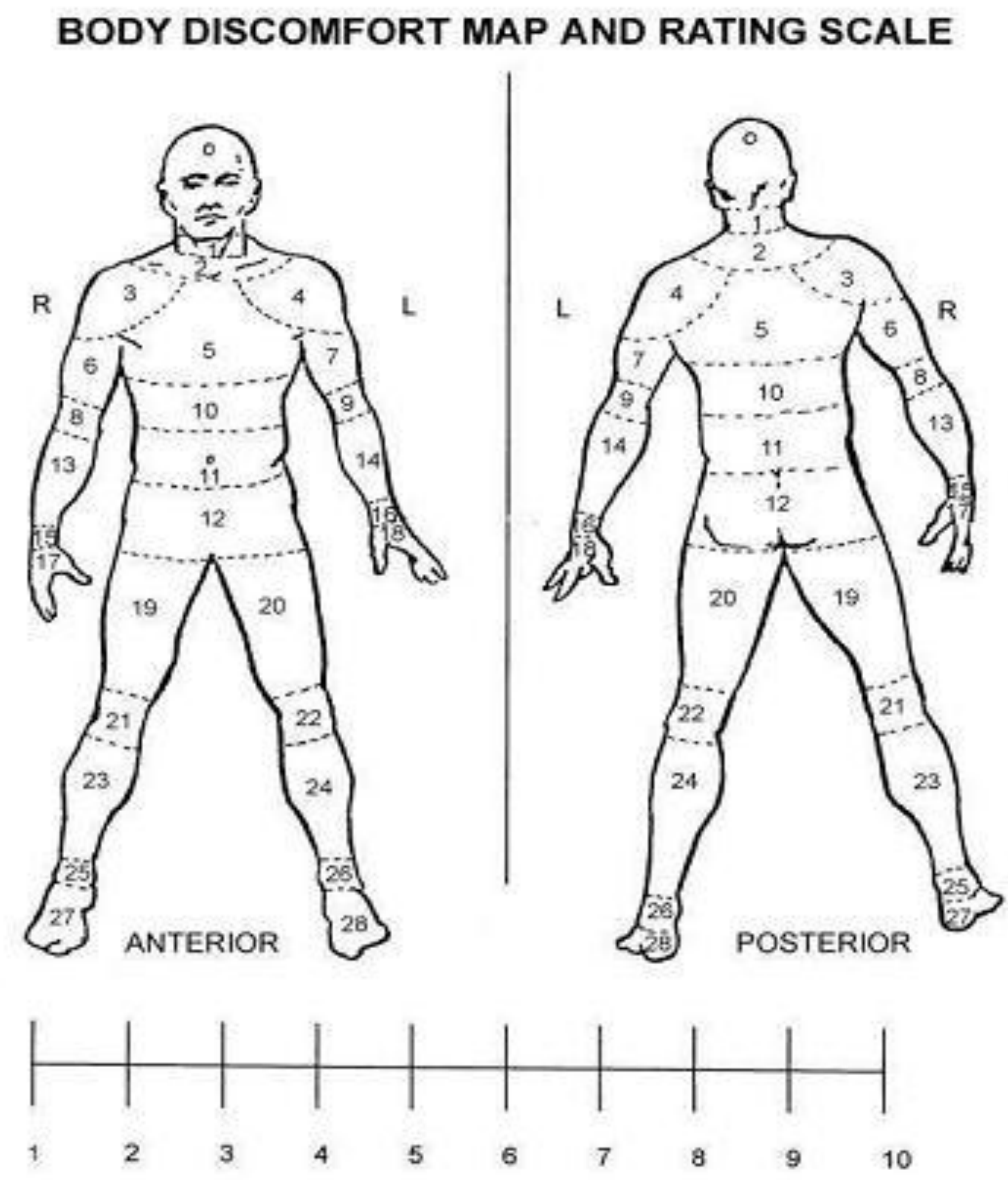
Rating of perceived exertion scale

RPE SCALE

6.	
7.	VERY, VERY LIGHT
8.	
9.	VERY LIGHT
10.	
11.	FAIRLY LIGHT
12.	
13.	SOMEWHAT HARD
14.	
15.	HARD
16.	
17.	VERY HARD
18.	
19.	VERY, VERY HARD
20.	

Adapted from Borg (1982).

Body discomfort scale



Adapted from Corlett and Bishop (1976).