

# **THE EFFECT OF BAREFOOT TRAINING ON SPEED, AGILITY, POWER AND BALANCE IN NETBALL PLAYERS**

BY

**JOHANNA ELSABÈ DU PLESSIS**

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Supervisor: Dr. Ranel Venter

Faculty of Education  
Department of Sport Science

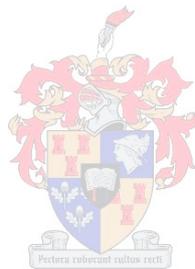
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## DECLARATION

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*“I can do everything through Him who gives me strength.”* Philippians 4:13

## DEDICATION

*I dedicate this study to my Mum.*

*Through her life she has taught me to always trust in God and be positive no matter what!*

*Thank you Mum that you always believed in me!!*



## SUMMARY

The running industry has seen a lot of changes over the past years. Minimalistic footwear and barefoot training are redefining the running industry and community. These new developments have led to extensive research being conducted on the effects of barefoot running on kinetics, kinematics, energy expenditure and the prevention of injuries. Most of the shoe manufacturers have come up with an idea to mimic barefoot running. Barefoot running has shown to increase running economy and decrease impact forces. Inconclusive evidence exists as to whether barefoot training improves proprioception and muscle strength or reduces running-related injuries.

The primary aim of the study was to determine the effects of barefoot training on speed, agility, power and balance in netball players.

Twenty women netball players (age:  $20 \pm 2$  years) volunteered for the study and were randomly assigned to the barefoot group ( $n = 10$ ) and the shod group ( $n = 10$ ). All participants had to attend at least 14 training sessions, where the barefoot group gradually increased the barefoot exercise time. Speed, agility, vertical jump height, single leg stability and lower leg circumferences were measured prior to and after completion of the intervention programme.

At the completion of the intervention programme, participants had to give verbal feedback regarding their subjective experience of barefoot training. Seventy percent of the barefoot participants preferred barefoot training to shod training. The speed test showed a small improvement over 10-metres ( $P > 0.05$ ), but not over 20-metres ( $P > 0.05$ ). Agility had a significant improvement ( $0.14 \text{ seconds} \pm 0.10 \text{ seconds}$ ;  $P < 0.05$ ) on the left and right leg ( $0.19 \text{ seconds} \pm 0.07 \text{ seconds}$ ;  $P < 0.05$ ) for the barefoot group. There was also an improvement in the single leg stability with the right leg showing a significant improvement ( $P < 0.05$ ) in anterior/posterior, medial/lateral and overall stability for the barefoot group. All except the left anterior/posterior index had a small practical effect post-intervention. No significant increases were found in the circumferences or the vertical jump height.

The results show that barefoot training results in improved agility and single leg stability, compared to shod training. The effect it has on the prevention of injuries could not be determined, as the duration of the study was too short. In conclusion it can be deduced that barefoot training has a positive effect on agility and stability, thus possibly leading to improved performance.

**Key words:** Barefoot training, netball, speed, agility, proprioception.



## OPSOMMING

Daar het baie veranderinge in die hardloopwêreld plaasgevind die afgelope paar jaar. Minimalistiese skoene en kaalvoet oefening is van die grootste redes daarvoor. Baie navorsing oor die effek van kaalvoet hardloop op die kinetiese en kinematiese veranderinge in die voet, sowel as die energieverbruik en die voorkoming van beserings is die laaste tyd gedoen. Die meeste van die groot skoenvervaardigers het ook nie agtergebly nie en spog elk met hul eie minimalistiese skoen.

Daar is reeds bewys dat kaalvoet oefening effektiwiteit tydens hardloop verbeter en dat die kragte wat op die liggaam inwerk tydens kaalvoetaktiwiteite, minder is tydens kaalvoethardloop as wanneer daar met skoene gehardloop word. Baie navorsers beweer ook dat kaalvoet oefening proprioëpsie en spierkrag verbeter en dat oefengeïnduseerde beserings verminder word as gevolg daarvan. Hierdie bewering is egter nog nie deur die navorsing bewys nie en kan dus net as bewering gesien word.

Die hoofdoel van die studie was om die effek van kaalvoet oefening op die spoed, ratsheid, plofkrag en balans van netbalspelers te bepaal.

Die steekproef het uit 20 vroulike netbalspelers bestaan (ouderdom:  $20 \pm 2$  jaar), wat lukraak in die kaalvoet- ( $n = 10$ ) en die kontrole groep ( $n = 10$ ) opgedeel is. Daar is van die spelers verwag om 'n minimum van 14 oefensessies by te woon. Tydens die oefensessies het die kaalvoet-groep die hoeveelheid tyd wat hulle kaalvoet oefeninge doen stelselmatig vermeerder. Spoed, ratsheid, vertikale sprong hoogte, eenbeen stabiliteit en omtrekke van die onderbeen is voor en na die intervensieprogram gemeet.

Die spelers het verbale terugvoering gegee oor hul ervaring van kaalvoet oefening. 'n Meerderheid van die deelnemers (70%) het kaalvoet oefening bo oefening in skoene verkies. Daar was 'n effense verbetering in die 10-meter spoedtoets ( $P > 0.05$ ), maar oor 20-meter kon dit nie volgehou word nie. 'n Betekenisvolle verbetering tydens die ratsheid toets is waargeneem vir die linker- ( $0.14$  sekondes  $\pm 0.10$  sekondes;  $P <$

0.05) en regterbeen ( $0.19\text{sek} \pm 0.07\text{sek}$ ;  $P < 0.05$ ) van die kaalvoetgroep. Daar was ook 'n verbetering in die stabiliteit van die regterbeen in die anterior/posterior, mediaal/lateraal en algemene stabiliteit ( $P < 0.05$ ). Daar was 'n klein praktiese effek in al die post-intervensie metings ten opsigte van stabiliteit, behalwe vir die anterior/posterior indeks van die linkerbeen. Geen betekenisvolle verskille het na die intervensie voorgekom vir die plofkrag of onderbeen omtrekke nie.

Die resultate van die studie dui daarop dat kaalvoetoefening kan lei tot 'n verbetering in ratsheid en stabiliteit. Die invloed wat kaalvoetoefening het op die voorkoming van beserings kon egter nie bepaal word nie, aangesien die duur van die studie nie lank genoeg was nie. Die gevolgtrekking van die studie is dat kaalvoetoefening 'n positiewe effek op ratsheid en stabiliteit het, dus kan dit ook moontlik 'n positiewe effek op prestasie hê.

**Sleutelwoorde:** Kaalvoetoefening, netbal, spoed, ratsheid, proprioëpsie.



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## List of Abbreviations

X	:	Mean
%	:	Percentage
ACL	:	Anterior cruciate ligament
APSI	:	Anterior-posterior stability index
BW	:	Body weight
BW/sec	:	Body weight per second
cm	:	Centimetre(s)
EMG	:	Electromyography
ES	:	Effect size
i.e.	:	Specifically
ISAK	:	International Society for the Advancement of Kinanthropometry
kg	:	Kilogram(s)
km	:	Kilometre(s)
km/h	:	Kilometres per hour
m	:	Metre(s)
min	:	minute(s)
MLSI	:	Medial-lateral stability index
mm	:	Millimetre
M/sec	:	metres per second
n	:	Sample size
OSI	:	Overall stability index
P	:	Probability
R	:	Reliability
SD	:	Standard deviation
sec	:	second(s)
SWC	:	Smallest worthwhile change
u	:	Under





## CHAPTER ONE

# INTRODUCTION

### A. Introduction

Since the 1950's the running industry has seen an improvement in the development of running shoes. Jenkins and Cauthon (2011) noted that despite all these changes, the injuries sustained during running have not decreased. Due to this, athletes are seeking additional preventative methods. The minimalist running culture is one of these novel methods that have revolutionized the running industry. No matter what the reason for barefoot running, it is a hotly debated subject. If barefoot running is so popular amongst runners and research has shown some advantages, the question arises if it would not be transferable to other sports as well?

An extensive amount of research has been conducted on the kinetic and kinematic effects of barefoot running (Stacoff, Nigg, Reinschmidt, Van den Bogert & Lunberg, 2000, De Cock, De Clercq, Willems & Witvrouw, 2005, Lieberman *et al.*, 2010, De Wit, De Clercq and Aerts, 2000, and Squadrone and Gallozzi, 2009). Furthermore, numerous studies have been conducted on the kinematics of netball (Steele & Milburn, 1987, Steele & Milburn, 1988, Neal & Sydney-Smith, 1992, and Otago & Neal 1999). Thus far, no studies have been done to determine the effect of barefoot training on performance parameters in netball players.

Kinematic changes observed when running barefoot include a smaller inversion angle of the ankle during ground contact (Stacoff *et al.*, 2000). Researchers found the foot roll-over pattern of heel, metatarsal V, metatarsal IV, metatarsal III, metatarsal II, metatarsal I and hallux to be constant when running barefoot at a slow speed (De Cock *et al.*, 2005). Barefoot running was also found to significantly influence the biomechanics of the foot. A flatter foot placement was observed by De Cock *et al.* (2005), Lieberman *et al.* (2010), De Wit *et al.* (2000), and Squadrone and Gallozzi (2009). De Wit *et al.* (2000) found that barefoot runners had a significantly

shorter stride length, had a higher stride frequency and foot contact time was shorter. Furthermore, a more upright body and more horizontal foot position (De Koning & Nigg, 1993) were observed in barefoot runners. The major shortcoming of these studies is that they used habitually shod runners. The only studies that used habitually barefoot runners, were conducted by Lieberman *et al.*, (2010), and Squadrone and Gallozzi (2009). Divert, Mornieux, Baur, Mayer and Belli (2005) found a higher pre-activation of the plantar flexor muscles when running barefoot. The muscles of the lower leg are not only pre-activated, they also appear to be stronger, with an increase found in muscle strength of the lower leg muscles (Jenkins & Cauthon, 2011). Energy cost of barefoot running or running on hard surfaces was shown to be less than shod running or running on softer surfaces (Hardin, Van Den Bogert & Hamill, 2004, and Squadrone & Gallozzi, 2009).

Jenkins and Cauthon (2011) concluded in their review study that impact forces during barefoot running were lower than when running with shoes. For proper adaptation to barefoot training, there needs to be a gradual increase in time and variance of terrain and a gradual decrease in shoe support (Hart & Smith, 2008). A positive adaptation to barefoot training could take place in four months if one hour of barefoot activity is completed daily (Robbins & Hanna, 1987). Further benefits of barefoot running or training include increases in proprioceptive ability due to the absence of a barrier between the soles of the feet and the ground. If there is no barrier between the soles of the feet and the ground, this results in a greater degree of feedback regarding the running surface, which leads to better awareness of foot placement. It is because of this feedback and awareness of the feet that proprioception would be improved (Jenkins & Cauthon, 2011).

Most of the research done on barefoot running thus far has been on men and women runners. There are, however, differences in gait between the different genders. This could be due to the difference in the bone structure (especially pelvic area). Women runners have greater hip flexion as well as knee flexion during heel strike (Ferber, McClay Davis & Williams, 2003). The kinetic variables showed that women had a smaller peak vertical force when adjusted for body weight, and higher peak vertical force during push-off when compared to men (Nigg, Fisher & Ronsky, 1994). It is because of these differences that this current study used only women participants.

To determine the effect of barefoot running on the prevention of injuries, long-term studies have to be done. Until now, no such studies have been done. Therefore, claims about the benefits of barefoot training on injuries are based on anecdotal evidence.

When analysing the kinetics of netball players, peak vertical ground reaction forces during play were 3.9 to 4.3 times the person's body weight. Ground reaction forces during running are only 2 to 3 times the person's body weight. In this regard, netball can be viewed as a physically demanding sport (Steele & Milburn, 1987). The right conditioning is of utmost importance to prevent severe injuries. From the studies done by Ferreira and Spamer (2010), and Venter, Fourie, Ferreira & Terblanche (2005), the lack in research and testing in South African netball became clear. Hopper, Elliot & Lalor (1995) found that more elite players' injury incidence were higher, with the ankle being the most affected joint (84 percentage (%)). These findings were confirmed by Ferreira & Spamer (2010) who found the ankle and knee to be the most and second most injured joints respectively. Netball is a sport that requires lower limb strength, lower leg stability, speed and agility. It has been suggested that barefoot running would have a positive effect on the biomechanics, muscle activation and kinetics of the lower limb.

## **B. Aim of the current study**

The primary aim was to determine if barefoot training had a positive effect on the physical performance parameters of netball players. Furthermore, this study aims to shed more light on the existing issues of barefoot training.

## C. Research questions

To determine the effect of barefoot training on selected physical fitness parameters, the following research questions were asked:

1. Will barefoot training lead to significant changes in the maximal circumference of the lower leg and the circumference 30 centimetre (cm) from the floor if compared to shod training?
2. Will barefoot training lead to a significant change in the 20-metre (m) sprinting speed of a netball player when compared to shod training?
3. Will barefoot training lead to a significant change in the agility of a netball player when compared to shod training?
4. Will barefoot training lead to a significant change in the vertical jump height of a netball player compared to shod training?
5. Will the ankle stability of a netball player significantly change after barefoot training compared to shod training?



## D. Research method

In this experimental study, 20 netball players (experimental group = 10, control group = 10) that participated in regular in-season netball training completed a series of tests before and after at least 14 training sessions. Intervention consisted of barefoot and shod speed, agility, plyometric and muscle endurance exercises. Participants underwent the intervention as part of netball conditioning, concurrent with their netball training. Testing of the participants was performed a week prior to and a week after the cessation of the 10-week intervention. Participants were tested for speed (over 10 metres and 20 metres), lower leg circumferences, agility, vertical jump height and single leg stability.

## **E. Outline of the thesis**

Chapter Two consists of the theoretical background for this study and reviews current literature and related studies on barefoot training with an overview of netball. In Chapter Three the specific methods for data collection and barefoot-intervention are discussed. The results are presented in Chapter Four. Chapter Five contains a discussion of the results, as well as a conclusion to this study, limitations of this study, and recommendations for future research.

## **F. Conclusion**

In a response to questions regarding her barefoot years, Zola Budd-Pieterse (June 9, 2011) replied: "It is an investment in one's future to help with the prevention of injuries. You just have to take it slow, be conservative in what you do and where you do it. I won't encourage someone to run barefoot on a tar road, but if grass surface is available, then go for it. But remember, when running barefoot one tends to run on the ball of your feet, but your heel still touches the ground after landing. One can easily get injured, even on grass."

## CHAPTER TWO

# THEORETICAL BACKGROUND

### A. Introduction

Although research on barefoot running is relatively new, the idea itself has been around for many years. Athletes like Zola Budd-Pieterse from South Africa in the 1980's and the late Abebe Bikila from Ethiopia in the 1960's are good examples. When searching the internet, there are a lot of ongoing discussions regarding barefoot running and training. A lot is being said about barefoot running; its advantages and disadvantages. Even the shoe industry has been caught up in the hype and almost every shoe manufacturer in the running industry has come up with a minimalist shoe. One of the reasons suggested for this fresh interest in barefoot running is that, despite the constant advances in running shoes, running related injuries are still increasing (Jenkins & Cauthon, 2011).



### B. Kinematic and kinetic variables related to barefoot running

#### *Talar and calcaneal movements*

During running a normal sequence of movements for the subtalar joint has been established to understand the interaction between, and the work of the different structures. At the time of heel contact, inversion occurs with the foot in a slightly plantar flexed position. While shortly after heel contact (or strike) the foot is flat on the floor. It is followed by a rapid eversion of the calcaneus until it reaches maximal eversion at mid stance. During this time, the subtalar joint moves in the opposite direction towards inversion. At heel-strike the calcaneus is in a neutral position but moves into maximal inversion at toe off. Shortly after heel-strike the ankle goes into a plantar flexed position, and reaches its maximum angle just after toe off (Simoneau, 2002).

A study to determine the three-dimensional tibiocalcaneal kinematics was conducted by Stacoff *et al.* (2000). Five healthy men volunteers with no previous injury ( $28.6 \pm 4.3$  years, body mass  $83.4 \pm 10.2$  kilograms and height  $185.1 \pm 4.5$  centimetre) were asked to run barefoot, with a normal running shoe, with three running shoes each with a different sole, and two orthotic modifications. The tibiocalcaneal kinematics of the barefoot group was compared to those in the normal and the modified shoes with the use of a joint coordinate system approach. Results of the study showed no significant differences between barefoot and shod running regarding eversion and tibial rotation. With barefoot running however, the participants tended to show less inversion compared to those in the modified shoes at touchdown.

### ***Foot strike and roll-over patterns***

A sample of 105 participants was tested to obtain normative data for temporal foot roll-over patterns in healthy adults while walking barefoot indoors. A total of 181 feet were tested and 3252 walking cycles. The participants (75 women and 30 men) walked unobserved, at their own pace along a 19 m long and 2.8 m wide corridor. Sensors were placed beneath the heel, the first, fifth metatarsal heads and the great toe of each foot. In 92.9 % of the walking cycles the pattern of heel strike, metatarsal V, metatarsal I and great toe occurred (Blanc, Blamer, Landis & Vingerhoets, 1999).

In a study by De Cock *et al.* (2005), 220 physical education students participated to set up a reference dataset to determine certain characteristics of the foot roll-over during barefoot running. All participants had to be injury-free for at least six months and had no pre-existing foot condition or pathology. Participants (133 men, 87 women) were asked to run at a set speed of 3.3 m/sec along a 16.5 m long running track. Characteristics of the foot were obtained by using eight anatomical pressure sub-areas that were semi-automatically identified on the peak pressure footprint. According to the results, 81% of the participants had a common foot roll-over pattern of heel, metatarsal V, metatarsal IV, metatarsal III, metatarsal II, metatarsal I and hallux when running at a slow speed. Furthermore, some differences were also found between the two genders for some temporal parameters. De Cock *et al.* (2005) noted that, although they were able to indirectly link four functional phases with functional movements, plantar pressure measurements should be combined with

biomechanical evaluation tools such as 3D-kinematics and functional measurements from podiatry.

A difference in the foot strike patterns and collision forces in habitually barefoot versus shod runners were noted by Lieberman *et al.* (2010). Unlike De Cock *et al.* (2005) who used a set speed, participants were allowed to use an endurance running speed between of 4m/sec to 6 m/sec. The study consisted of five groups, controlled for age and footwear usage, namely, habitually shod adults from the USA (sample size (n) = 8), recently shod adults from Kenya (n = 14), habitually barefoot adults from the USA (n = 8), barefoot adolescents from Kenya (n = 16), and shod adolescents from Kenya (n = 17). They found that habitually shod runners mostly had a rear-foot strike pattern when compared to the habitually barefoot runners. This rear-foot strike was also seen when habitually shod runners ran barefoot with the only difference being a flatter foot placement during foot strike (ankle dorsiflexion seven to ten degrees less). In the habitually barefoot group or those that switched to barefoot running it was evident that forefoot strike landing, followed by heel contact, was used most often. The difference in the studies done by De Cock *et al.* (2005) and Lieberman *et al.* (2010) is the fact that the latter used habitually barefoot runners and not just shod runners completing a barefoot trial. According to Lieberman *et al.* (2010), one of the main factors for the rear-foot strike in shod runners is the cushioned sole. The sole of the modern running shoe is cushioned more at the heel. It is because of this cushioning that the soles of rear-foot strike runners, that dorsiflex with impact, show greater dorsiflexion relative to the ground. This is also relevant to those forefoot strike runners that plantarflex during impact. Because of the softness of the soles, the shoes will be less plantarflexed (flatter) relative to the ground.

### ***Sagittal and frontal plane kinematics***

In a study to define the 'normal' dynamic functional relationships between certain movement components of the lower legs during the support phase of running, college-aged women runners (n = 10), doing more than 40.2 kilometre (km) per week, were used by Bates, Osternig, Mason and James (1978). The study was conducted with three different running conditions, namely: running on a treadmill at

3.35 metres per second (m/sec) (slow shoe), running between 3.38-4.47 m/sec (fast shoe), and running barefoot (fast shoe pace). Participants had three supervised training sessions to familiarise themselves with the treadmill. One single footfall was evaluated by the researchers for the pronation, supination and patella cross (position in which the patellas of both legs are in line with the lateral camera axis). Comparisons were only done between the fast shoe and fast-barefoot conditions. Significant differences in the pattern of pronation were observed. In the fast-barefoot condition, pronation of the foot began sooner and ended later. This was significant when viewed in absolute time or as a percentage of the support phase. During the barefoot condition, the mean time of maximum pronation increased and it occurred significantly later as a percent of the support phase.

Researchers wanted to get a better understanding of the role of shoes in the control of movement during running. This is the reason for the investigation regarding the effect of different running conditions on kinematics (De Koning & Nigg, 1993). Six participants (mass 75.6 kilogram (kg), height 1.80 metre (m)) had to run at a controlled speed of 4.5 m/sec. Three experimental situations were used, namely: running barefoot, running in soft shoes and running in hard shoes. Each participant had to complete ten trials in each specific condition. Results revealed that when running barefoot, the trunk was in a more upright position and the foot in a more horizontal position compared to running in shoes. During a barefoot stride, the flexion-extension movements in the knee joint were less compared to running in shoes. This more horizontal foot position resulted in a larger vertical stiffness of the body and a smaller vertical displacement of the body's centre of gravity. There was, however, no difference in the leg stiffness between the three experimental conditions. De Koning and Nigg (1993) found that there were some adaptations in the muscular system, which could be seen in the net knee moments. The researchers stated that this was the reason why the knee stiffness values were similar. Their results showed that the vertical accelerations of the leg segments were affected by the body configuration during landing and that muscular moments influenced the leg stiffness. Impact forces were affected by the leg segmental acceleration and leg stiffness. Measured ground reaction forces, on the other hand, were influenced by the adaptations in foot velocity prior to landing and the attenuation in impact time due to

the cushioning properties of the shoe. Their study concluded that running kinematics was altered by footwear.

The difference in the angle of the ankle before touchdown was not the only difference noted between barefoot and shod runners. In the study by De Wit *et al.* (2000), nine trained men long distance runners were investigated with regards to the spatio-temporal variables, ground reaction forces and sagittal and frontal plane kinematics during the stance phase of running barefoot and shod at three different velocities. Results from this study confirmed findings by previous researchers (De Cock *et al.*, 2005, Squadrone & Gallozzi, 2009, Lieberman *et al.*, 2010), who found that participants running barefoot had a flatter foot placement with touchdown compared to shod runners. De Wit *et al.* (2000) found this to be true for all three running speeds (3.5 m/sec, 4.5 m/sec and 5.5 m/sec). There was a significant difference in the angle of the ankle at touchdown, with barefoot runners having a more plantarflexed ankle before touchdown. When looking at the initial eversion at impact, this was significantly smaller in the barefoot runners. These results differed from Stacoff *et al.* (2000) regarding eversion where Stacoff *et al.* (2000) found no significant difference between the barefoot and shod conditions. De Wit *et al.* (2000) found that when participants ran barefoot, the strides were significantly ( $P < 0.05$ ) shorter, at a higher frequency and that each stride had a shorter contact time. The reduction in stride length during barefoot running can be explained by the smaller horizontal distance travelled through the stance phase.

In another study comparing biomechanical and physiological aspects of running, the comparison was made between barefoot running, shod running and running with a lightweight shoe (Squadrone & Gallozzi, 2009). Eight habitual barefoot men runners (age  $32 \pm 5$  years, 10 kilometre (km) race time,  $40.3 \pm 4$  minute (min)) participated in the study. Although all participants were habitually barefoot runners, all of them had the opportunity to familiarise themselves with the lightweight shoe (Vibram Fivefingers Classic ®) and running on a treadmill. Each participant had to complete three running bouts of six minutes each at 12 kilometres per hour (km/h) in random order. They were not instructed to use a specific foot strike technique. Foot or shoe-ground interface was measured using an instrumented treadmill. Results from the study were very similar to the studies of De Cock *et al.* (2005) and Lieberman *et al.*

(2010). Participants landed significantly ( $P < 0.05$ ) more dorsiflexed when running in the standard running shoes compared to the other conditions. There were no significant differences found at the knee joint. Significant differences were also found in the range of motion of the ankle joint, with more ankle joint mobility when running with Vibram Fivefingers® compared to standard running shoes. Once again, no significant difference was found at the knee joint. A significant difference was also found in the stride length and frequency. In barefoot runners, the stride length was shorter and the stride frequency higher compared to the other two conditions. Flight time was also found to be significantly lower in barefoot running.

### ***Sensory information***

In one of the earliest studies on barefoot running, researchers implied that barefoot runners could unknowingly be activating an intrinsic foot shock absorption system (Robbins & Hanna, 1987). With this they would avoid landing on a sensitive area to make barefoot running more comfortable by avoiding these areas. The data suggested that with their participants, normal footwear did not produce the necessary sensation to bring about those protective adaptations that naturally occurs with barefoot weight-bearing activity. The researchers concluded that it appeared that the running shoe diminished the perception of pain and pressure from the plantar surface of the foot. The runner was not aware of any changes in ground surfaces and could not adapt to it. Due to the loss of sensation it was also difficult for them to adapt their running style to diminish impact.

Researchers have hypothesized that alterations in footwear would lead to changes in kinematic variability during the stance phase of running due to sensory information influencing the variability or mechanical changes. Eight healthy men volunteers ( $44.5 \pm 29.5$  km per week, mean age of  $27.1 \pm 4.9$  years) participated in the study by Kurz and Stergiou (2002) to examine this hypothesis. All participants were familiar with the treadmill and ran at a self-selected, comfortable pace. They had to run barefoot and with two types of footwear, with differences in hardness of the shoes. Sagittal plane kinematic data were collected on the right foot with a high speed camera. Ten consecutive footfalls were collected for each running condition after which a minimum

of 5 minutes of rest had to be taken. Results showed significant differences in variability occurred in both the knee and the ankle joint when comparing barefoot running to the soft and the harder shoe condition. There was also a bigger overall variability at the ankle and knee joint during barefoot running compared to the two shod conditions. From these results the researchers concluded that, if sensory information was the primary factor influencing variability, these changes would have been evident throughout the stance phase. This was, however, not the case. Variability could also have been due to mechanical changes that took place while running barefoot.

In a recent review article, Jenkins and Cauthon (2011) examined the evolving barefoot movement and its claimed advantages and disadvantages regarding the enhancement of performance and the reduction of injury. The authors used several evidence-based research articles to give a thorough review of what research currently suggests. In the discussion regarding the alterations to the gait of runners, they found no argument in any of the literature to deny the fact that barefoot running changes many aspects of the gait patterns compared to wearing shoes. An advantage of barefoot running could be the increased proprioceptive ability. From the literature it was gathered that when running barefoot, there is better awareness in terms of foot positioning and feedback regarding the surface. With this the proprioception should also improve.

### ***Muscle activation***

Various muscles function in a pattern to ensure an efficient running style. Each of these muscle groups needs to be trained in a specific way to get the most advantage of them. It is not only the lower leg muscles that help to ensure the correct running technique, but also the erector spinae; iliopsoas and abdominal muscles; gluteus muscle group, tensor fasciae latae and iliotibial tract; hamstrings, quadriceps femoris and the adductors (Bosch & Klomp, 2011).

A change in the biomechanics of running occurs when the runner is barefoot, as mentioned previously. These changes would not only affect the skeletal system, but the muscles would also be influenced. Some of the changes happen prior to impact

and others happen with impact. Divert *et al.* (2005) conducted a study where three women and 31 men runners volunteered to participate. All participants were healthy, experienced in leisure running and had no injury at the time of the study. The mean age of the participants was 28 ( $\pm 7$ ) years and mean body mass 72 ( $\pm 9$ ) kg. There were two testing sessions. In the first session, participants had to familiarise themselves with the treadmill. During the second session, the participants were asked to perform two running trials of 4 minutes each at a speed of 3.33 (m/sec). One of the trials had to be barefoot and the other in shoes. Participants were also asked to use a rear-foot strike. A treadmill with the ability to record and analyse forces were used during the study. Muscle activation was measured using an electromyography (EMG). Five superficial lower leg muscles: tibialis, peroneus, gastrocnemius lateralis, gastrocnemius medialis and soleus were measured. A significant difference was found in the pre-activation phase of the plantar flexor muscles. The activity in the gastrocnemius lateralis and medialis and soleus was 13.7%, 23.6% and 10.8% respectively higher in the barefoot condition than in the shod condition.



An increase in the strength of the musculature of the lower leg, following barefoot training and minimalistic shoe training, was also mentioned by Jenkins and Cauthon (2011). They emphasised it as another advantage of barefoot training in their review study. The researchers found conflicting evidence regarding the actual manner in which the barefoot condition was strengthened. Their conclusion was that there were too few scientific studies to confirm these findings.

Nigg and G erin-Lajoie (2011) found age to have a greater influence on gait than gender. Results of the normalized EMG intensities for the gastrocnemius and biceps femoris were significantly lower for low frequency and significantly higher for high frequency wavelets in the older runners. For the vastus medialis, lower levels were found in the older runners, but with no significance. Some of the studies done on barefoot running were also done on college aged runners (Hanson, Berg, Deka, Meendering & Ryan, 2010; De Cock *et al.*, 2005; Bates *et al.*, 1978).

A study conducted by Dolenc, Stirn & Strojnik (2011), compared the muscle activity of the lower leg in running on tarmac and grass. They found that, in heel strikers, the tibialis anterior muscle is responsible for lowering the front part of the foot as well as the absorption of the load. Tarmac, the stiffer surface of the two, produced higher impact than grass. It could be assumed that the runner prepares himself for the higher impact and activates the tibialis anterior earlier. Therefore, the difference in surface only affects the preparation before landing and not during the actual heel strike phase.

### ***Kinematic adaptations and energy cost***

To determine the effects of footwear, surface and duration of running bout on kinematic adaptations during running, 22 volunteers from a university population were used by Hardin *et al.* (2004). All participants ran for 6 min at a 3.4 m/sec pace in six different shoe conditions, which were specifically designed for this study. The shoe had the same mass, but the hardness of the midsoles differed. Experiment one was done on the different surface stiffness and midsole hardness. Kinematic adaptations due to the change in surface occurred at the knee and hip joints. On the hard surfaces, the hip and knee joints showed a greater angle of extension at contact than on other surfaces. Maximum hip flexion was also less on the hard surface. Oxygen consumption was greater ( $P < 0.001$ ) when running on the softer surface and it decreased with an increase in surface stiffness. The ankle was the only joint to adapt to changes in the midsole hardness. The difference in midsole hardness had no effect on energy cost. Furthermore, kinematic adaptations occurred because of the change in the running surface and not the hardness of the midsole.

Results from the study done by Squadrone and Gallozzi (2009) showed that running barefoot decreased the energy cost of running by 1.3%. This difference was, however, not statistically significant. According to the researchers, the difference could be due to the fact that the runners used in this study were habitually barefoot runners. These runners could have changed their running style making their running style more economical, even when they ran in shoes. The results of oxygen consumption while running in the Vibram Fivefingers® shoes showed a significant

decrease of 2.8% compared to the standard running shoe. One of the reasons for the difference between these two could have been the weight of the different shoes, with the difference being 400g. Another reason could be that the actual work done by the foot with the different soles of the shoes (rotating, flexing and compressing) was much less in Vibram Fivefingers® than in the normal shoe.

It was suggested that the weight of running shoes was not the only factor influencing the energy expenditure. Jenkins and Cauthon (2011) suggested the energy expenditure could be influenced in the gait cycle when running barefoot. According to the researchers, the gait adopted by barefoot runners could be more efficient.

### ***Impact forces***

Most of the studies explained earlier in the chapter were done with the use of a treadmill. There are some beliefs that runners adjust their gait when running on a treadmill. A study to determine the difference on rear-foot parameters when running on a treadmill and overground was conducted by Clarke, Frederick and Cooper (1983a). Ten participants were used in the study and each used conventional running shoes during the test. A 7-minute mile pace had to be run on the treadmill, as well as a rubberised runway in a laboratory. There were no significant differences between the two testing conditions. Correlations of 0.7 were obtained, which could mean that some participants may have responded differently to the two running conditions than others. There was, however, no consistent altering of rear-foot parameters when running on a treadmill compared to normal running.

Foot strike patterns have a great influence on the forces exerted on the body during ground contact. Since the foot strike pattern is different when running barefoot compared to running in shoes, the ground reaction forces will also change (Clarke, Frederick & Hamill, 1983b). A study was done on the effects of shoe cushioning on these forces (Clarke, Frederick & Cooper, 1983c). Ten well-trained men distance runners (mean weight = 68.0 kg) were used in the study. Participants had to run at a pace of 4.5 m/sec on a runway in a laboratory. Two pairs of shoes that represent the extremes of midsole hardness available in the running industry were specially constructed for the study. Cushioning is seen as the ability of a material to decrease

peak force between two bodies colliding. There were significant differences between the hard and soft shoe soles for four of the parameters measured. The impact peak force was similar in magnitude between the soft and hard soles, but it occurred significantly later in the soft sole. Despite the fact that there was no significant difference in magnitude, the researchers noted that the individual response was quite different. Absolute differences of 0.24 x body weight (BW) between the hard and the soft shoe were observed. According to these results, the researchers came to the conclusion that there was not a consistent adaptive scheme to either of the shoes. The other significant differences were with the impact peak minimum. This value was significantly greater in magnitude and occurred significantly later in the soft shoe. Researchers reported that this difference could be because of the different leg stiffness adopted before landing and the decrease in downward acceleration of the body at that time. This supported findings by other researchers that there was a pre-programming before landing, especially when there were changes in the shoe or sole stiffness. The last significant difference was between the vertical force propulsive peaks. It occurred at the same time in both shoes, but it was significantly greater in the soft shoe. An explanation for these results was given at the hand of modelling the cushioning systems as springs. The hard shoe had a high spring constant, while the soft shoe was a relatively lower spring constant. If the same load was being placed on the springs, the deflection would be greater in the spring with the lowest constant. The last conclusion the researchers came to during this study was that runners, despite various mechanical and adaptive responses, seem to adjust their force application so as to hold the vertical force impulse and contact time roughly the same.

The ankle and foot are not the only joints affected by the forces during landing. There are also forces and moments acting on the hip joint while walking and running (Bergmann, Kniggenndorf, Graichen & Tohlmann, 1995). Although this study was done on an edoprotheses, researchers claimed that the results would be the same as on a normal leg, because of the impact pressure of every stride taken. The participants in the study wore different sports shoes, normal leather shoes, hiking boots and clogs, and walked barefoot with soft, normal and hard heel strikes. During jogging, the curves representing forces, showed only one peak, unlike with walking where two peaks were noted. The resultant hip joint forces (R) was described by a

femur-based coordinate system x-y-z. It was just the barefoot condition which produced a low  $R_{\max}$  value of 472% BW for hip joint loads. All the other shoes caused +3 % BW and +6 % BW greater  $R_{\max}$  values. During walking, the loading rate was the lowest for the sport shoe with the hardest heel. Barefoot walking produced forces of 2933% body weight per second (BW/sec), differences of -24% BW/sec and +5% BW/sec compared to other shoes. Only a linear correlation ( $R = 0.26$ ) was found between the hardness of the heels and loading rate. For jogging the lowest loading rate was once again the sports shoe with the hardest heel (5597% BW/sec), but the highest loading rate was the hiking boot (8452% BW/sec). Barefoot was 6796% BW/sec and an even lower correlation was found ( $R = 0.06$ ). The researchers concluded that these findings cannot be generalised, especially not for activities or sports which are much faster or cause extreme accelerations.

Another study that looked at the impact forces of the foot was the study done by De Wit *et al.* (2000). They found that there was more than one impact peak during barefoot running. A significantly larger loading rate was also noted in barefoot running compared to shod running. It should be remembered that this study used habitually shod runners to run barefoot. It was evident that even when habitually shod runners ran barefoot, a flatter foot placement was present and they had a non-different touchdown velocity. The absolute difference for the sole angle at touchdown was  $14^{\circ}$  between the two conditions at 4.5m/sec. This flatter foot placement was a result of the larger knee flexion in the barefoot condition. But the flatter foot placement did not correspond with a strategy to reduce severity of the impact. Another interesting observation by the researchers was that the more horizontal foot placement was prepared well before touchdown. Researchers implicated that there was an actively induced adaptation strategy to barefoot running. De Wit *et al.* (2000) mentioned that there may be yet one more functional demand that could explain the flatter foot placement – this being the fatty tissue in the heel. It has been confirmed that the fatty tissue in the heel is deformed proportionally to the local stress acting on the bare heel. Therefore the more horizontal the foot during initial contact, the smaller the pressure will be that is acting on the heel.

During barefoot running, flight time (0.09 seconds (sec)) was lower when compared to running in shoes (0.11 sec). Contact time and stride duration were also lower in the barefoot condition (0.25 sec and 0.69 sec respectively compared to 0.26 sec and 0.73 sec respectively). There was a significant lower value for amplitude of active and passive peaks in the barefoot condition (Divert *et al.*, 2005).

Squadrone and Gallozzi (2009) found the magnitude of impact forces significantly lower in barefoot runners compared to the shod runners. The study showed that peak local pressure under specific areas of the foot; heel, mid-foot and hallux, was significantly higher ( $P < 0.05$ ) for participants when in shoes than any of the other two conditions. Peak pressure measurements under the toes were significantly higher ( $P < 0.05$ ) with the Vibram Fivefingers compared to barefoot running. In some studies mentioned earlier, differences in stride kinematics between barefoot and shod running were found (Divert *et al.*, 2005; Lieberman *et al.*, 2010). Those studies hypothesized that this adjustment could help to limit the impact forces experienced while running barefoot because those impact forces need to be absorbed by the muscular-skeletal system. Results from the study by Squadrone and Gallozzi (2009) supported this hypothesis. It was noted that when running barefoot, the runners adopted a flatter foot placement. The peak pressure values were reduced under the heel and pressure was higher under the metatarsal heads.

Researchers compared collision forces at the ground in habitually shod and barefoot runners from the USA (Lieberman *et al.*, 2010). Force plates were used to obtain the data. Rear-foot strike landing in the shod condition and more so in barefoot runners caused a large impact transient, whilst forefoot strike landing lacked a distinct impact transient. It was found that the magnitude of the peak vertical force during impact is approximately three times bigger in habitually shod runners who rear-foot strike, whether in shoes or barefoot, than in habitually barefoot runners. This was obtained by runners running at similar speeds. The average loading in forefoot strike barefoot runners was found to be seven times lower than in the habitually shod runners. However, it is similar to the rate of loading of the rear-foot strike shod runners. Lieberman *et al.* (2010) explained the difference in the magnitude of impact forces as follows. Because the foot and leg is an L-shaped double pendulum that collides with the ground, the researchers identified two biomechanical factors, namely initial point

of contact and ankle stiffness. During rear-foot strike running, impact occurred just below the ankle. This was the centre of mass of the foot plus leg. Plantarflexion could vary in this position and the ankle could convert very little translational energy into rotational energy. Most translational energy was lost and therefore the higher impact forces when landing on the rear-foot. Forefoot strike running initial point of contact was to the front of the foot. After initial contact the ankle dorsiflexed and the heel dropped whilst under control of the triceps surae muscle and Achilles tendon. Ground reaction forces were therefore used to torque the foot around the ankle and the lower limb's translational kinetic energy was turned into rotational kinetic energy and thus the lower impact forces.

Research indicates that barefoot running differs from running in shoes because of, amongst others, the quicker, shorter strides and the forefoot landing in barefoot runners (Jenkins & Cauthon, 2011). These gait changes in barefoot runners, with the ankle in a more plantarflexed position, forefoot strike with contact and the subtalar joint more inverted are known as ankle coordinative strategies. A number of studies (also studies explained earlier) showed that these changes reduce the shock at impact and therefore also reduce the shock-related running injuries. It was reported that the reduced ground reaction forces at foot strike were due to the ankle plantarflexion musculature that reduced the impact. Shorter stride length could also have an effect on this. This, however, does not mean that the loading of the lower extremity in general is reduced. If the muscles responsible for ankle plantarflexion (gastrocnemius and soleus) were taken into account with forefoot landing, the impact ground reaction forces were reduced, but the additional muscle forces increased joint and skeletal loading forces. An increased load would therefore be put on the bones and interposed joints such as the ankle, knee and even the hip. In the studies observed, Divert *et al.* (2005), Squadrone and Galozzi (2009), De Wit *et al.* (2000), and Lieberman *et al.* (2010), found an increased variability of gait in barefoot runners compared to shod runners. These researches noted that there were also a higher braking and pushing and higher pre-activation of the triceps surae muscles. These findings suggested that there was an improved sensory feedback in barefoot runners and this could also form part of the reduction in impact forces. As explained by Bosch and Klomp (2001), as well as Robbins and Hanna (1987) stronger intrinsic musculature helps to raise the longitudinal arch, which results in a more efficient

shock absorber. However, Robbins and Hanna (1987) mentioned that maximal arch deformation and peak impact did not correlate chronologically. Another aspect they discussed was the shorter strides in barefoot running. This meant that there would be an increase in stride frequency and the overall impact during a training run may not be affected.

From all the literature discussed in this section, it can be seen that there are still contradictions regarding the actual impact forces experienced during barefoot running. This is one of the fields that need further investigation.

### **C. Gender differences in gait**

Differences in the gait pattern are noticeable when comparing barefoot running to shod running. Participants used in the previous studies (Robbins & Hanna, 1987; Divert *et al.*, 2005; Squadrone and Galozzi, 2009; De Wit *et al.*, 2000; Lieberman *et al.*, 2010) were from both genders. However, it cannot be assumed that the gait pattern for men and women is the same. In a study to determine the gait characteristics as a function of age and gender, 60 men and 58 women, between the ages 20 and 79 years old performed a walking analysis in four different conditions (Nigg *et al.*, 1994). Participants had to complete at least five practice trials and only when they felt comfortable, data were collected on the left foot. Although age was discussed as part of the results, for the relevance to this study, age will not be included in the review. A significant difference between the barefoot and the shod conditions was found, independent of age and gender, for kinetic (up to 2.3% body weight) and kinematic (up to 7.8 degrees) variables during the movement of the lower leg and ankle. One of the differences found between the genders, across shoes, was that women had a 1.1 degrees smaller initial eversion compared to men. There was also a smaller tibial rotation of 2.0 degrees and knee flexion path of motion of 2.4 degrees in women, which is associated with the greater knee flexion (2.4 degrees) at heel strike. The kinetic variables across shoes showed that women had a smaller peak vertical force (3.4% of body weight) during weight acceptance. There was a higher peak vertical force during push-off (3.0% of bodyweight) in the

women compared to the values of men. During the initial 50% of ground contact, there was a smaller medial force peak (0.8% of bodyweight) observed in women than in men. Some of these findings showed a small but significant difference between men and women.

Further research was done on this topic and significant differences were found between the genders (Blanc *et al.*, 1999). Results revealed a gender effect on stride, stance phase, swing duration, cadence and contact time of the heel, 5<sup>th</sup> metatarsal head and 1<sup>st</sup> metatarsal head ( $P < 0.05$ ), but not for the contact time of the great toe. Woman had a faster stride, stance phase and swing duration.

In another study regarding the influence of gender on gait, Ferber *et al.* (2003) used 40 recreational runners between the ages of 18 and 45 years. All participants were rear-foot strikers and free of injury. Physiological characteristics of the participants were: men (weight:  $82.26 \pm 11.79$  kg, height:  $1.81 \pm 0.06$ m) and women (weight:  $59.97 \pm 9.25$  kg, height:  $1.67 \pm 0.07$ m). Markers for three-dimensional movement were placed on specific areas of the body. Participants had to run along a 25m runway at a speed of 3.65m/sec. A force plate in the centre of the runway was used to collect the data. Participants had to repeat the trial five times. Results showed no difference in the duration of the stance phase between the men and women runners. A slightly greater hip flexion and production of a greater hip extensor moment were observed in the sagittal plane for the women runners. Sagittal plane joint moments, angles and power were similar for both genders in the knee joint. With regard to the frontal plane kinematics, the women runners tended to have a greater hip adduction and knee abduction position and they absorbed greater amounts of energy through the hip joint compared to the men runners. A significantly greater peak hip adduction angle ( $P < 0.05$ ), hip frontal plane negative work ( $P < 0.05$ ) and greater peak hip adduction velocity were obvious in the frontal plane. There was also a significantly greater peak knee abduction angle ( $P < 0.05$ ) for women in the frontal plane compared to men. In the transverse plane women had a slightly greater hip internal and knee external rotation position, as well as greater energy absorption in the hip and knee joints. The peak hip internal rotation angle and the transverse plane negative work showed a significant difference between the women and the men, with the women showing greater values. The last difference observed was the greater

peak hip external rotation velocity in the women, but no significant value. The researchers concluded that, because of the differences in the hip and knee kinematic and kinetic gait patterns between genders, these differences should be taken into account when conducting a research study across groups.

From the previous studies mentioned, it is evident that differences in the gait cycle occurred when comparing men to women. The question could be raised if there are also gender differences in a more sport-specific movement, like jumping or landing? Twelve men (age  $28.3 \pm 3.9$  years; height  $1.8 \pm 0.06$  m; body mass  $81.8 \pm 9.1$  kg) and nine women (age  $26.4 \pm 4.5$  years; height  $1.7 \pm 0.06$  m; mass  $60.1 \pm 5.6$  kg) participated in the study to determine the gender differences in lower extremity kinematics during landing (Decker, Torry, Wyland, street & Steadman, 2003). All the men (12) and women (9) were recreational participants in court sports namely volleyball and basketball. After familiarising themselves with the landing, data from eight vertical drop-landings were collected. Participants had to step from a 60 centimetre (cm) box onto a landing platform. One foot had to land on a force plate and the other next to it. The results showed that all participants performed a forefoot rear-foot landing. Similar angles for knee flexion were also observed. There was, however, a difference in the knee extension and ankle plantarflexion angles at initial ground contact, with the women showing greater angles than the men ( $P < 0.05$ ). Both groups used the knee joint as their primary joint to absorb energy, with the women using 34% less negative hip work and 30% and 52% more negative knee and ankle work respectively (all  $P < 0.05$ ). The women had a greater energy absorption during the impact phase compared to that of the men [women:  $-18.3$  (SD,  $2.1\%BW \times ht$ ) and men:  $-16.2$  (SD,  $1.6\%BW \times ht$ );  $P < 0.05$ ]. Results also showed that the peak angular velocities for the lower extremity joints were greater in the women compared to the men ( $P < 0.05$ ). A significant difference was found within group comparisons. The peak hip extensor moment was significantly larger than the peak ankle plantar flexor moment for the women group (all  $P < 0.05$ ). No peak moment difference was found between the men and women groups for each joint. There was, however, a significant difference between the genders for the temporal occurrence of peak knee extensor moment ( $P = 0.004$ ). The peak knee extensor moment occurred  $0.063$  (SD  $\pm 0.023$ ) seconds after ground contact for the women in comparison to the  $0.038$  (SD  $\pm 0.013$ ) seconds for the men.

Because of the differences observed, it can be assumed that the muscle activation of the (lower) leg would also be influenced. It was hypothesized that muscle activity in the gastrocnemius medialis, biceps femoris and vastus medialis during heel-toe running would change as a function of gender (Nigg & Gérim-Lajoie, 2011). Recreational runners (75 men, 75 women) participated in the study to test whether midsole hardness, gender and age change the muscle activity pre- and post-heel strike during heel-toe running. Only 54 of the participants (mean age  $33.9 \pm 20.1$ ) entered the muscle activity analysis. This subset consisted of 18 women runners and 36 men runners, who ran an average of 4.3 h/week. Muscle activity was measured on the bellies of the muscles using EMG. Participants had to complete five good 20 m running trials at a speed of  $12.0 \pm 6$  km/h. Results showed that, on average, the men exhibited less pre- and more post-heel strike bicep femoris activity. It could be suggested that men made more use of the fast muscle fibres during running. The bicep femoris showed a higher relative EMG intensity prior to heel-strike in the women runners. As the role of the bicep femoris in pre-heel strike is to flex the knee, it allows the foot to have a more pronounced action during initial contact. Researchers speculated that this could be the reason why the women group in general preferred the softer shoe.

#### **D. Imitating barefoot running**

In the 21<sup>st</sup> century, where consumers have a say in everything, they are also demanding functional shoes that will enhance their quality of life and improve their health. Shoe companies had to adjust their shoes and included special features that were only previously used for therapeutic purpose (Chen, Chua, Park & Lee, 2011). One such shoe is the rocker bottom shoe, with a thick, uneven sole. This results in a non-flat footing along the proximal-distal axis of the foot. Another unstable shoe is the wedged shoe, which is uneven along the medial-lateral axis of the foot. It is stated that these shoes are beneficial for correction of body posture and the reduction of excessive loading on the lower extremities. Chen *et al.* (2011) investigated the double rocker/wedged bottom shoe and determined the biomechanical and

physiological effects on healthy subjects. The researchers especially focused on the lower extremity joints and muscles used during walking. Both genders were equally represented, with five men and five women volunteers each. Kinetic and kinematic data, as well as the muscular activity of the lower limb during walking, were recorded. The double rocker bottom shoe had lower values for the ankle joint moments in all 3 planes of motion, when compared to the control shoe. There was also a substantially lower moment for maximum knee internal rotation as well as for hip adduction. This could potentially decrease the risk for ankle, knee and hip osteoarthritis for those who wear these shoes often. A higher muscular activity was found in the quadriceps, shin muscles and hamstrings, for the double rocker bottom shoe condition. It was also found to be advantageous for weight loss due to higher muscle activity which leads to a higher energy consumption during normal walking. Through a subjective feedback from the participants, it was more comfortable to walk in the double rocker/wedged bottom shoe than in the stable shoe. It is suggested that wedged shoes/double rocker shoes reduce the load on the joints of the lower extremity.

A slightly older version of the unstable shoe is the Masai Barefoot Technology (MBT). It is known for its unstable rounded sole, and according to the manufacturers, it reduces the concentration of pressure on the heels. A comparative study was done to assess the in-shoe pressure distribution in Masai Barefoot Technology shoes compared to that of flat-bottomed training shoes (Stewart, Gibson & Thomson, 2007). Participants of the study, four men and six women, were all university students (mean age of 24 years). Each participant had the opportunity to walk on a walkway three times and to stand still for 30 seconds on both feet with their normal training shoes as well as the Masai Barefoot Technology shoes. There was a decrease in pressure in the forefoot and mid-foot areas while walking with the MBT shoes and in the mid-foot and hind-foot when standing. There was, however, a dramatic increase in pressure (76%) under the toes during standing in the MBT shoes. The researchers also compared their findings with findings for pressure distribution in rocker-bottomed shoes. The pressure in the rocker-bottomed shoe was found to decrease under the toes and forefoot and increase under the mid-foot and heel. This was almost directly opposite to that of the MBT shoe. The area of weight bearing in the MBT shoe was found to be close to the weight bearing surface when barefoot. The researchers concluded that the Masai Barefoot Technology shoes could be beneficial for people

with pes planus, obesity and degeneration of the calcaneal fat pad, due to their reduced pressure in these areas.

Vibram ® has constructed a shoe, the FiveFingers ®, which also claims to mimic barefoot. It is a minimalist shoe with only a small rubber cushioning, more for the protection of the surface of the sole rather than shock absorption. When the lower extremity kinematics of Vibram FiveFingers ® was compared to those of barefoot walking and walking in a standard sports shoe, differences were seen (James & Cook, 2011). The nine women participants had to complete five trials in each condition. A significantly earlier phase shift was seen in the sagittal plane of the ankle and knee kinematics in the barefoot condition compared to the other two conditions. No temporal differences were found at the hip joint. There was a significant difference in the knee joint for the phase shift in the frontal plane, with a more pronounced shift in the barefoot condition. The researchers concluded that although shoe manufacturers claim to have developed a barefoot shoe, the claims were not true. Results from the study showed that there were temporal differences in the lower extremity kinematics during walking barefoot compared to walking with Vibram FiveFingers ®.



In the past, stability and muscle training were addressed as two different aspects. Muscle training was usually done during independent training sessions and the stability aspect was provided through the specific construction of the shoe. Researcher however reasoned that it would be advantageous if daily locomotion activities and stability training could be combined (Nigg, Hintzen & Ferber, 2006). Therefore, Nigg *et al.* (2006) compared the kinematics, kinetics and muscle activity during standing and walking, of Masai Barefoot Technology (MBT) and a stable control shoe. Eight subjects volunteered for this study. The five men and three women (mean age:  $28 \pm 3.6$  years, mean mass:  $70.1 \pm 7.5$  kg, mean height:  $169.5 \pm 6.4$  cm), were free of injury in the lower extremities. Participants were given a two-week period to wear the unstable shoe as much as possible. During the testing, retroreflective markers were used to identify specific anatomical position, namely the rear-foot, shank, thigh and pelvis of the right lower extremity. The standing test consisted of three trials of 10 seconds each while standing on both feet and in both shoe conditions. Ten walking trials, first with the unstable shoe and second with the

stable control shoe, were conducted at a walking speed of  $5.0 \pm 0.5$  km/h. Electromyography (EMG) data were gathered from the tibialis anterior, medial gastrocnemius, biceps femoris, vastus medialis, and gluteus medius muscles of the right limb. Results revealed that, during standing the centre of pressure excursions were significantly greater for the unstable shoe, in the anterior-posterior and medio-lateral directions, compared to the control shoe. The EMG activity during standing in the unstable shoe showed an average increase in intensity. It was only the tibialis anterior muscle that had a significant increase ( $70 \pm 85\%$ ). The other four muscles also showed increases, however, not significant. During walking the ankle joint was significantly more dorsiflexed during the first half of the stance phase in the unstable shoe compared to the stable shoe. No significant differences in EMG activity were noticed during walking between the unstable and control shoe. The following muscles showed an average reduction in activity: tibialis anterior ( $26 \pm 24\%$ ) and biceps femoris ( $55 \pm 60\%$ ). Other muscles showed an average increase: gastrocnemius ( $52 \pm 82\%$ ), vastus medialis ( $4 \pm 13\%$ ) and gluteus medius ( $16 \pm 25\%$ ). Researchers commented that these non-significant changes could be due to the different strategies used by participants when changing shoes. In conclusion the researchers mentioned that the changes that were produced in kinematic, kinetic and EMG characteristics in the unstable shoe seemed to be advantageous for the locomotor system.

In the previous studies it was evident that unstable shoes decreased the pressure in certain areas of the foot when comparing them to normal running shoes. It was also found that it was more comfortable to wear when walking than normal running shoes. The unstable shoe was, however, not compared to barefoot walking in any of the previous studies, only the barefoot shoe. Therefore Germano (2011) conducted a study to compare the muscle activity and balance while standing with various unstable shoes and barefoot. Twenty healthy women (age:  $22.4 \pm 2.2$  years) volunteered for the study. Each participant had to complete one-legged stances ( $3 \times 20$  sec) under six different conditions. The plantar pressure distribution was measured with a PEDAR-x® insole system and muscle activation was measured using surface electromyography. Eight muscles were analysed on the right leg, namely the tibialis anterior, medial gastrocnemius, lateralis gastrocnemius, rectus femoris, vastus medialis, vastus lateralis, biceps femoris and gluteus maximus. The

centre of pressure excursion (millimetre (mm)) was calculated and no significant differences were found between the unstable shoes compared to the stable shoe. When comparing barefoot standing to unstable and the stable (reference) condition, barefoot showed a significantly larger centre of pressure excursion. The same results were also seen for the muscle activation. Only when the barefoot standing was compared to the unstable shoes, greater values for muscle activation in the lateral gastrocnemius, vastus medialis, vastus lateralis and rectus femoris were found. The researcher mentioned that the age of the participants could play a role in muscle activity. From the results of this study it was suggested that the benefits obtained from wearing unstable shoes could be more easily obtained by walking barefoot.

Barefoot training is being used more often nowadays by various runners, especially long distance runners. Some people use footwear that mimics the barefoot condition. It was found that the strength of the toe flexor muscle increased by almost 20% over a five-month period after wearing flexible shoes. The effect on the gait patterns and sport performance remained unclear. Therefore, Goldmann, Sanno, Willwacher, Heinrich & Brüggemann (2011) conducted a study to evaluate the effects of increased toe flexor strength on the function of the foot and ankle in walking, running and jumping. Participants were divided in the experimental group ( $n = 14$ ; age:  $24 \pm 4$  years, weight:  $77 \pm 9$  kg) which performed heavy resistance toe flexor strength training, while the control group did not participate in a specific training programme, but just continued with their daily activities. The intervention was carried out for seven weeks, four days per week with four sets per session at 90% of the maximal voluntary isometric contractions. The control group ( $n = 9$ ; age:  $25 \pm 3$  years, weight:  $76 \pm 6$  kg) participated in no training but continued with their daily activities. The results showed that the toe flexor muscles responded to the increased loading. There was, however, no alteration to the gait patterns during walking or running. A definite improvement in the standing long jump performance was seen. This could be due the high moments of force that occur in the metatarsal-phalangeal and ankle joint during jumping. There is also an enlargement of the functional base of support, due to the anterior shift of the centre of force application under the distal phalanx. This may influence the centre of mass take off angle. Whether toe flexor strength is improved through a specific training programme on a dynamometer or through barefoot training activity, it could be assumed that it has a positive effect on sports performance.

## E. Injuries

Robbins and Hanna (1987) wanted to determine if running-related injuries could be prevented through the adaptations made when running barefoot. The researchers hypothesized that adaptations responsible for shock absorption were an inherent consequence of barefoot activity. According to them, the mechanism responsible for the low injury rate in the barefoot population was related to the deflection of the medial longitudinal arch of the foot on loading. They also stated that the rigidity of the shod foot (medial arch's inability to deflect without failure) was a cause for the high injury rate in the shod population. Seventeen recreational runners volunteered to take part (14 men, 3 women) in the study, lasting four months. The controls were a subgroup of the volunteers entered (they were unable to increase their barefoot weight-bearing activity). Participants in the experimental group were told to increase their barefoot weight-bearing at home as much as possible. A special platform was developed to obtain data regarding force-deflection characteristics of the internal arched subsystem of the foot, where a repeatable loading on either side of the arch could be examined. During the experimental period, six imprints and two X-rays of the participant's right foot during the relaxed barefoot weight-bearing were taken monthly. The distance from the medial tubercle of the calcaneus to the most distal point of the first metatarsal head was measured. In the experimental group ( $n = 17$ ) there was a positive change, showing a significant shortening (1 mm) of the medial longitudinal arch with increased barefoot weight-bearing activity. From the 18 readings, two changed negatively, three showed no change at all and 13 showed a positive change ( $P < 0.05$ ). In the control group ( $n = \text{unknown}$ ), one reading changed positively and ten readings changed negatively ( $P < 0.05$ ). Researchers explained that the changes after barefoot training could only happen if there was an activation of the normally inactive musculature of the foot. This was due to the increased barefoot weight-bearing activity, but also because it was a progressive change over two to three months. This was suggested to be an ideal period for skeletal muscular conditioning to take place. According to the researchers, during the contractions of muscles responsible for the lifting of the medial arch the following could happen: the arch rises, the digits plantarflex and the contact at the medial-posterior joints is diminished. According to the researchers, the shortening of the medial longitudinal

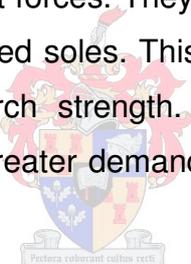
arch can be the ultimate prevention of plantar fasciitis. Robbins and Hanna (1987) stated that the normal function of the plantar fascia is to act as the support of the medial longitudinal arch. Any impact produces a strain on the fascia, especially at the attachment and induces plantar fasciitis. Barefoot activity stimulates an adaptation that is capable of transferring the impact to the elastic musculature, sparing the fascia and therefore preventing plantar fasciitis.

It was suggested that barefoot running causes fewer injuries than shod running. That is only if no injuries occur due to the lack of foot protection (Stacoff *et al.*, 2000). Researchers defined inversion, eversion and tibial rotation variables and the justification that shoes might bring to it. With these definitions they also claimed that certain abnormalities to the gait pattern can cause injuries. These claims are as follows: excessive eversion can force the Achilles tendon to bend laterally producing an unwanted asymmetric stress distributed across the tendon, leading to Achilles tendon problems (Clement, Taunton, Smart & McNicol, 1981). Medial tibial stress syndrome is another injury that has been associated with excessive eversion (Segesser & Nigg, 1980; Viitasalo & Kvist, 1993). Changes in patella tracking may also relate to the occurrence of patellofemoral pain syndrome (Stergiou, 1996).

In a study to investigate the biomechanical factors associated with tibial stress fractures in women runners, 40 participants were recruited (Milner, Ferber, Pollard, Hamill & Davis, 2006). Twenty of them had a history of tibial stress fractures and 20 had no history of lower extremity bone injuries. All participants were women runners (age: 18 – 45 years) with a rear-foot strike pattern. To be able to determine three-dimensional kinematics of the stance phase of running, markers were placed on the lower extremity and pelvic region. A force platform was used to capture data of the ground reaction forces. Participants ran on a 23 m long overground runway at a velocity of 3.7 m/sec while wearing standard, neutral running shoes. From the results, it could be seen that runners who had sustained a previous tibial stress fracture showed a small, yet non-significant increase (8 %) in the magnitude of the vertical impact peak compared to the non injured participants. A moderate effect size (ES = 0.51) was found and this showed that over time (cumulative effect) these higher impact forces might become important if repeated over thousands of foot strikes. There was an increase in shock absorbed by the tibia in the stress fracture

group, as well as an increase in vertical loading rates. The body's response to load applied and the magnitude of the load affected the magnitudes of loading rates and peak tibial shock experienced during running. The conclusion made from this study was that a history of tibial stress fractures in women runners was associated with several changes in loading-related variables.

According to Lieberman *et al.* (2010), evidence that barefoot and minimally shod runners avoid rear-foot strike landings, may have health implications. Runners are prone to repetitive strain injuries, as an average runner has a foot strike rate of 600 times per kilometre. Despite all the technological advances in the shoe industry, the incidence of injury in runners has remained the same. Cushioned, high heeled running shoes may be comfortable, but they limit proprioception and made it easier for runners to land on their heel. With this heel landing, no active adjustment was made to try and dampen the impact forces. They also noted that most of the running shoes had arch support and stiffened soles. This could lead to weaker foot muscles that may indirectly reduce the arch strength. With the weaker arch, excessive pronation occurred and placed a greater demand on the plantar fascia, which might eventually lead to plantar fasciitis.



Van Gent *et al.* (2007) reported on the incidence and determinants of lower extremity running injuries in long distance runners. Researchers reviewed 17 articles that fitted their inclusion and exclusion criteria. From the results they gathered that most injuries in the lower extremity occur at the knee (7.2 % to 50.0 %), then the lower leg (9.0% to 32.2%) followed by the foot and upper leg. They looked at the causes or determinants of these injuries, and strong evidence in men runners was found for a greater training distance per week. A risk factor for both men and women was running with a previous injury. An increase in training distance per week, however, was seen as a protective factor, only for knee injuries with the reason for this remaining unknown. There was a fine balance between overuse and under-conditioning in runners and it would therefore not be as simple to explain. A few other risk factors were mentioned in the study, but they only had limited supporting evidence. The researchers recommended that in the future, more literature review studies need to be done, as their inclusion and exclusion criteria could have been too limited.

To conduct a study on the influence of barefoot running on the prevention of injuries, long term monitoring needs to take place. Very few long term studies have been done on this issue and, according to Jenkins and Cauthon (2011), most of the claims made in research were made on the basis of logical assumptions. Once again, a limited number of studies have been carried out on barefoot running and the impact it has on injury prevention or reduction to confirm such statements.

## **F. Implementing barefoot training**

Although it is difficult to scientifically support claims regarding the impact of barefoot training on injury, there are some basic principles that could be implemented to limit or prevent injuries. Hart and Smith (2008) made suggestions on how to prevent running injuries through barefoot activity. Their main aim was to give coaches and runners the theory behind the use of barefoot activity as an aid to limit or prevent injuries. According to these researchers, the main contributors to chronic running injuries are impact forces and overpronation. The impact forces present during barefoot running were less than when running in shoes, as discussed earlier in this chapter. An advantage of barefoot training is that no special equipment is needed. Anyone can be successful, it just depends on your tenacity, time spent on it and the availability of a suitable terrain. The researchers mentioned that, although barefoot activity is important, one should not ignore the role that the external support plays in the prevention of running injuries. Weakened foot structures will, however, not benefit from barefoot training or the elimination of the external support if there is no intentional strengthening of the supporting muscles and ligaments. Hart and Smith (2008) recommended that barefoot training should begin on an even surface. The researchers also gave guidelines for the progression of barefoot activity (see Table 1). In conclusion, the researchers gave a few key factors when implementing a barefoot activity programme. One needs to maintain a running and injury journal to compare the frequency of the prior injuries and the current progress. There needs to be a gradual increase in time and variance of terrain (as set out in Table 1). There should also be a gradual decrease in shoe support. Consistency and determination is important for maintaining the strength.

Table 1: Progressions of barefoot activity

Level	Time	Terrain	Notes to be made in journal
Beginner 1-2 weeks	30min total; multiple sessions as needed	Grass, sand	Record history, begin tracking current activities and injuries
Intermediate 2 -16 weeks	1 hour total; 1 session	Sidewalk, blacktop	Track activities and injuries
Advanced 16+ weeks	1+ hours	Wood chips, hiking trails	Compare frequency and severity of injury before and after barefoot training programme

As mentioned earlier in the study by Robbins and Hanna (1987), positive adaptations after four months of one hour of barefoot activity per day were found. Another important finding is that if one discontinues barefoot activity, it can lead to the loss of the lifting of the medial arch.



## G. The sport of Netball

Netball is a team sport, with seven players in each team. The sport developed in the 1890's in England and was derived from the early versions of basketball. Netball has the highest number of participants in the Commonwealth nations and is predominantly played by women. There are over 20 million participants in more than 70 countries and it is played from school level through to international level. The sport has become an Olympic event in 1995 and the major international competitions include Commonwealth Games, Netball World Championships and World Netball Series. Games are played with a round ball on a hard surfaced rectangular court, divided into thirds, with a goal post at each short end. The object of the game is to score as many goals as possible by shooting the ball into the goal ring. Each player has their own assigned position and is only allowed in certain areas on the court, depending on their role or position. Players are not allowed to run with the ball and must pass or shoot the ball within three seconds of receiving the ball. Goals can only

be scored by certain players and only from a specific area on the court. A game is usually played for four 15-minute quarters (Netball-sa.co.za, 2011; Shakespeare & Caldon, 2009)

### ***Physical profile and testing of netball players***

Because netball is a professional sport in some countries, it could be assumed that a battery of fitness tests and normative data would be available. Creagh (1998) provided an educational resource regarding netball. Limited data was available regarding the anthropometric values of netball players. The researcher also looked at fitness assessments in netball players and found no standardised tests were available for testing physical and motor fitness skills, or evaluation of skill achievement. A battery of tests was compiled in 1968, but since the game had evolved, those tests became outdated and had to be updated. In 1981, Barham and Wilson set up a new test battery via the analysis of game characteristics. Validity for these tests was established by correlating the ranking assessment of four expert judges with the ranking of 24 players' results. Most of the tests produced high correlation coefficient with level of significance set at  $P = 0.01$ , it was only the long throw that had a moderate correlation coefficient with the level of significance set at  $P = 0.05$ . Reliability of these tests were determined by repeating the tests of 15 of the players ( $R = 0.63$  to  $R = 0.82$ ). Normative data were set up by testing 120 netball players from all levels of competition. Some of these tests were also used in this current study and will therefore be discussed later (Creagh, 1998).

One of the earliest studies to determine the physique, body composition and training variables of elite and good netball players in relation to playing position was conducted by Bale and Steele (1986). Two groups were observed, an elite group, consisting of 17 players of the under 18 (u/18) and u/21 international side of England, and 12 players of county standard who represented the good players. Results showed that the elite players were significantly ( $p < 0.05$ ) taller than the good group. The elite group was also heavier, although not significantly. It was also noted that the elite players had lower mean total skinfold and fat percentage values, as well as a higher lean body weight when compared to the good players. This suggested that a

larger muscle mass, with lower adiposity levels in relation to height, exists in top class netball players. The somatotype of both groups showed that all players were predominantly meso-endomorphs, which means that their muscle mass is slightly lower than the adiposity levels. Researchers also examined the different training variables of the two groups. Ball skill practice and match play were the main training the good players relied on to improve their performance. The elite players included sprint and distance training, bounding and weight training in their weekly programme to improve their overall fitness and strength.

Since the 1990's more studies on netball players were conducted. In a study to determine the physical and physiological profiles of netball players, 48 netball players from the Boland region participated. Participants were from the super- and first-league and included provincial and national-level players. Anthropometrical and power measurements were taken first. This was followed by the testing of speed, agility and aerobic endurance. Results obtained during this study were compared to the results of the Australian under-21 players. There was no significant difference in weight between the two groups, but in height there was a significant difference with the Boland team being shorter ( $172.6 \pm 7.5$  cm for Boland and  $177.3 \pm 4.3$  cm for the Australian team). The sum of the skinfolds of the Boland group had a greater value ( $108.2 \pm 29.7$  mm) than those of their Australian counterparts ( $82.4 \pm 29.4$  mm). Another significant difference was in the flexibility, with the Boland group being less flexible in their lower backs and hamstring muscles. When looking at the results for agility, the Boland (left:  $2.71 - 0.15$  sec,  $P < 0.05$ ; right:  $2.69 - 0.12$  sec,  $P < 0.05$ ) players were inferior to the great agility that the Australian players (left:  $2.44 \pm 0.10$  sec,  $P < 0.05$ ; right:  $2.40 \pm 0.10$  sec,  $P < 0.05$ ) showed in both left and right feet. Another statistically significant difference was observed in the vertical jump height. The Australians jumped 12 cm (average) higher than the Boland group. During the sprinting test, the Boland players were faster over the first 5 metres of a 20 metres sprint, but they were unable to maintain that speed and no differences were found at 10 m and 20 m between the groups (Venter *et al.*, 2005).

Although there are data available regarding the anthropometrical and physiological profiles of netball players, extensive research still needs to be done in South Africa. In 2010, Ferreira and Spamer conducted a study to determine the physical profile of elite netball players. The study was limited to the netball players of the North-West University in South Africa. Researchers found limited data currently available on the physical profile of netball players, especially in South Africa. Players from the first, second, third and fourth and the u/19 A and B teams participated in this study. Forty players were tested during the initial testing occasion and only twenty five players were able to attend the second testing occasion. First testing was done pre-season, March 2007 and the second testing occasion was post-season during August 2007. The training programme that was followed during the season and between the two testing sessions focused on agility, balance, explosive power, plyometrics and speed endurance. The study consisted of biomechanical assessment that measured a combination of symmetry, dynamic mobility and local stability of the body. Three standard measurements, body fat percentage (pre-season: 26.6%, post-season:27.5%), stature (pre- and post season: 1.74 m) and body mass (pre-season: 68.2 kg, post-season: 70.2 kg) were used to describe the anthropometric components. Another area that was tested was the physical/motor abilities. The battery of tests included the Illinois agility run test, a computerised balance test and a vertical jump test for explosive power. Physical/motor abilities are most relevant to this current study and therefore only these results will be discussed. According to Ferreira and Spamer (2010) there were significant differences with all three motor tests between the pre-season and post-season testing values. Balance improved from 69.31% to 81.87% ( $p = 0.000005$ ) and agility improved from 19.44sec to 18.95sec ( $p = 0.00002$ ). These two are the only measurements that showed a significant improvement during the season. In this study they found a significant decrease in explosive power, from 33.74cm to 28.61cm ( $p = 0.000003$ ). The researchers mentioned that a reason for the decrease in explosive power could be due to the fact that there was not enough plyometric exercises included in their training programs. Other literature (Baltaci & Kohl, 2003, and Clark & Burden, 2005) confirms the fact that, when including the correct exercises, a netball player's physical/motor abilities could be enhanced during a netball season.

## ***Kinetics in netball***

Previous studies regarding kinetics were done on running and the impact forces of running. Steele and Milburn (1987) conducted a study where the vertical ground reaction forces during landing in netball were compared to those of running. They used a Kistler force platform to quantify the ground reaction forces. Fifteen skilled centre-court netball players were used in this study. These participants had to perform a typical attacking movement pattern, under four different footwear conditions. Results of the study showed that the peak vertical ground reaction force was 3.9 - 4.3 times body weight, compared to the 2 – 3 times body weight in running. The mean time to peak vertical ground reaction force was similar to that found in runners. The researchers stated that players, whose musculoskeletal systems are properly aligned, should be able to endure these high stresses. It is those with a skeletal malalignment, or the occasional unusual foot placement in landing, that increases the risk of injury. Steele and Milburn (1987) also suggested that a method to reduce the vertical ground reaction forces needs further investigation to reduce the risk of injury.



The stepping rule in netball does not allow the player to take an extra step after landing on the specific foot. Since the ground reaction forces during landing in netball were found to be very high, Steele and Milburn (1988) also conducted a study to investigate changes in peak vertical ground reaction forces when two or three additional steps were allowed. They found that there were no significant differences in the forces under special landing conditions which include normal stepping, illegal stepping and a normal landing and pivot when two types of passes (chest and high level) were used. Landing after receiving a high pass or using the extra steps landing technique generated lower landing forces than when receiving a chest pass. Steele and Milburn (1988) concluded that the height of the pass has a bigger influence on the vertical force impact and load than allowing the extra step.

In another study to determine the effect of passing height and footfall pattern on ground reaction forces in landing, used six elite netball players as participants (Neal & Sydney-Smith, 1992). The results were similar to those of Steele and Milburn

(1988), with the peak vertical ground reaction force being 4.65 times body weight. Neal and Sydney-Smith (1992) found that the speed of the approach to the force plate of the high pass was significantly lower than those of the chest pass.

If an extra step does not decrease the forces experienced on the body during landing, which type of landing would then be the best? There were the main questions asked and also the main objectives for the study by Otago and Neal (1999). The researchers wanted to investigate if the forces experienced by the body during landing would decrease if an extra step was taken. Secondly, to determine the softest landing technique, and lastly, examine the best way to land for the pivot landing technique, which is the most common landing. Twenty women State or State u/21 netball players participated in the study (age:  $21.34 \pm 3.62$  years, mass:  $68.64 \pm 7.85$  kg, height:  $172.82 \pm 7.05$  cm). Participants were excluded from the study if they had a significant knee injury, grade II or above. During the period of data collection, all participants were still actively involved in netball. Researchers used five different landing techniques during their study. Three of these techniques were legal and the other two illegal with an extra step allowed. A pivot was incorporated in one of the legal and illegal landing techniques respectively. The other legal landing technique was a double foot landing and the remaining two techniques were with an extra step. The results from the study showed no significant differences between the legal and illegal landing techniques for either the pivot or the run-on regarding the vertical loading rate. Both pivot landings showed a significantly higher vertical loading rate than any of the other three landing conditions. The researchers also compared the difference in braking force loading rates between the different conditions. There were significant differences between the legal pivot, legal run and extra step run, where legal pivot was higher than the other two. The extra step pivot also showed a significant higher braking force loading rate compared to the legal run condition. Otago and Neal (1999) emphasised the similarity between the loading rates for the pivot landings. When looking at the angles of the knee joint during landing, the researchers found no significant difference. The run-on technique appeared to have a greater angle of knee flexion compared to the pivot techniques. Results for the change in angle of the knee showed no significant difference. There was, however, an increase in the knee angle for the run-on techniques and this enhanced the suggestion that a decrease in stress on the knee and body occurred when there was

an increased angle in the knee joint. Otago and Neal (1999) stated that this trend, which obviously places less stress on the body, could be used in a landing technique to decrease the loads on the body and knee joint.

### ***Injuries in netball***

Studies regarding netball injuries date back as far as the mid 1980's. Hopper (1986) conducted a study to investigate the causing factors of netball injuries. All players who reported to the first aid station of a district netball association in a 14-week netball season were surveyed. The ankle was the most affected joint accounting for 58.2% of the total injuries requiring treatment at the first aid station. Hopper (1986) also looked deeper into the level of the players obtaining these injuries. It was found that most injuries occurred in the higher grade teams (A-grade). The researcher found that at senior level (16 years and above), 35.3% of the injuries occurred in the higher grade teams (A-grade) where only 3.5% of the injuries occurred in the lower grade (G-grade) teams. The hypothesis was made that the higher grade players would be more competitive and focused on winning. With more determination comes taking greater risks and this could make them more vulnerable to injury.

It is therefore suggested that the occurrence of injuries is higher in higher levels than in lower levels of the same sport. Another study using a 14-week competition held in Western Australia was done to determine the main site of injury, cause of injury and to determine the prevalence of new or recurring injuries (Hopper *et al.*, 1995). The researchers used the data from five consecutive years, 1985 to 1989. Teams competed on a weekly basis and grades ranging from A1 to D6 participated. A total of 11 288 players competed at the centre. There were 608 players who presented themselves to the first aid room with an injury. Injuries obtained at any other time than during the specific competition were not taken into account. Mean age of players was 18.8 ( $\pm$  5.6) years. When a player got injured, they had to report to the first aid centre. There they were evaluated by a physiotherapist and proper treatment was given. All injured players had to complete a questionnaire, divided into categories each of which had a different focus. Categories were general information, occurrence of injury, incidence of injury, footwear used during competition and

mechanism of injury. Results showed that the average injury incidence was 5.4% (608 injured players out of 11 288 players in total). It was also noted that the higher grade level had more injuries (A grade, 8.5% followed by B grade, 5.2% and lower into the lower levels). From the results the researchers noted that the ankle was the region that was mostly affected by injury (84.3%). A lateral ligament complex sprain was more common than the deltoid ligament. The results for knee injuries were lower than that of previous studies. The anterior cruciate ligament (ACL) was the least injured structure at 1.8% of the total injuries. Injuries to the medial and lateral meniscus were 2.6% of the total and players that presented with collateral ligament sprain injuries were 2.5% of the total injuries presented. Another statistic that came from the research was the fact that 65% of the injuries were new injuries, as to the 35% who experienced recurring injuries. When players were asked what the cause of their injury was, 38% of the players considered that it could have been because of incorrect landing techniques. The results from this study can verify results from the previous study by Hopper (1986) that the higher level of play produced more injuries. The ankle is the most affected site of injury, especially the lateral ligaments. Knee injuries were more severe than the ankle injuries obtained.

As discussed earlier in the study done by Otago and Neal (1999), the braking force loading rate in the pivot landings was significantly higher than in the extra step conditions. They stated that through the rotation and translations of the knee joint, these two components of the braking force can cause stress in the ACL. Researchers noted that a lot of the participants had a near full extension angle of the knee during landing. One of the mechanisms for an ACL rupture is hyperextension. If players are therefore not trained in the correct way of landing, with the knees bend, the possibility of an injury is much bigger.

From the previous studies, it was seen that netball players from South Africa have a few shortcomings in their physical profile (Venter *et al.*, 2005). The secondary aim of the study by Ferreira and Spamer (2010) was to determine whether the shortcomings in the physical profile of netball players could lead to musculoskeletal injuries. During that specific season (March – August 2007), 46 injuries occurred. 8.69% were classified as Grade III (serious) injuries, 56.52% graded as Grade II (moderately-serious) and 34.78% of them were classified as Grade 1 (minor) injuries. The ankle

joints were the body parts mostly affected by injuries, similar to previous studies. Of the total amount of injuries, 39.13% occurred in the ankle, 28.26% in the knee and 8.69% in the cervical region. Ferreira and Spamer (2010) found that the mechanism responsible for most of the injuries was an incorrect landing technique. This was responsible for 52.17% of the injuries while a fall incident was responsible for 4.34% of the injuries. The researchers concluded that a reason for the high injury rate could be due to not only the results of the biomechanical deviations, but also the poor anthropometry and relatively average physical/motor abilities. They recommended that prior to a netball season, basic testing should be done, to get a physical profile of each player.

## **H. Conclusion**

It is clear from current literature that there are different views and results regarding the benefits or disadvantages of barefoot running. Researchers have shown a definite change in kinematic variables when running barefoot. This could have an effect on the prevention or reduction of injuries, but has not been scientifically shown to do so. Because of the changes in kinematics while running barefoot, the development of the lower leg could also be influenced. The influence of barefoot training on other sporting modalities is still unclear.

## CHAPTER THREE

# METHODOLOGY

In this chapter, the methods of research will be discussed. The research design of the study and the utilized participant population will be explained. Finally the testing protocol implemented to substantiate the aims, objectives, and research questions will be explained.

### A. Study design

This study was a field-based experimental study to determine the effects of concurrent barefoot and shod training on selected physical performance parameters in netball players. All participants completed a similar intervention programme combined with their normal netball training programme over a period of six weeks. Participants attended a total of three training sessions per week, varying from 30 to 45 min per session, for the duration of the study. A battery of tests was performed prior to the first training session of the intervention programme, as well as after completion of the intervention programme.

### B. Participants

Participants were recruited from the netball club of Stellenbosch University. Players from the third, fourth, fifth and sixth teams participated in the study. All players were on the same performance level and played in the same league. Participation in the study was not compulsory and players volunteered to be part of the study. Each participant had to complete an informed consent form, once the study was explained to them. They also received a health screening form to complete. Participants were randomly assigned to the shod ( $n = 10$ ) or barefoot ( $n = 10$ ) group. Although it was impossible to blind participants to the study, the real aim of the study was never made clear to them. The study took place while the normal training regime for the

netball season was underway. Players were asked not to do any training other than their normal netball training sessions. The reasons for only using women players as part of this current study are threefold: 1) all the players from the Stellenbosch University netball club are women; 2) very little data are available regarding the physiological characteristics of men netball players; and 3) gender differences showed to have an effect on the gait cycle. According to Nigg *et al.* (1994), women have a smaller initial eversion, tibial rotation and peak vertical force during weight acceptance. They produce a bigger peak vertical force during the push-off phase. Women showed to have a faster stride, stance phase and swing duration (Blanc *et al.*, 1999). Another difference that was observed was that the women athlete activated the bicep femoris more pre-heel strike compared to the men. Men runners had greater relative EMG intensity at higher frequency for the following muscle groups: vastus medialis, biceps femoris and gastrocnemius medialis, than their women counterparts. It could therefore be assumed that men make more use of the fast muscle fibres during running than women (Nigg & Gérin-Lajoie, 2011).



### **Inclusion and exclusion criteria**

Participants were included in the study if they represented the third, fourth, fifth or sixth team of the university, were without any current injuries and had no other health issue that could be made worse by physical activity. They had to attend 70% of the training sessions, which equated to 14 of the 20 training sessions.

### **C. Assumptions**

It was assumed that the netball programme, set up to improve certain performance parameters, would achieve these goals despite the two different groups. Another assumption that was made was that ethnicity would not play a role in the response to the training programme.

## **D. Limitations**

The duration of the study was limited to the term dates of Stellenbosch University. Attendance of the exercise sessions was influenced by writing tests or exams. Since netball is a competitive sport and regular training and matches were scheduled as normal, injuries played a role in the total number of participants who finished the study.

## **E. Experimental overview**

Participants performed a battery of baseline tests. It was followed by an eight week intervention program consisting of three training sessions per week. The duration of the training session on a Monday was 45 min while the other two training sessions, on a Tuesday and Thursday, was 30 min each. Training sessions focused on speed, agility, plyometrics and cardiovascular conditioning. Pre- and post testing took place in the DF Malan indoor sports hall and the Stellenbosch Biokinetics Centre, both situated at the Department of Sport Science, Stellenbosch University. The control group performed all the exercises with their normal training shoes, while the experimental group performed the same exercises barefoot.

### **Intervention programme**

#### **Pre-intervention testing**

The protocol of the study was explained to the participants verbally and given to them in writing. Written informed consent (Appendix A) was acquired from each participant. Every participant had to complete a health questionnaire (Appendix B) where their history of injuries and overall health was noted. Body composition, speed, agility, vertical jump and single leg balance were tested and baseline values were obtained for each participant. According to the NSCA (Baechle & Earle, 2000) a battery of physical fitness test should occur in the following order: non-fatigue tests, agility, maximal strength and power tests, sprint tests and muscle endurance tests. In this study however, we followed the sequence given by the Australian Sports

Commission. These tests and the specific order have been used by the Australian national netball squads for the past six years (Ellis & Smith, 2000).

### **Intervention**

The main foci of the training sessions were cardiovascular conditioning, speed, agility and plyometrics. Adjustments to the programmes were made on a regular basis to ensure progression. Although the control group (shod) completed all the exercises with shoes, the experimental group (barefoot) had a gradual build-up to doing all the exercises barefoot. They started off by doing only 5 min of barefoot training and increased the time spent in the barefoot condition gradually.

### **Post-intervention testing**

The post-intervention testing was completed with the same instruments and in the same order as the initial testing. No results or feedback were discussed with the participants.

### **Ethical Aspects**

Approval for the study protocol was given by the Ethics Subcommittee of the Stellenbosch University (Reference number 304 / 2010; Appendix C). Care was taken to make sure that participants understood the protocol and they had the opportunity to ask any questions before they gave their consent. Emphasis was put on the fact that the study was voluntary and they could withdraw at any time without any consequences.

### **Dependent and Independent Variables**

The independent variable was the fact that 10 of the participants were training barefoot, while the control group (n = 10) were training with shoes. This might have had an effect on the dependent variable which is the response of the participants to the intervention programme.

## **F. Measurements and tests**

The primary outcome variables were speed, agility, vertical jump height and single leg balance. The secondary outcome variable was the anthropometrical measurements.

### **Anthropometric measurements**

Participants were barefoot and wore light-weight clothes. Recommendations from the International Standards for Anthropometric Assessment (ISAK) published by the International Society for the Advancement of Kinanthropometry, Australia (Marfell-Jones, Olds, Stewart & Carter, 2006) were followed during the anthropometric measurements. Stretched stature, body mass, a maximum left and right calf circumference, as well as a circumference 30 cm from the floor on the left and right leg were taken.

#### **Stretched stature**

The player was positioned with the heels together and the heels, buttocks and upper back touching the stadiometer. The head of the player was placed in the Frankfort plane, the lower edge of the eye socket (Orbitale) in the same horizontal plane as the notch superior to the tragus of the ear (Tragion). Once aligned, the player was asked to inhale and the measurement was taken at the highest point of the skull, the Vertex. A sliding steel anthropometer was used and the reading was taken to the nearest 0.1 centimetre (cm).

#### **Body Mass**

Body mass was determined with a calibrated sliding scale (439 Eye-Level Physician Scale, Web City, USA) and recorded to the nearest 0.1 kilogram (kg). Participants had to stand in the middle of the scale with weight equally distributed on both legs looking straight ahead.

## **Circumferences**

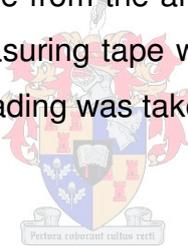
Players stood on a 40 cm anthropometrical box which made the measuring and the reading easier for the investigator. Players stood with their legs shoulder width apart and weight equally spread on both legs. Circumferences of the lower leg were taken using the cross-hand technique according to ISAK regulations. The tape (*Rosscraft*, Canada) was held horizontal with the tension kept constant. Readings were taken more lateral than on the medial side.

### *Maximum Calf*

The measuring tape was placed around the calf, horizontal to the floor and perpendicular to the axis of the lower limb. With the help of the middle fingers, the tape was moved up and down until the level of the maximal girth of the calf was found. The measurement was taken to the nearest 0.1 cm.

### *30 cm from the floor*

A measurement of 30 cm was made from the anthropometrical box and a mark was made on the exact place. The measuring tape was placed horizontal to the floor on the mark that was made and the reading was taken to the nearest 0.1 cm.



## **Subjective experience to barefoot training**

All players participating in this study were new to training barefoot. Regular feedback was asked during training sessions regarding their comfort levels. If any player experienced pain or extreme discomfort, her training session would be ceased. This however, did not happen with any of the participants. During the post testing, participants were interviewed by the researcher regarding their subjective experiences towards barefoot training. It was only asked to the barefoot group, since it was only they that had the experience.

The following questions were asked:

1. Did you experience any pain/discomfort during the barefoot training?
2. If so, where did you experience the pain/discomfort the most?
3. Did you experience pain or discomfort a day after the training session?
4. Do you prefer barefoot or shod training?

All answers were written down by the researcher.

## **Speed**

Prior to the speed test, a warm-up of five minutes was done. The warm-up consisted of jogging, “stride-throughs” over 20 metres, and two sprints from stationary starts. The warm-up and speed test were performed indoors, on a non-slip artificial surface. The speed test was done over 20 metres using the Swift speed light sport timing system (SL 9501 – 83). Reliability of the test has been reported by Gabbett, Kelly and Sheppard (2008), to be  $r = 0.96$  (TE = 1.3%). All participants had to wear normal training shoes for the speed test. Players were instructed to position themselves behind the starting line, with one foot in front of the other and to stand absolutely still. When the signal was given that the speed cells were ready, players could start on their own time. The player had to run as fast as possible through the gate formed by the second pair of speed cells 20 metres away and decelerate only thereafter as seen in Figure 1. Participants ran two trials and both times were recorded. There was a two minute rest between the runs.

Times were recorded simultaneously for the sprint over 10- and 20 metres. The fastest time of the two trials were used in the statistical analysis. Times were recorded to the nearest 0.01 seconds.



Figure 1: Participant performing the 20-m Speed test (photograph by E. du Plessis)

## Agility 505

Participants were instructed to take position behind the starting line. This test was performed by wearing normal training shoes. When the signal was given that the speed cells were ready, the participant could start when ready. The lay-out of the test is shown in Figure 2.

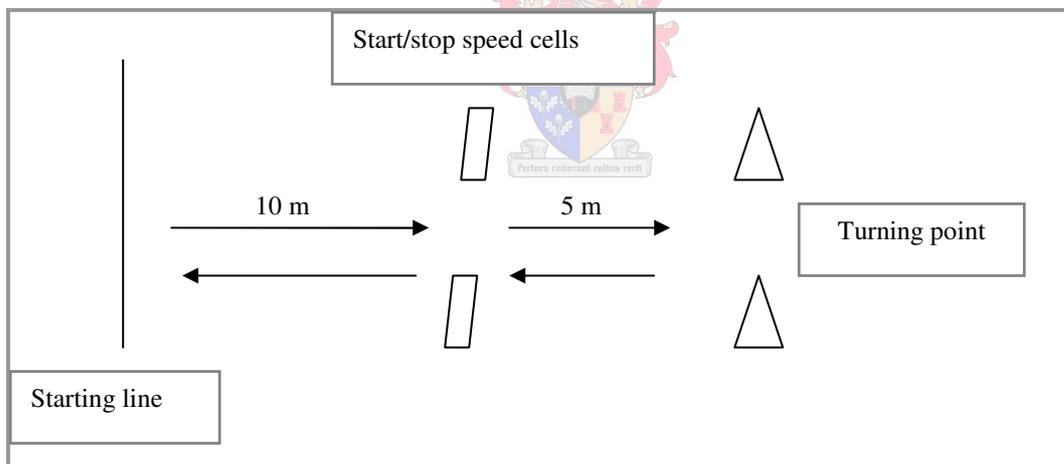


Figure 2: 505 Agility-tests

Participants sprinted from the starting line, through the gates, formed by the speed cells to the zero line, formed by one cone on each side. Once they reached the zero line, they had to turn, the first trial on the dominant foot and the second trial on the non-dominant foot. They had to accelerate back to the starting position and only slow down thereafter. Times were recorded to the nearest 0.01 seconds for each trial on

both legs. Both the times for the left and right leg were used in the statistical analysis. Gabbett *et al.* (2008) reported the validity of the test to be 0.90 ( $r = 0.90$ ) with a typical error of measurement 1.9% ( $TE = 1.9\%$ ).

## **Vertical Jump**

Participants were instructed to position themselves next to a wall with a measuring tape mounted to it. Participants had to reach as high as possible with the arm closest to the wall with feet kept flat on the floor. The reaching height was recorded. Participants had to colour their fingertips with chalk and jump as high as they could, touching the wall at the top. They had to complete three trials and the best value of the three trials was used in the statistical analysis. Measurements were recorded to the nearest 1 centimetre. The relative jump height was calculated from the difference between the reach and jump height. The participants had to wear their normal training shoes for this test.

## **Ankle stability**

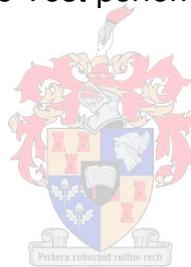


The Athlete Single Leg Balance Test was performed on the Biodex Balance System SD #950-300 (Biodex Medical Systems, Inc, New York, USA) to determine an overall stability index (OSI), anterior-posterior stability index (APSI) and medial-lateral stability index (MLSI). The reliability (OSI reliability:  $r = 0.94$ ; APSI reliability:  $r = 0.95$ ; MLSI reliability:  $r = 0.93$ ) of the Biodex Balance System SD has been reported by Cachupe, Shifflett, Kahanov, and Wughalter (2001). The player was instructed to perform the test barefoot and to position herself with one leg on the Biodex Balance System SD platform. On the firm surface of the platform, the player had to move her foot to move the marker, which helps with the visual feedback, to the centre of the circle on the screen. Each player was given the same instructions before commencing the test. Dynamic balance was assessed during the Athlete Single Leg Balance Test. The test comprised of three 20 sec trials on each leg. The spring resistance started at level twelve and ended at level one. Spring resistance levels range from 1 (least stable) to 12 (most stable). Between each set, a rest period of 10 seconds was allowed. The player was not allowed to hold onto the railings and limbs

were not to touch each other or the platform during the test as seen in Figure 3. Due to the on-screen visuals there was a continuous biofeedback given of their weight displacements. Results were reported as scores on an OSI, APSI and MLSI, which could range from zero to 20. A score closer to zero was considered better.



Figure 3: Athlete Single Leg Balance Test performed by a participant (photograph by E. du Plessis)



## G. Intervention

Participants had to attend at least 14 of the 20 (70%) training sessions (Appendix D) to be included in the study. Each training session was presented by a staff member of Stellenbosch Biokinetics Centre. On a Monday, participants had a 45-minute training session, focusing on cardiovascular conditioning. The other two sessions were 30 minutes each on a Tuesday and Thursday, directly after normal netball practice. Each of these training sessions had a different focus. It was either speed, agility, plyometrics or muscle endurance. There was a build-up to performing the whole training session barefoot. Initially only one, then two exercises were done barefoot, approximately five to seven minutes. As the participants got used to barefoot activity, the duration of barefoot activity was increased to the full 30 minutes or 45 minutes. Exercise sessions were performed on an indoor court and on grass, weather permitting.

## H. Statistical Analysis

Microsoft Excel (Windows®, 2003; USA) and STATISTICA® 9.0 (Statsoft, Inc; 2009, USA) was used for the statistical analysis of the data. All the descriptive data of participants were reported as mean ( $\bar{x}$ ) and standard deviation ( $\pm$  SD), unless otherwise specified. A mixed model repeated measures ANOVA was used to determine the interaction between the groups over the intervention period (time\*group). The level of significance was set at  $P \leq 0.05$ .

Cohen's effect size (ES) of changes for each parameter was also calculated. The values used for Cohen's effect size were  $\geq -0.15$  and  $< 0.15$  (negligible effect),  $\geq 0.15$  and  $< 0.40$  (small effect),  $\geq 0.40$  and  $< 0.75$  (moderate effect),  $\geq 0.75$  and  $< 1.10$  (large effect),  $\geq 1.10$  and  $< 1.45$  (very large effect) and  $> 1.45$  (huge effect) (Thalheimer & Cook, 2002).

In addition, within-/between-group comparisons were done to determine the chance that the true values for each training programme were of practical significance (i.e., greater than the smallest practically important effect, or the smallest worthwhile changes (SWC), [0.2 multiply by the between-subject standard deviation, based on Cohen's effect size principle]), unclear or disadvantageous/worse for performance were calculated (Hopkins, Marshall, Batterham & Hanin, 2009). To assess the quantitative chances of advantageous / better or disadvantageous / poorer effect qualitatively, the following values were used:  $< 1\%$  to  $5\%$ , unlikely;  $5\%$  to  $25\%$ , trivial;  $25\%$  to  $75\%$ , possibly;  $75\%$  to  $95\%$ , probably;  $> 95\%$  almost certainly. If both chances of having an advantageous / better or disadvantageous / poorer performance were  $> 5\%$ , then the true difference was unclear (Buchheit, Mendez-Villanueva, Quod, Quesnel & Ahmaidi, 2010).

## CHAPTER FOUR

## RESULTS

The aim of the study was to determine the effect of barefoot training on speed, agility, power and balance in club-level netball players. To this end, players were evaluated on a laboratory based test for single leg balance, and a number of field-based tests namely: 20-metre sprint, 505-agility test and vertical jump.

### A. Participant characteristics

Thirty women students, all members of Stellenbosch University netball club, volunteered to be part of the study. Only twenty participants met the inclusion criteria of attending at least 70% of the training sessions. Participants were randomly assigned to the barefoot / experimental (n = 10) and shod / control (n = 10) group. Both groups followed the same intervention programme, while also taking part in their normal weekly netball training. The only difference between the two groups was that the barefoot group gradually increased the amount of exercises performed barefoot, while the shod group did every exercise with their training shoes. Table 2 illustrates the physical characteristics of the participants. No significant differences ( $P \leq 0.05$ ) were found between the two groups for any of the baseline measurements for physical characteristics.

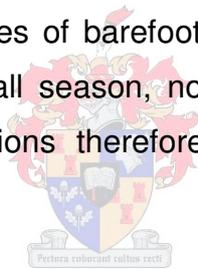
Table 2: Physical characteristics (mean  $\pm$  SD, range) of the control and experimental group.

Characteristics	Control group (n = 10)			Experimental group (n = 10)		
	Mean	SD	Range	Mean	SD	Range
Age (years)	20	$\pm 1$	18 – 22	20	$\pm 2$	17 - 23
Height (cm)	170.58	$\pm 6.36$	166.03 - 175.13	174.59	$\pm 8.22$	168.71 - 180.47
Weight (kg)	68.95	$\pm 8.88$	62.60 - 75.30	69.30	$\pm 5.48$	65.38 - 73.22

## **B. Intervention programme**

The intervention programme took place over a period of ten weeks. Most of the participants were students at the Stellenbosch University; therefore the researchers had to adhere to the term dates of the University. There was a week holiday during the ten week period where participants did not take part in any formal type of training. Participants had to attend at least 14 of the 20 (70%) exercise sessions. The attendance of participants was very good, with only 15% of the participants attending less than 80% of the training sessions.

During this current study, barefoot activity was introduced progressively. The time of barefoot activity was increased weekly, with an initial session consisting of approximately five to seven minutes of barefoot activity. Because the intervention programme took part in the netball season, normal netball training sessions also continued. The intervention sessions therefore had to focus on netball-specific training drills.



## **C. Circumferences**

The maximum calf circumference and the calf circumference 30 cm from the floor were taken on both legs. After completing the study, no significant increases ( $P \geq 0.05$ ) were found when comparing the two groups. There were however some changes in certain individuals, but the changes were the same for both groups. Although not significantly different, the left leg showed a small practical difference post intervention (effect size = 0.22) with the measurement 30cm from the floor. Table 4 depict the descriptive statistics of the maximum calf circumference and calf circumference 30 cm from the floor.

Changes in the maximum circumference for right calf were trivial and for the left calf were trivial towards a positive change, therefore an increase in the maximum circumference. There were possible chances of a practical effect present in the circumference taken 30 cm from the floor for both the left and the right leg. There was a decrease in the 30 cm from the floor circumference in both legs. Quantitative chances (%) of improvement in circumferences are represented in the Figure 4.

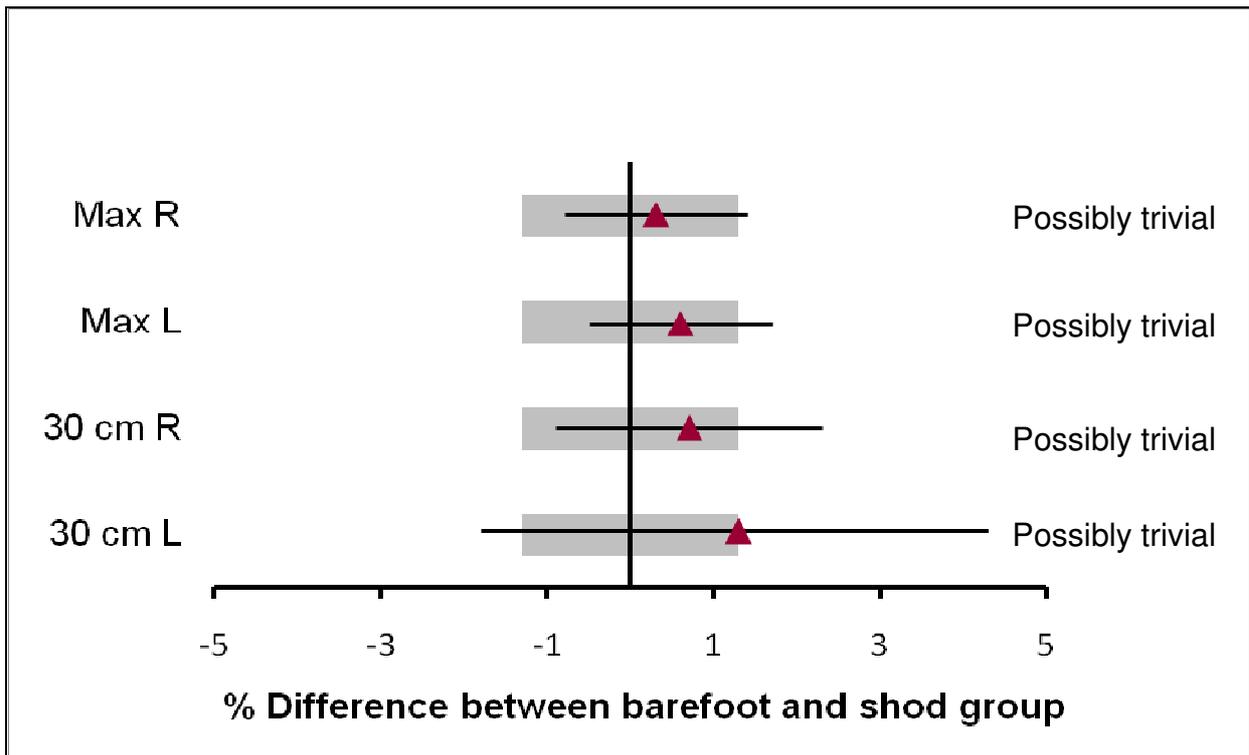


Figure 4: The percentage changes between the groups for maximum calf circumference and calf circumference 30 cm from the floor post intervention.

## D. Subjective experience of barefoot training

After completion of the intervention program, participants were asked a couple of questions regarding their physical experience while training barefoot. Questions asked to the participants in the experimental / barefoot group were:

1. Did you experience any pain/discomfort during the barefoot training?
2. If so, where did you experience the pain/discomfort the most?
3. Did you experience pain or discomfort a day after the training session?
4. Do you prefer barefoot or shod training?

Most participants (70%) experienced sensitivity on the soles (balls) of their feet or a tightness in their arch or plantar fascia. This was however just at the beginning of training. The longer the training session went on, the more they got used to the feeling and no further discomfort was felt. The other 30% of participant did not experience any discomfort or pain at any time due to the barefoot training. None of the participants experienced pain the day after the training sessions. Of the ten participants questioned, seven (70%) preferred barefoot training to training in shoes. Some participants (20%) felt that there was no difference between barefoot and shod training, and only one participant (10%) preferred training in shoes to training barefoot.

Table 3: Subjective experience to barefoot training

Participant	Prefer barefoot training or shod	Discomfort / Pain
1	Barefoot	Slight discomfort (soles)
2	Barefoot	No discomfort
3	Barefoot	Sensitive plantar fascia
4	No Preference	Slight discomfort (soles)
5	Barefoot	No discomfort
6	Barefoot	Slight discomfort (soles)
7	No Preference	Slight discomfort (soles)
8	Barefoot	No discomfort
9	Barefoot	Slight tightness in feet
10	Shod	Discomfort (soles & balls of feet)

## E. Changes in performance parameters

### Speed

The 20-metre sprint test was performed with measurements also taken at 10-metre mark. Two trials of this test were performed and both times were recorded. The better of these two times were used in the statistical analysis. Table 5 illustrates the descriptive statistics of the speed test.

Results of the 10-metre sprint tests showed no significant difference between the groups during the post-intervention testing ( $0.10 \pm -0.04$ ,  $P = 0.3$ ) or within any of the groups. There was however a weak tendency ( $0.16 \pm 0.09$ ,  $P = 0.09$ ) towards a positive change in the barefoot group. The shod group showed an increase in the time it took to complete the 10-metre sprint test after the intervention period ( $-0.05 \pm 0.22$ ,  $P = 0.59$ ) as seen in Figure 5. The practical difference between the groups were however large ( $ES = 1.01$ ) after the intervention.

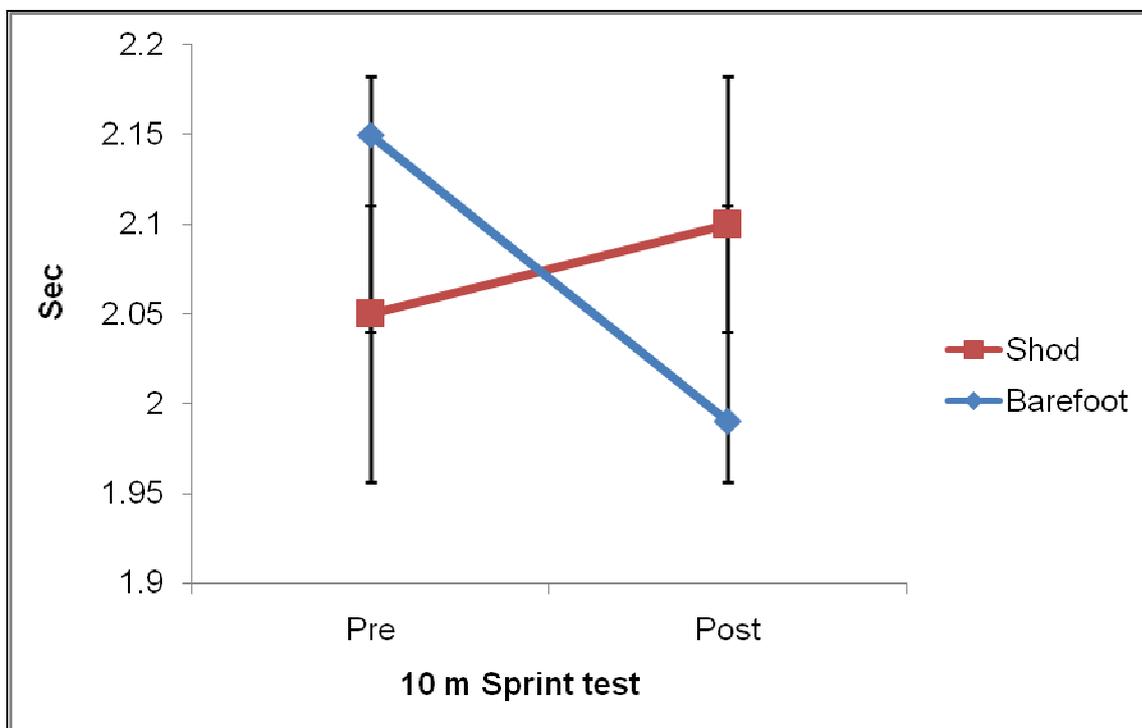


Figure 5: Difference in time for each group for the 10-metre sprint. A large effect ( $ES = 1.01$ ) were noticed between the groups following the intervention programme. 95% CI: 1.91 – 2.07 (barefoot); 95% CI: 2.02 – 2.19 (shod).

The 20-metre sprint test showed only a slight change in the barefoot group ( $0.02 \pm 0.00$ ,  $P = 0.48$ ). The shod group showed a decrease in speed with the 20-metre sprint test ( $-0.07 \pm 0.06$ ,  $P = 0.05$ ). Figure 6 illustrates the actual difference in the time it took to complete the 20-metre sprint test between the pre-intervention testing and the post-intervention testing. Although no significant difference was found between the two groups, a large practical effect ( $ES = 0.80$ ) was noted between the barefoot and the shod group after the intervention period.

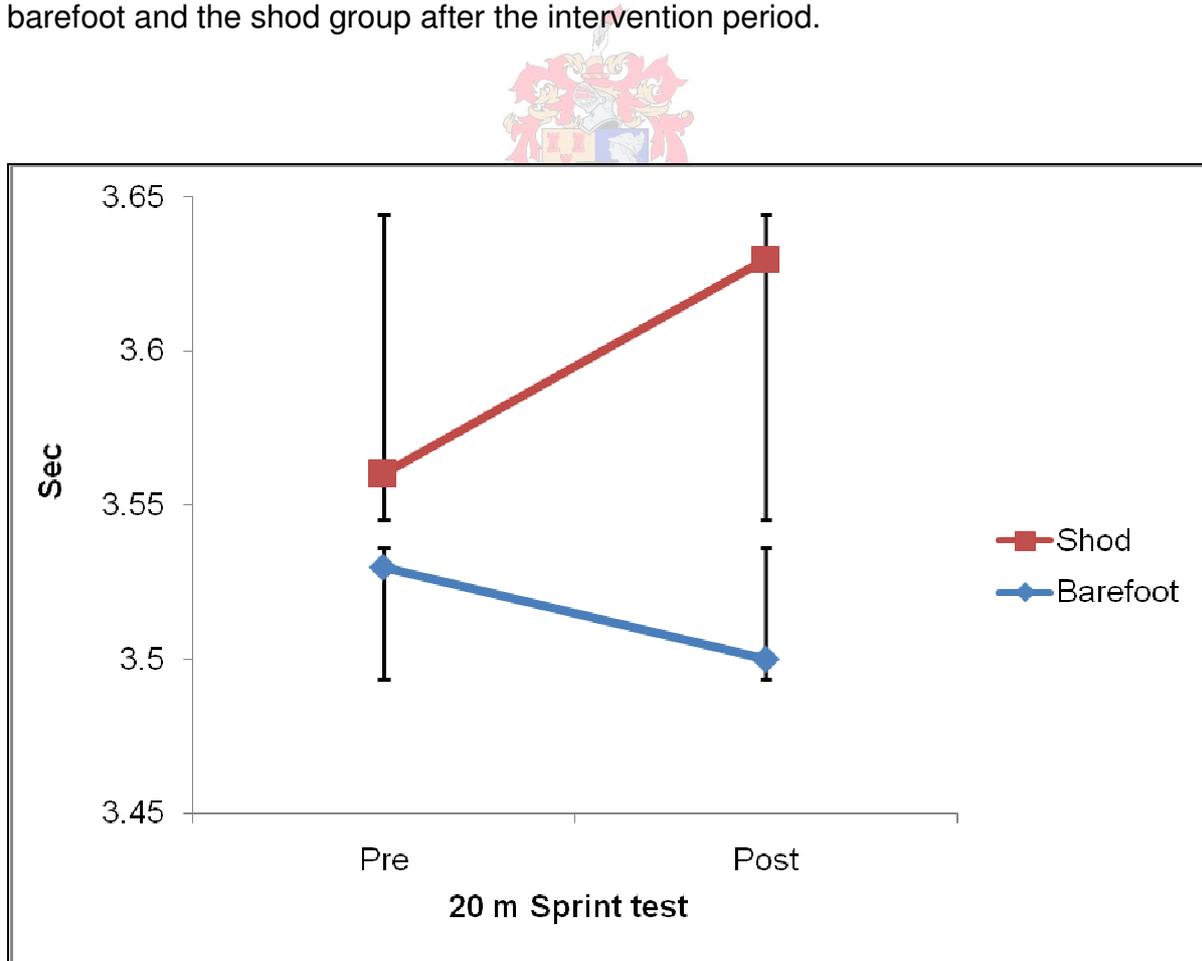


Figure 6: Actual difference in time to complete the 20-metre sprint test. A large practical effect was noted between the two groups ( $ES = 0.80$ ) post intervention. 95% CI: 3.42 – 3.68 (barefoot); 95% CI: 3.55 – 3.82 (shod).

In Figure 7 the chance for the real changes to have an effect is shown. Results were unclear for both distances. Therefore it is evident that the intervention programme did not lead to an improvement in speed.

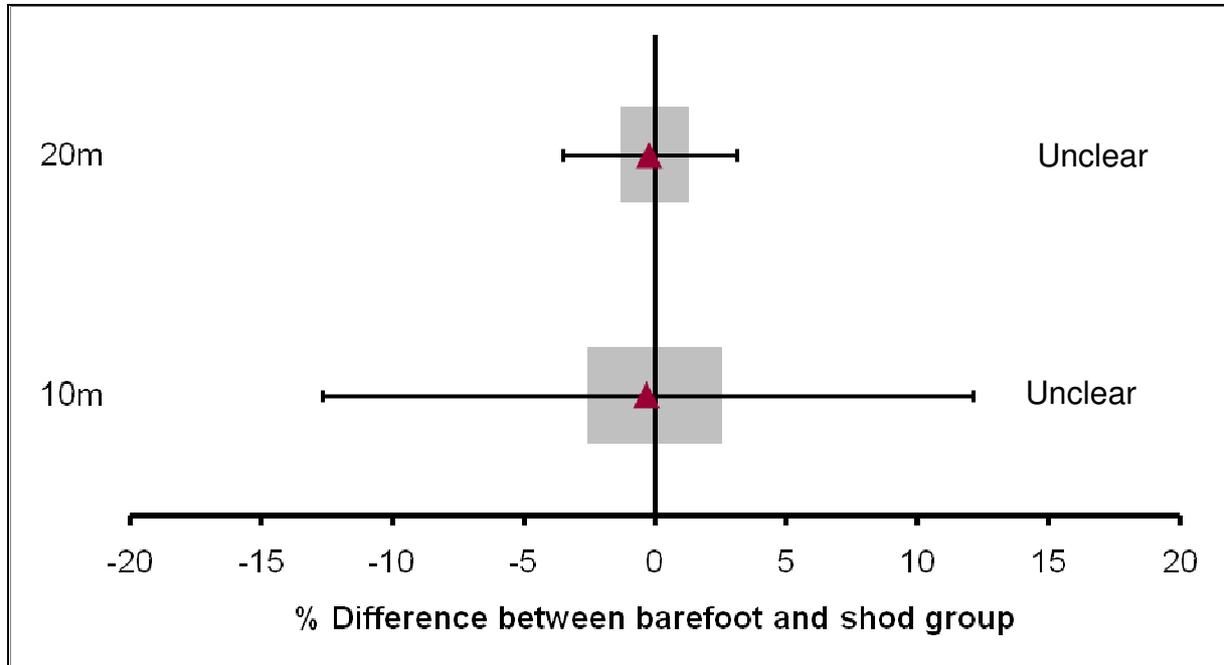


Figure 7: The percentage changes between the groups for the 10-metre and 20-metre sprint test post intervention.



## Agility

Agility was tested to the right and left. The total time it took to complete the 505 agility-test was recorded to the nearest 0.01 sec. Results are given in sec and average changes. Figure 8(A&B) illustrates the changes in time to complete the agility test. The time to complete the agility test improved significantly in the barefoot group ( $0.14 \pm 0.10$ ,  $P < 0.05$ ) for turning on the left and ( $0.19 \pm 0.07$ ,  $P < 0.05$ ) for turning on the right leg. A slight improvement in the shod group on the right leg was also noticed, but it was not statistically significant ( $0.04 \pm 0.02$   $P = 0.37$ ). There was a moderate practical significant effect ( $ES = 0.74$ ) for the left as well as the right leg ( $ES = 0.42$ ) after the completion of the intervention programme. Table 6 illustrates the descriptive statistics of the agility as well as vertical jump test.

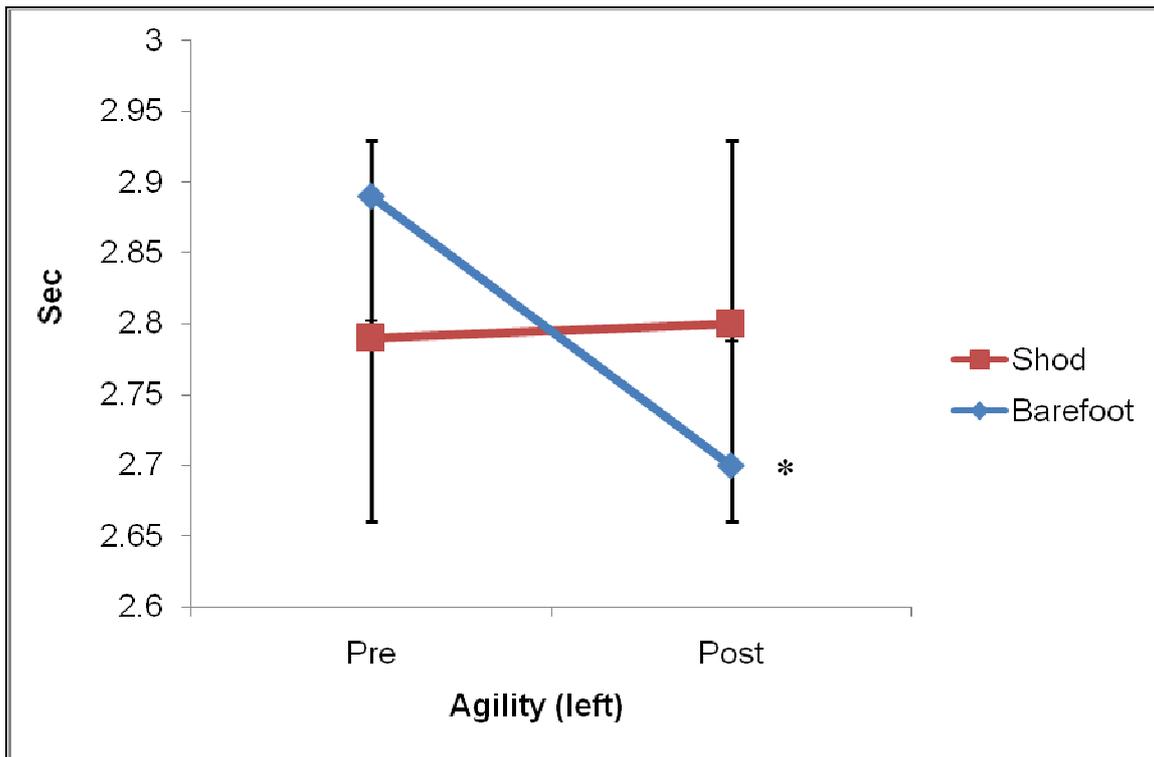


Figure 8A: Changes in average time for agility test in left leg. A significant difference was seen in the barefoot group for the left leg. Medium effect (ES = 0.74) was present in the left leg post-intervention. 95% CI: 2.68 – 2.81 (barefoot); 95% CI: 2.74 – 2.87 (shod). \* Denotes significant change over time ( $P < 0.05$ )

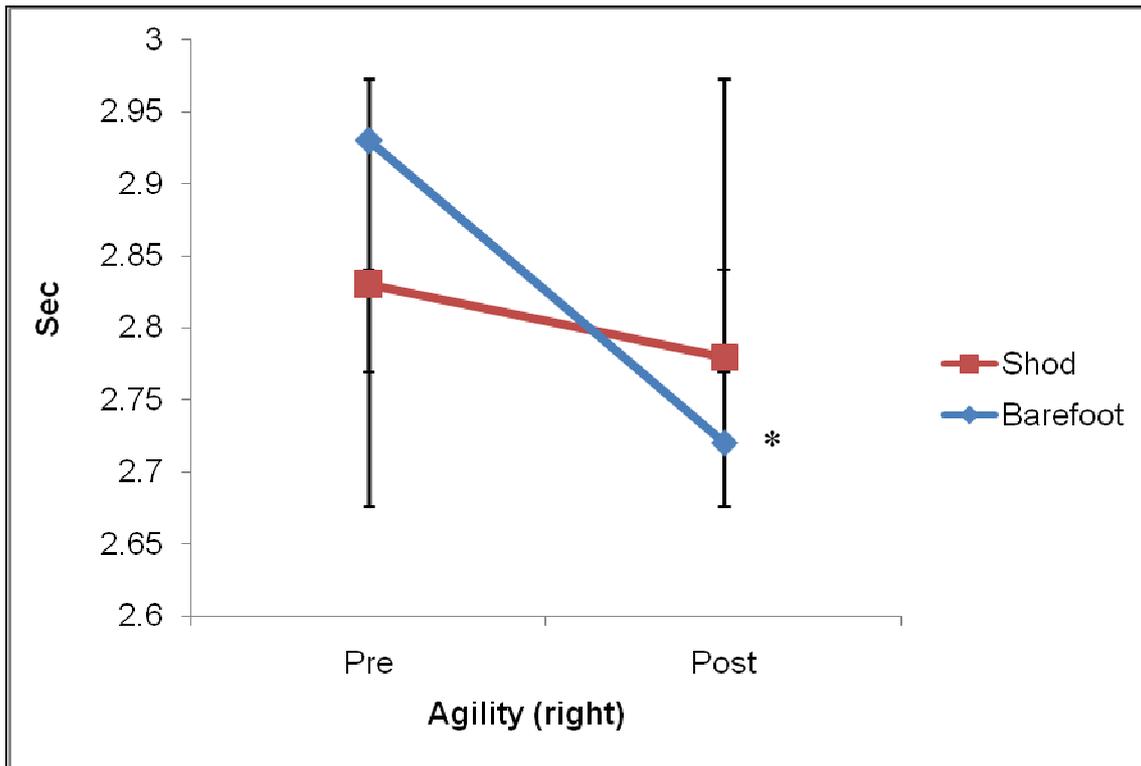


Fig 8B: Changes in average time for agility test in right leg. Significant difference was seen in the barefoot group for the right leg. A very medium practical effect (ES = 0.42) was present in the right leg post-intervention. 95% CI: 2.65 – 2.80 (barefoot); 95% CI: 2.66 – 2.91 (shod).

\* Denote significant difference from baseline ( $P < 0.05$ )

Once again the chances for the true changes to be of an advantage were unclear. Figure 9 depict the quantitative changes (%) of improvement, together with that of the vertical jump test.

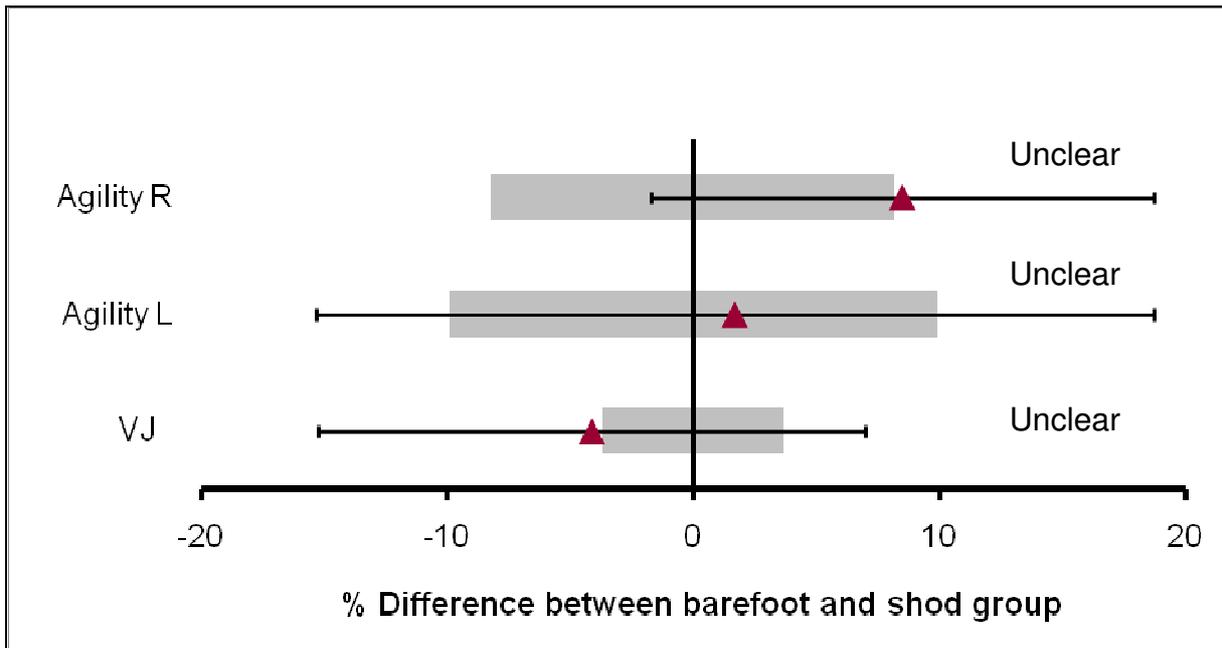


Figure 9: The percentage difference in vertical jump height and agility between the barefoot and shod groups post intervention

## Vertical Jump

The difference between the reaching height and the highest vertical jump was used to determine vertical jump height. There were no significant differences between the groups with the initial testing and no significant difference after the intervention period. An actual decrease in vertical jump height was noted ( $0.02 \pm 0.08$ ,  $P = 0.14$ ) in the barefoot group as well as in the shod group ( $0.02 \pm 0.10$ ,  $P = 0.16$ ), as seen in Figure 10. A medium practical effect ( $ES = 0.70$ ) was noted after the intervention programme. Figure 9 shows, combined with the agility test results, the unclear chance that the true changes in the vertical jump height are of any advantage. Table 6 shows descriptive statistics of the vertical jump as well as agility.

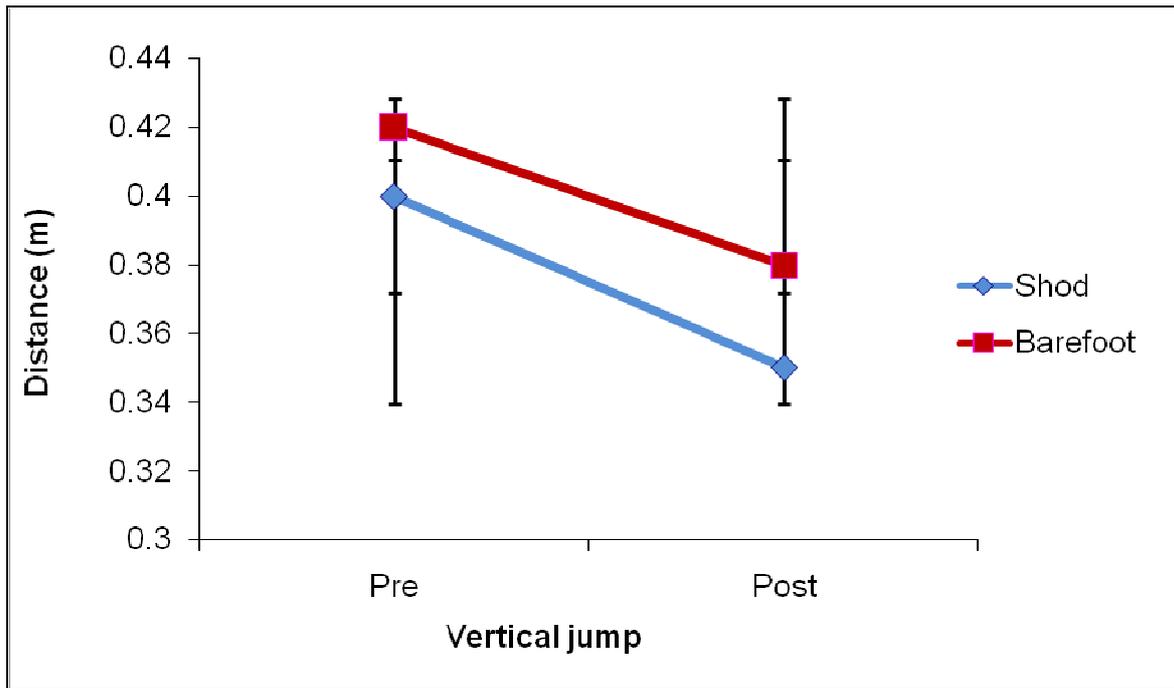
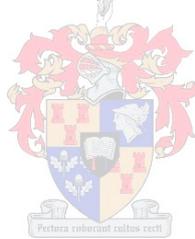


Figure 10: Changes over time for average height of the vertical jump. Post-intervention 95% CI: 0.35 – 0.42 (barefoot); 95% CI: 0.33 – 0.39 (shod).



## Ankle stability

Single leg stability was measured on the Balance Biodex System (USA). Table 7 shows a summary of the results obtained from the testing. Both legs were tested and there were significant changes in the barefoot group on the right leg for the anterior/posterior plane ( $0.68 \pm 0.43$ ,  $P = 0.012$ ), for the medial/lateral plane ( $0.39 \pm 0.22$ ,  $P = 0.04$ ) and for overall stability ( $0.81 \pm 0.36$ ,  $P = 0.008$ ). There were some changes over time in the left leg as well, but none of them significant. In the anterior/posterior plane ( $0.24 \pm -0.06$ ,  $P = 0.13$ ), the overall stability index ( $0.18 \pm -0.29$ ,  $P = 0.4$ ). The medial/lateral plane showed no real improvement ( $0.00 \pm -0.39$ ,  $P = 0.1$ ).

A practical effect was found in almost all the tests. The anterior/posterior plane test on the right leg, the medial/lateral on the right leg and left and the overall stability on both legs showed a small practical effect for the post-intervention testing.

The chance for the real changes to be true was unclear for the anterior/posterior test on the right leg. On the left leg it was possible that it could have had a positive effect on leg stability. The medial/lateral plane on the left leg also showed that the intervention can have a possible positive change, but with the right leg it was unclear if the intervention programme had a positive effect. A probable positive effect is evident with overall stability in the left leg while the right leg shows an unclear result. All the chance for real changes can be seen in Figure 11.

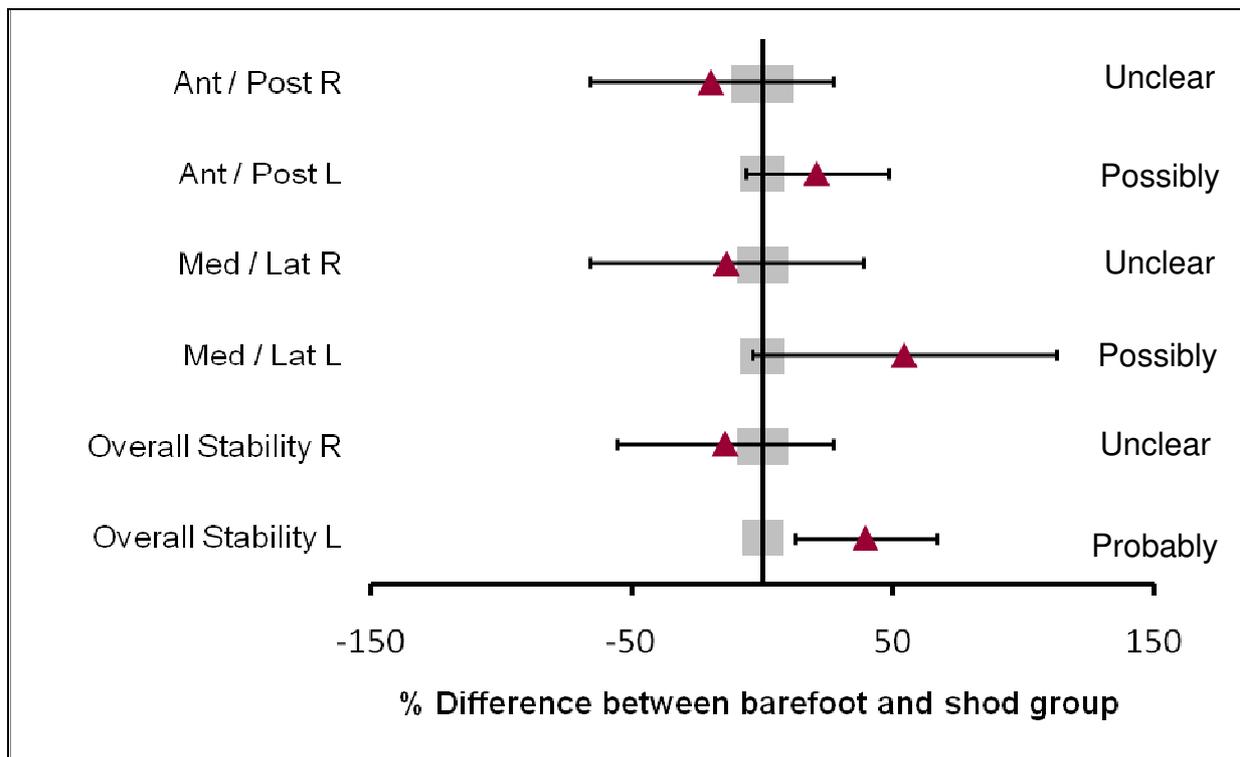


Figure 11: Percentage change in stability over time between barefoot and shod group



Table 4: Maximum calf circumference and circumference 30 cm from the floor (mean  $\pm$  SD) of the control and experimental group.

Circumference	Shod group (n = 10)			Barefoot group (n= 10)			ES	SH-BF	SWC
	Pre	Post	P	Pre	Post	P		P	
Maximum L (cm)	37.6 $\pm$ 2.4	38.0 $\pm$ 2.7	0.20	37.7 $\pm$ 1.4	37.9 $\pm$ 1.6	0.52	0.05	0.95	14/86/0
Maximum R (cm)	37.5 $\pm$ 2.6	38.0 $\pm$ 2.9	0.17	37.5 $\pm$ 2.9	38.0 $\pm$ 1.4	0.09	0.00	0.89	7/92/1
30cm from floor L (cm)	35.9 $\pm$ 2.2	35.7 $\pm$ 1.9	0.14	36.5 $\pm$ 1.5	36.1 $\pm$ 2.1	0.13	0.22 <sup>^</sup>	0.53	50/49/1
30cm from floor R (cm)	36.0 $\pm$ 2.5	35.8 $\pm$ 2.2	0.20	36.2 $\pm$ 1.6	36.0 $\pm$ 1.9	0.13	0.06	0.82	26/72/2

<sup>^</sup> Small effect size (ES)

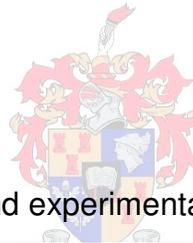


Table 5: Descriptive statistics of speed test of the control and experimental group

Speed	Shod group (n = 10)			Barefoot group (n= 10)			ES	SH-BF	SWC
	Pre	Post	P	Pre	Post	P		P	
10 metre	2.05 $\pm$ 0.24	2.10 $\pm$ 0.12	0.59	2.16 $\pm$ 0.31	1.99 $\pm$ 0.11	0.09	1.01 <sup>∞</sup>	0.31	34/30/36
20 metre	3.57 $\pm$ 0.22	3.69 $\pm$ 0.19	0.05	3.53 $\pm$ 0.22	3.55 $\pm$ 0.18	0.48	0.80 <sup>∞</sup>	0.13	21/50/29

<sup>∞</sup> Large practical significant effect.

Table 6: Depicts the descriptive statistic of the agility and vertical jump test for the experimental and control group

	Shod group (n = 10)			Barefoot group (n= 10)			SH-BF	SWC	
	Pre	Post	p	Pre	Post	P	ES	p	
<b>Agility R</b>	2.84 ± 0.16	2.79 ± 0.18	0.38	2.94 ± 0.19	2.73 ± 0.11	0.00*	0.42#	0.42	69/22/9
<b>Agility L</b>	2.80 ± 0.16	2.81 ± 0.09	0.83	2.89 ± 0.19	2.74 ± 0.09	0.01*	0.74#	0.37	28/32/40
<b>VJ</b>	0.40 ± 0.08	0.36 ± 0.04	0.16	0.43 ± 0.07	0.39 ± 0.02	0.15	0.70#	0.49	11/36/53

# Moderate practical effect

\* Statistical significant difference



Table 7: Differences in the anterior/posterior, medial/lateral plane and overall stability (mean ± SD).

Stability	Shod group (n = 10)			Barefoot group (n = 10)			Effect Size	SH-BF	SWC
	Pre	Post	P	Pre	Post	P		P	
<b>Ant/Post L</b>	1.16 ± 0.53	1.01 ± 0.16	0.13	1.2 ± 0.42	0.99 ± 0.48	0.13	0.06	0.96	78/18/4
<b>Ant/Post R</b>	1.18 ± 0.76	0.89 ± 0.29	0.17	1.51 ± 0.71	0.83 ± 0.28	0.01*	0.22^	0.87	8/24/68
<b>Medial/Lateral L</b>	0.86 ± 0.40	0.86 ± 0.28	0.96	0.75 ± 0.23	0.75 ± 0.62	0.98	0.24^	0.56	90/7/3
<b>Medial/Lateral R</b>	0.9 ± 0.55	0.75 ± 0.16	0.35	1.08 ± 0.45	0.70 ± 0.23	0.04*	0.27^	0.81	16/25/59
<b>Overall L</b>	1.55 ± 0.57	1.4 ± 0.23	0.31	1.47 ± 0.48	1.31 ± 0.77	0.41	0.17^	0.80	96/3/1
<b>Overall R</b>	1.59 ± 0.87	1.22 ± 0.35	0.11	1.94 ± 0.68	1.14 ± 0.32	0.01*	0.25^	0.86	12/27/61

\* Significant difference from baseline.

^ Small practical effect

## CHAPTER FIVE

# DISCUSSION

Through this study the researcher wanted to create new understandings regarding the existing issues of barefoot training and to determine if barefoot training would be advantageous to physical performance parameters of netball players. The findings of this study will be discussed around the research questions stated in Chapter One.

### A. Introduction

The study examined the effect of barefoot training on physical performance parameters of netball players. There has been continues debating regarding the efficacy of barefoot running on kinetics and kinematic variables over the past few years. Many assumptions are also made regarding the influence it has on injury prevention, but very little research to support these assumptions. Thus far, no research has been done on the effects of barefoot training on physical performance parameters.

The study would therefore contribute to recent research regarding barefoot running, not just the short-term effect and not just on running, but also the effect of an intervention programme on specific parameters on netball players.

Specific research questions were asked to determine if barefoot training has an effect on certain performance parameters of netball players. The questions were the following:

1. Will barefoot training lead to significant changes in the maximal circumference of the lower leg and the circumference 30 cm from the floor if compared to shod training?

2. Will barefoot training lead to a significant change in the 20-metre sprinting speed of a netball player when compared to shod training?
3. Will barefoot training lead to a significant change in the agility of a netball player when compared to shod training?
4. Will barefoot training lead to a significant change in the vertical jump height of a netball player compared to shod training?
5. Will the ankle stability of a netball player significantly change after barefoot training compared to shod training?

### **Subjective experience of barefoot training**

For most participants, training barefoot was a new experience. It takes time to get used to no external support and the exposure of the soles of the feet to different surfaces. This is exactly the reason why Hart and Smith (2008) recommended a gradual increase of time and exposure to different surfaces. According to Robbins and Hanna (1987), for an intervention programme to have a positive effect, a four-month period of one hour barefoot activity per day was enough. After completion of the intervention programme and the post-intervention testing, participants were asked to report back on their subjective experience. Most players initially experienced discomfort or slight pain (70%). This discomfort subsided with time and only one participant still experienced this discomfort at the end of the intervention programme. There was also a majority (70%) preferring barefoot training to shod training. They felt more comfortable being barefoot especially on grass. An additional comment given by one of the participants is that she felt 'light on her feet' when running barefoot.

The other studies had a bigger age range including ages of 18 years up to 45 years. Most of the elite netball players fell in the age category of 18 to 25 years, with a few exceptions. In the studies regarding netball players the mean ages were 18 to 24 years old (Ferreira & Spamer, 2010; Venter *et al.*, 2005; Otago & Neal, 1998; Hopper *et al.*, 1995). Other physical characteristics of participants were comparable to characteristics of the Boland and North West University netball players (Ferreira & Spamer, 2010; Venter *et al.*, 2005). The mean height (172.6 cm) and mean weight (69.1 kg) of the players are similar to those participants used in those studies.

**B. Research question one: Will barefoot training lead to significant changes in the maximal circumference of the lower leg and the circumference 30 cm from the floor if compared to shod training?**

No significant differences were noted in the maximum circumference of the calf, although the right leg (dominant) showed a tendency towards positive change. This measurement was done to determine if there was an increase in the size of the lower leg muscles.

Literature reveals that changes were observed in the activation of the lower leg muscles when running barefoot (Divert *et al.*, 2005). There was also an increase in lower leg muscle strength during barefoot running (Jenkins & Cauthon, 2011). The higher activation of muscle and improvement of strength could be due to the changing of the configuration of the foot during the support phase of the running. The arch of the foot flattens by about 1cm; the energy that is loaded in the foot is mainly stored in the stretch of the strong ligaments in the foot (e.g. plantar aponeurosis). These ligaments act as a spring and by the end of the stance phase, it regains its original form. The efficacy of this spring depends on how well the lower leg muscles can keep control. Lower leg muscles, most of which extends into the foot, play an important role in this spring action to regulate the position and motion of the foot. By doing so, the total movement pattern can be controlled. The function of the foot is threefold: the transfer of sensory information from the joints and sole of the foot to regulate movement; the storage and return of energy and to transfer energy from the knee extension to the ground surface, making use of the gastrocnemius muscle (Bosch & Klomp, 2001). Although an increase in the circumference is not directly related to an increase in muscle strength, it could be an indication of muscle strength development, which can then be tested using other methods.

No person is built the same way nor are they symmetrical. The maximum girth of the calf can be at different heights for different people due to the multiple muscles in the lower extremities. Therefore the measurement of the circumference 30 cm from the floor was taken. No statistically significant difference in the circumference measured

30 cm from the floor was found. There was, however, a small practical difference between the barefoot and shod group in the left leg's circumference 30 cm from the floor. Once again the assumption cannot be made that there was no increase in muscle strength.

Another reason for the lack of increase in lower leg circumference is the lack of strength exercises, specifically for the lower leg. To increase muscle size, hypertrophy needs to occur. In a review study by Bird, Tarpenning, and Marino, (2005) they reported that a training programme consisting of the following: 4-6 sets, 8-15 maximum repetitions, 1-2 min rest between the sets and exercises, completed 3 to 5 days per week and with the use of large to small muscles, would result in hypertrophy.

The measuring of circumferences is not just a measurement of the muscle component of the lower leg, but it also includes the fat and skeletal component of the lower leg. Therefore, more measurements should have been done, for example fat percentage, to reflect a more accurate measurement.



The conclusion can be made that there is no increase in the maximal circumference of the calf or the circumference 30 cm from the floor due to barefoot training.

### **C. Research question two: Will barefoot training lead to a significant change in the 20-metre sprinting speed of a netball player when compared to shod training?**

The 20-metre speed test was selected for the study to test the players' ability to accelerate from a stationary position and maintain their speed for 20 metres. During a netball match, a player would seldom have to run the full 20 metre sprint, but this test is a good indication of their anaerobic power (Venter *et al.*, 2005).

A reading at the 10-metre mark was also taken, to measure acceleration. No significant difference was found between the groups, but the barefoot group showed

a tendency towards a scientifically significant difference post intervention. The shod group showed an increase in their time over 10 metres. There was a large practical effect between the two groups post intervention.

When looking at the 20-metre sprint time and comparing the two groups, it can be seen that the players were unable to maintain their speed for the last 10 metres. There was also no statistically significant difference observed over the 20 metres. The barefoot and the shod group showed minimal differences or changes, with the shod group once again showing an increase in time.

Speed training involves maximal output with a maximal passive recovery. It makes use of the neuromuscular system and the body's ability to recruit a maximal number of motor units/muscle fibres for the given task (Warpeha, 2007). In a study comparing sprint interval training to speed/agility training, researchers found that speed interval training is likely to have only a moderate impact on the intermittent endurance capacity of a player. On the other hand, speed/agility training is more likely to improve single 10-metre sprint time as well as repeated sprint time performance (Buchheit *et al.*, 2010). The demands of a netball match include having the ability to change direction and to accelerate from a standing position. Therefore it is very important to obtain and improve these abilities.

If in exercise sessions, the goal is to maximize short distance/sprinting speed, the training sessions should consist of low training volumes, high intensities, and high quality with long resting periods. It should also be performed under conditions where fatigue is not a factor. Another important aspect is that the distances for training should be specific to the typical requirements of the sport (Warpeha, 2007).

It can therefore be assumed that because most of the barefoot training sessions only took place once the normal netball practice was done, a level of fatigue was already present in the players. The speed training would not have had the optimal benefit it was supposed to have.

Although there was a tendency towards a faster 10-metre time, barefoot training showed to have no effect on the increase in speed over 20-metres.

#### **D. Research question three: Will barefoot training lead to a significant change in the agility of a netball player when compared to shod training?**

A netball player must possess the ability to run at a high speed, change direction (with both feet), and be able to regain that speed as soon as possible (Venter *et al.*, 2005). The 505-agility test was done on both legs to test the players' abilities. The barefoot group showed a statistically significant improvement in the right leg as well as the left leg. In this case, it was not only the non-dominant leg that improved, but the dominant leg as well. There was also a slight improvement, though not statistically significant for the right leg of the shod group. The practical effect of the left and right leg was both medium.

For agility to improve, redirection, change of direction and transitions must be mastered (Goodman, 2008). Once at full speed, the player has to prepare her body for a turn / change of direction or transition. It usually happens through giving shorter strides. It can therefore be assumed that because barefoot runners run with a shorter stride length (Divert *et al.*, 2005; Lieberman *et al.*, 2010; Jenkins & Cauthon, 2011), it could be easier to adjust their body to change direction. The possible loss of traction due to the barefoot condition has not been studied. Another important aspect of agility is balance. When you move forward, and need to change direction suddenly, the stabilising muscles have to react and control the movement because the trunk provides the foundation for dynamic movement of the arms and legs. Poor balance would therefore result in poor ability to change direction (Luger & Pook, 2004).

Another possible explanation for the improvement of agility in the barefoot group is the increased proprioceptive feedback ability (Jenkins & Cauthon, 2011). The player has a better feeling of the positioning of her ankle to the ground and better and faster placement is possible.

Because of the improvements, it could be concluded that barefoot training improves the agility of netball players. Although no significant differences were found between the barefoot and shod group, a moderate practical significant effect occurred post intervention.

#### **E. Research question four: Will barefoot training lead to a significant change in the vertical jump height of a netball player compared to shod training?**

The vertical jump height, from a static position, was determined by the difference in the maximum jumping height and the reaching height. No statistically significant improvement was found in the current study for the vertical jump height in either the barefoot, or the shod group. There was, however, a slight decrease in the vertical jump height for both groups.



For a vertical jump to be optimal or to improve the vertical jump height, the ability to produce explosive lower-body power is essential and needs to be trained. This explosive power can be obtained through plyometric training (Markovic, 2007). In a review study, the researcher examined various studies to determine the effect of plyometric training programmes on vertical jump height. For the squat jump, only three studies had a decrease in height. Only one of the studies measuring the counter movement jump, and counter movement jump with arms, had a negative effect. No studies done on the drop jump had negative results (Markovic, 2007). From these results it is therefore evident that plyometric training will help to improve the vertical jump height.

Results from a study by Luebbers *et al.* (2003), showed that after a four and seven week plyometric training programme, the differences were either negative or not significant, but after a four week recovery period, both groups showed a significant improvement in vertical jump height. Plyometrics should be done, especially for netball, but if doing it barefoot, participants should either be conditioned to barefoot

training, or it should be done on a softer surface to ensure that participants do not injure themselves while not yet conditioned to barefoot training.

Goldmann *et al.* (2011) found that toe flexor strengthening could contribute to an increase in the distance for standing long jump. This was however after a seven week training programme just for toe flexors. The current study did not include foot specific exercises. It could be asked that if foot specific exercises were included in the programme, would there be an improvement in the vertical jump height of netball players? But since the participants were in the middle of their netball league, isolated exercises (non-functional) were not a priority.

The present study was done on participants who were unaccustomed to barefoot activities. Robbins and Hanna (1987) as well as Hart and Smith (2008) recommended that barefoot activities should start at low intensity and progress gradually. The participants of the study also experienced some discomfort on the soles of their feet and some in the foot structures. Therefore, plyometric training was not one of the main foci of the exercise programme. This could be the reason for the decrease in vertical jump height.

In netball, vertical jump height is, however, a very important part of the game. Jumping up to intercept a ball or to receive an overhead throw is vital during a match. Plyometric training should be part of a netball training programme, but it should either be done with shoes on, or it should be done once the players are used to training barefoot.

During this study, the barefoot training intervention programme had no positive effect on the vertical jump height of netball players. A shortcoming of the training programme could be that it did not emphasise power enough and that could be an explanation for the decrease in vertical jump height of the shod group.

## **F. Research question five: Will the ankle stability of a netball player significantly change after barefoot training compared to shod training?**

The Athlete Single Leg Balance Test, performed on the Biodex Balance System, was used to assess stability. Dynamic overall stability; anterior-posterior stability and medial-lateral stability were reported on a stability index. Results were given as the average position from the centre. The overall stability index takes into account the centre of gravity displacement in the anterior-posterior and medial-lateral directions. The anterior-posterior stability index reports the displacement in the sagittal plane and represents neuromuscular control of the thigh muscles as well as the anterior/posterior compartment muscles of the lower leg. The medial-lateral stability index reports the displacement in the frontal plane and represents neuromuscular control of the inversion and eversion muscles of the lower leg (Biodex, 2008). A good stability (no displacement) would be reported as a score of zero on the scale, a higher score would therefore indicate poor neuromuscular control.

The sensory and motor systems have an influence on balance control. The proprioceptive inputs from postural muscles of the leg are very important in maintaining balance (Hosseinimehr, Norasteh, Daneshmandi, Rahpemay-Rad & Rahimi, 2009). Therefore we let the players see the visual feedback.

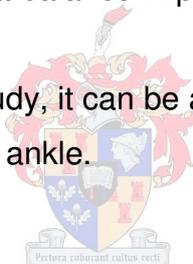
No significant differences were found for the baseline measurements between the groups for any of the stability indexes. Statistically significant differences were noted post intervention for the barefoot group on the right leg in the anterior/posterior plane, the medial/lateral plane, and for overall stability. The practical effect between the two groups was also calculated and a small effect was found in the post intervention testing in all planes on both legs, except the anterior/posterior plane for the left leg.

In a study to determine the effect of neuromuscular training sessions on stability, statistical significant improvements were noticed in overall stability and anterior-posterior stability, but not in medial-lateral stability. The training programme for this study comprised of three 90-minute neuromuscular training sessions per week over a

period of 6 weeks. They explained that their training programme failed to properly stimulate stability improvement in the medial-lateral direction. They used the following three components of the dynamic neuromuscular training protocol: 1) balance training and hip/pelvis/trunk strengthening, 2) plyometrics and dynamic movement training, and 3) resistance training (Paterno, Myer, Ford & Hewett, 2004).

The review study conducted by Jenkins and Cauthon (2011), found that there is an increase in proprioceptive ability because of barefoot running. The mechanism behind this increase still needs to be examined thoroughly. The improvement of balance in the current study could have been due to the barefoot training as well as the training regime. But since the statistically significant improvements were only seen in the barefoot groups and only in the right leg, it can be assumed that it is because of the barefoot training that balance improved.

From all the results found in this study, it can be assumed that barefoot training has a positive effect on the stability of the ankle.



## **G. Evaluation of the intervention programme**

The intervention programme took place over a period of ten weeks. Most of the participants are students at the Stellenbosch University; therefore the researchers had to adhere to the term dates of the University. There was a week holiday during the ten week period where participants did not take part in any formal type of training. Participants had to attend at least 14 of the 20 (70%) exercise sessions. The attendance of participants was very good, with only 15% of the participants attending less than 80% of the training sessions. For an intervention to have a positive effect, Robbins and Hanna (1987) found a four month period of one hour barefoot activity per day to be sufficient to strengthen the intrinsic foot musculature. No studies have been published on the optimal period of barefoot training to increase physical fitness parameters.

The intervention programme included exercises that focus on the improvement of netball fitness and sport specific aspects. Both groups shod and barefoot, performed the same exercise programme. It was therefore difficult to do too many plyometric exercises due to the barefoot group and the effect it would have on the soles of their feet. The training sessions focussing on cardiovascular conditioning were the only sessions not preceded by a normal netball training session. As discussed earlier, speed and power training is more efficient when done prior to any other training. It was, however, not possible in the current study, and the lack of improvement in speed could be a result of that.

During this current study, barefoot activity was introduced progressively. The time of barefoot activity was increased weekly, with a  $\pm$  5 to 7 minutes of barefoot activity start the first week. Hart and Smith (2008) recommended a gradual increase in training intensity as well as duration. They found that after 16 weeks, barefoot training sessions longer than one hour could be managed by runners.

Exercise sessions were either done outside on a grass field, or on an indoor netball court. The reason for the change in surface was due to the weather. In a study by Dolenc, Stirn & Strojnik (2011) no significant difference was found in the contact time of runners when comparing running on grass to running on tarmac. They measured muscle activation while participants ran on the different surfaces and found that pre-activation of the tibialis anterior muscle occurred when running on tarmac. No difference in muscle activation was found during the actual touchdown.

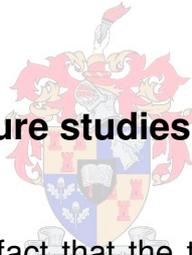
Because the intervention programme took part in the netball season, normal netball training sessions also continued. The intervention sessions therefore had to focus on netball-specific training drills.

## H. Conclusion

Limited studies have been done on the effect of barefoot training on performance parameters. No studies thus far have been conducted on the effect of barefoot training on netball players.

The primary finding of this study was that barefoot training leads to an improvement in some of the fitness parameters, namely agility and balance. A tendency towards the improvement of speed over 10m was also noticed. Practical effects were found in the results of the sprint test, agility and the balance / stability tests.

This suggests that barefoot training can be used to improve sport-specific fitness parameters, especially agility and balance.



## I. Study limitations and future studies

A limitation of the study was the fact that the training period was interrupted by a week of holiday, since adherence to the term dates of Stellenbosch University had to be kept. It would also have been better if training sessions could have taken part before the normal netball training sessions and not after that. A longer training period and bigger participant group would also have given better results. Future studies can be done over a longer period and also include the benefit of barefoot training on the prevention of injuries. These studies are long-term studies and proper monitoring is needed.

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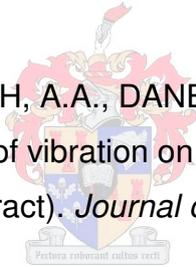
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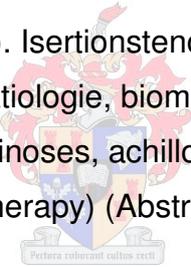
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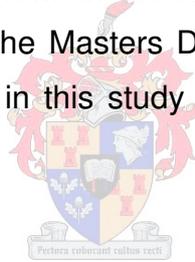
## APPENDIX A

# STELLENBOSCH UNIVERSITY CONSENT TO PARTICIPATE IN RESEARCH

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**Title of research project:** The effect of barefoot training on speed, agility, power and balance in netball players.

You are asked to participate in a research study conducted by Elbé du Plessis, BSc Sport Science (Biokinetics) from the Department of Sport Science at Stellenbosch University. The results obtained from the research will contribute to a thesis in fulfilment of the requirements for the Masters Degree in Sport Science. You were selected as a possible participant in this study because you meet all the inclusion criteria.



### 1. PURPOSE OF THE STUDY

The purpose of this study is to compare the effects of barefoot training and training with normal netball training shoes on certain performance parameters of netball players.

### 2. PROCEDURES

If you volunteer to participate in this study, we would ask you to do the following things:

Take part in a battery of tests before and after a training intervention of 6 weeks. The battery will consist of the following tests:

- Basic anatomical measurements – height, weight and circumferences.

- Power – Vertical jumps.
- Speed and agility – Agility-505 test and a 20-metre sprint test.
- Balance and proprioception – Athlete single leg balance test on Balance Biodex.
- Complete a six (6) week intervention programme that is incorporated in your netball training program. The sessions for the study will be 3 times a week for 30-45 minutes each.

### **3. POTENTIAL RISKS AND DISCOMFORTS**

Because you might be doing some exercises barefoot, the potential exist that you may experience slight discomfort that will last for 3 days while getting used to the training. The discomfort will ease of after a few sessions.

### **4. POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY**

Due to the fact that you will be doing regular performance specific physical activity, your physical fitness and performance should improve. The results of the study will also be conveyed to you once the researcher has completed the study and the knowledge that you gained regarding yourself should be of benefit to you.

### **5. PAYMENT FOR PARTICIPATION**

As a participant you will receive no payment for participation in the study and there are no costs involved for participation in the study.

### **6. CONFIDENTIALITY**

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of

withholding the names of the participants and only using numerical codes to represent subjects. This means that reported results will only include codes and no names at all.

Recorded data will be securely retained in a locked cabinet and on a password protected personal computer. No one except the researcher and project supervisor will be able to access these raw data. Please take note that final results may be published in a peer review scientific journal.

## **7. PARTICIPATION AND WITHDRAWAL**

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so. Participation will be terminated if you partake in other rehabilitation programs or club sport related training during the intervention period. Your consent to participate in this research will be indicated by your signing and dating of the consent form.

## **8. IDENTIFICATION OF INVESTIGATORS**

If you have any questions or concerns about the research, please feel free to contact the researcher Elbé du Plessis (084 515 7642 or [edup@sun.ac.za](mailto:edup@sun.ac.za)) or the project supervisor, Dr. R Venter 021 808 4915 or [rev@sun.ac.za](mailto:rev@sun.ac.za).

## **9. RIGHTS OF RESEARCH SUBJECTS**

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Ms Maléne Fouché [[mfouche@sun.ac.za](mailto:mfouche@sun.ac.za); 021 808 4622] at the Division for Research Development.

**SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE**

The information above was described to \_\_\_\_\_ by Elbé du Plessis (researcher) in Afrikaans/English and I am in command of this language or it was satisfactorily translated to me. I was given the opportunity to ask questions and these questions were answered to my satisfaction.

I hereby consent voluntarily to participate in this study I have been given a copy of this form.

\_\_\_\_\_  
**Name of Subject/Participant**

\_\_\_\_\_  
**Signature of Subject/Participant**

\_\_\_\_\_  
**Date**

**SIGNATURE OF INVESTIGATOR**

I declare that I explained the information given in this document to \_\_\_\_\_ and she was encouraged and given ample time to ask me any questions. This conversation was conducted in Afrikaans/English and no translator was used

\_\_\_\_\_  
**Signature of Investigator**

\_\_\_\_\_  
**Date**

## APPENDIX B

### PERSONAL INFORMATION

Name and surname: \_\_\_\_\_

Team: \_\_\_\_\_ Date of birth: \_\_\_\_\_ Age: \_\_\_\_\_

Address: \_\_\_\_\_

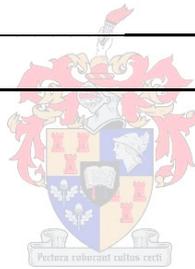
\_\_\_\_\_ Code: \_\_\_\_\_

Cell phone nr: \_\_\_\_\_ e-mail address: \_\_\_\_\_

Shoe size: \_\_\_\_\_ Shoe brand: \_\_\_\_\_

Please mention any previous injuries that you have had:

\_\_\_\_\_  
\_\_\_\_\_



#### Par-Q and You

YES NO

- \_\_\_ \_\_\_ 1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
- \_\_\_ \_\_\_ 2. Do you feel pain in your chest when you do physical activity?
- \_\_\_ \_\_\_ 3. In the past month, have you had chest pain when you were not doing physical activity?
- \_\_\_ \_\_\_ 4. Do you lose your balance because of dizziness or do you ever lose consciousness?
- \_\_\_ \_\_\_ 5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?

\_\_\_\_ \_\_\_\_ **6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**

\_\_\_\_ \_\_\_\_ **7. Do you know of any other reason why you should not do physical activity?**

*Canadian Society for Exercise Physiology. Revised 2002*

I hereby declare that the information is true and correct

\_\_\_\_\_  
Signature Participant

\_\_\_\_\_  
Date



## APPENDIX C

### ETHICAL CLEARANCE

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Researcher:	Ms Elbé du Plessis
Research Project:	The effect of barefoot training on speed, agility, power and balance in netball players
Nature of the Research Project:	Department of Sport Science, SU
Supervisor(s):	DR RE Venter
Reference number:	304 / 2010
Date:	25 February 2010

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The research proposal and associated documentation was circulated and considered by the members of the Ethics Committee (as prescribed by Council on 20 March 2009 and laid down in the SU policy framework) on 25 February 2010; the purpose being to ascertain whether there are any ethical risks associated with the proposed research project of which the researcher has to be aware of or, alternatively, whether the ethical risks are of such a nature that the research cannot continue.

### DISCUSSION

The Ethics Committee received the following documentation:

- An ethical clearance application form, duly signed and filled out;
- An informed consent form; and
- A copy of the research protocol.

The researcher will determine whether barefoot training is more beneficial than shod training with respect to posture, speed and agility, and power. Volunteer, women SU students between the ages of 19 and 23 will be allotted to two experimental groups and a control group. The testing will take place at the Coetzenburg Sports Grounds and the Department of Sport Science.

## **FINDING**

Adequate measures seem to be in place in terms of confidentiality in the study, data protection, and the handling of any physical distress during the testing sessions (a medical doctor will be on standby). Moreover, the students participating in the study will derive benefit and suffer no disadvantage.

However, there are one or two matters to which the committee would like to draw to the attention of the researcher.

1. There appears to be some dissonance between paragraphs 6 and 9 of the application form. In the first instance, reference is made to consent that is still to be requested from Prof Jan Botha. Paragraph 9 would seem to imply that such permission is already in place. Either way the researcher is requested to lodge a copy of the written consent of Prof Jan Botha in the office of Ms Maléne Fouché (mfouche@sun.ac.za), Research Development Division, Stellenbosch University, before research commences.
2. The observation schedule (checked in paragraph 7.3 of the application) is not attached to the submission for ethical clearance. The researcher is urged to submit this to the same office as soon as possible.

## **RECOMMENDATION**

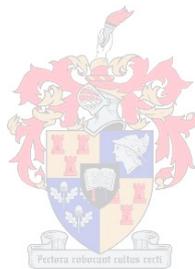
It is recommended, in view of the information at the disposal of the committee that the proposed research project continues provided that:

- a. The researcher remains within the procedures and protocols indicated in the proposal, particularly in terms of any undertakings made and guarantees given.
- b. The researcher notes that her research may have to be submitted again for ethical clearance if there is substantial departure from the existing proposal.

- c. The researcher remains within the parameters of any applicable national legislation, institutional guidelines and scientific standards relevant to the specific field of research.
- d. The researcher submits a copy of the letter granting institutional consent as well as the observation schedule to the office of Ms Maléne Fouché (mfouche@sun.ac.za), Research Development Division, Stellenbosch University.

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Johan Hattingh, Callie Theron, Elmarie Terblanche, Ray de Villiers, Christo Thesnaar, Ian van der Waag [For the Ethics Committee: 25 February 2010]



## APPENDIX D

### EXAMPLE OF TRAINING PROGRAMMES

#### Week 1 – 2

##### Day 1:

##### **Warm-up:**

- Jog around the outdoor soccer field x 2
- Butt kicks (20m and back)
- High knees(20m and back)
- Hamstring kicks(20m and back)
- Grapevine(20m and back)
- Side shuffles (x 2 each side - 20m and back)
- Big skips(20m and back)
- Forward lunges (twist - (20m and back)
- Backward lunges(20m and back)



**Exercise 1:** Various exercises – Tabata protocol (Do every exercise for 20 sec; rest 10 sec x 2)

- Split jumps (power lunge)
- Push-ups
- Squat jumps
- Crunches

**Exercise 2:** Planks (Tabata protocol - 20 sec on both sides, forward and backwards x 2 – 10 sec rest between exercises)

**Exercise 3: Suicides**

Run to the first 3<sup>rd</sup> line of the netball court, touch the line and turn back to the baseline. Run to the second line on the netball court, touch, and turn and run back to baseline. Run to the other baseline, touch, turn and run back. Rest for 20 sec and repeat the exercise. Do it 3 times.

**Exercise 4: Zig Zag (on netball court)**

Alternate between side shuffles and sprints

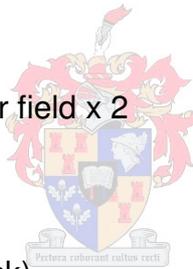
**Cool down:**

2 x around netball court.

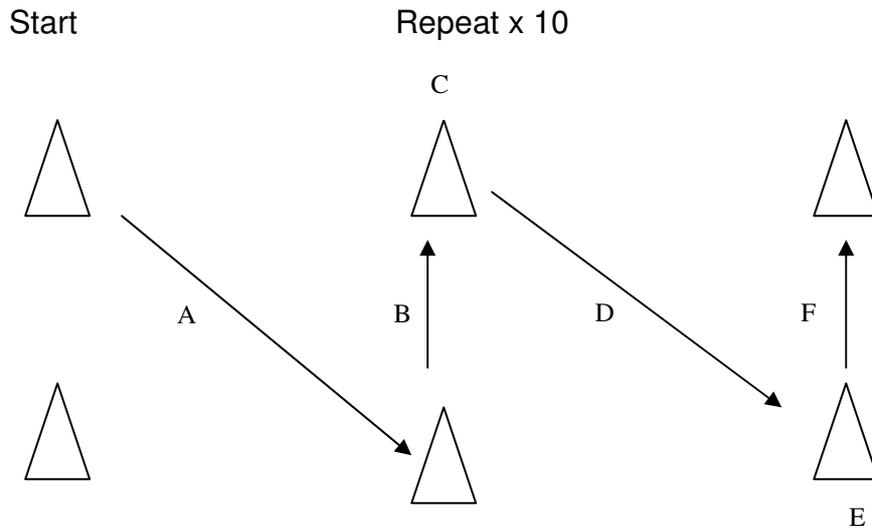
Day 2:

**Warm-up:**

- Jog around the outdoor soccer field x 2
- Butt kicks (20m and back)
- High knees (20m and back)
- Hamstring kicks (20m and back)
- Grapevine (20m and back)
- Side shuffles (x 2 each side - 20m and back)
- Big skips (20m and back)
- Forward lunges (twist - 20m and back)
- Backward lunges (20m and back)



**Exercise 1: Various exercises**



A – Heel Flicks @ 60%

B – Sidesteps with feet crossing @ 50%

C – Star jumps x 10

D – High knees running @ 60%

E – Power Jumps x 10

F – Twisties

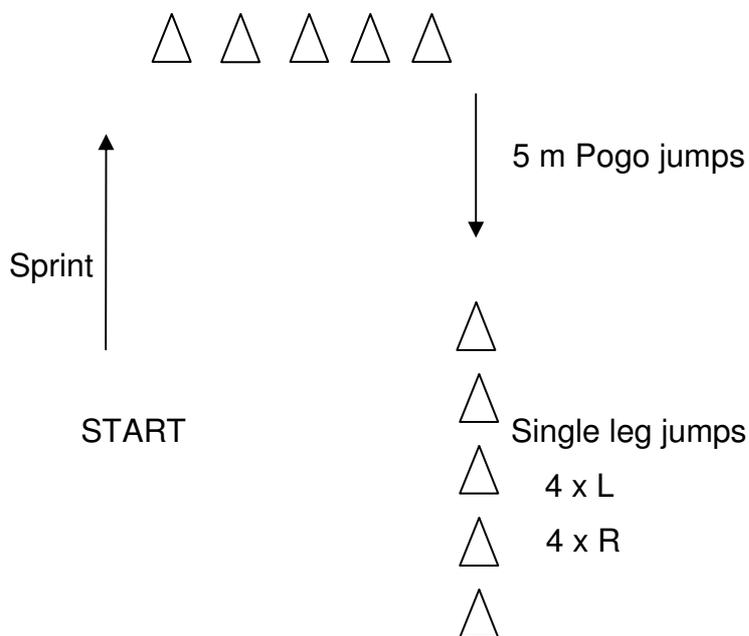
Sprint back to start



**Exercise 2: Plyometrics**

Repeat x 5

Double leg hops over cones



**Exercise 3:** Interval running

In groups of 7, the group jog in a row around 2 x soccer fields. The person at the back of the row needs to sprint to the front, past everyone. Once she reached the front the next person starts to sprint from the back. Repeat this for 5 minutes.

**Cool down:**

2 x around soccer fields

Day 3:

**Warm-up**

Netball training session

**Exercise 1:** Shuttle: supine walking on hands with hips up high

**Superset 1**

Reverse crunches, single leg drop from hip lift position, pilates 100's, pilates swimming x 12 each



**Exercise 2:** Shuttle: Wheel barrows

**Superset 2**

Bicycle crunch, scissor & flutter kicks, abduction combo, cook hip lift x 10 each

**Exercise 3:** Shuttle: leap frog

**Superset 3**

V-sit hold, 3 way crunches, prone supermans double arm x 12 each

**Exercise 4:** Sprints – line running x 2 minutes

**Cool down**

Stretch: Cat stretch, shell stretch, piriformis stretch and calve stretch

## Week 3 – 4:

### Day 1

#### Warm-up:

- Jog around the outdoor soccer field x 2
- Butt kicks (20m and back)
- High knees (20m and back)
- Hamstring kicks (20m and back)
- Grapevine (20m and back)
- Side shuffles (x 2 each side - 20m and back)
- Big skips (20m and back)
- Forward lunges (twist - 20m and back)
- Backward lunges (20m and back)

#### Exercise 1: Circuit 1

- Power lunges 30sec
- Sprint 10-metres, pivot, 10-metres back
- Push-ups 30 sec
- Sprint 10-metres, pivot, sprint 10-metres back



} x2

#### Exercise 2: Plyometric circuit

- Squat jumps 30sec
- Sprint 10-metres, pivot, sprint 10-metres back
- Sit-ups/crunches 30sec
- Sprint 10-metres, pivot, sprint 10-metres back

} x2

#### Exercise 3: Planks (Tabata protocol)

(20 sec on both sides, forward and backwards x 2 – 10 sec rest between exercises)

**Exercise 4: Jog (3min)**

50% → 70% → 100%

Run the 1<sup>st</sup> 1/3<sup>rd</sup> of the court @ 50% of maximum speed, increase to 70% speed on the 2<sup>nd</sup> 1/3<sup>rd</sup> and 100% speed on the last 1/3<sup>rd</sup>.

**Cool down:**

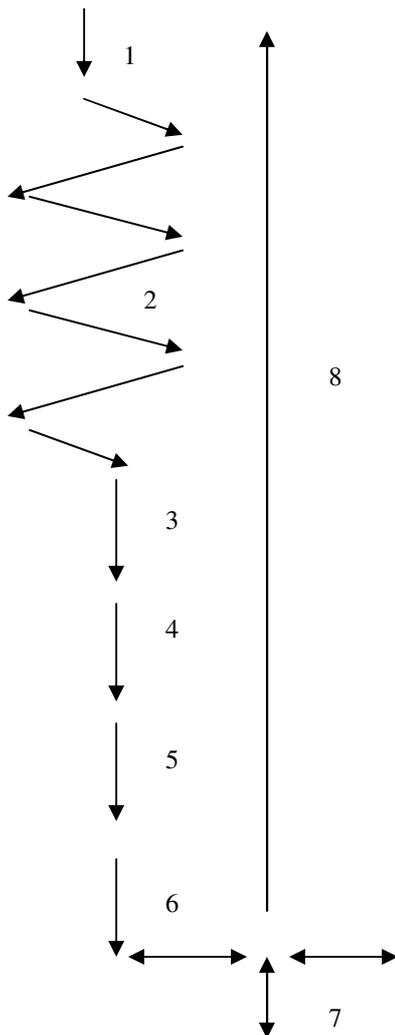
2 x around netball court.

Day 2

**Warm-up:**

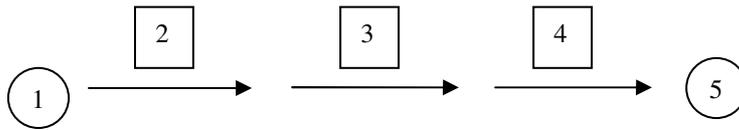
Netball training session

**Exercise 1**



- 1 – Jog (± 20-metres)
- 2 – side shuffle (± 20-metres)
- 3 – high knees (± 20-metres)
- 4 –sprint (± 20-metres)
- 5 – jog (± 20-metres)
- 6 – sprint (± 20-metres)
- 7 – T-test (cone ± 5-metres apart)
- 8 – Sprint (± 120-metres)

## Exercise 2



- 1 – Sit-ups x 10
- 2 – jog
- 3 – 1 leg hop
- 4 – 1 leg hop
- 5 – burpies

## Cool down:

**Stretch** - Hamstrings, quadriceps, gluteus, triceps, biceps and rhomboids

## Day 3

### Warm-up

Netball training session



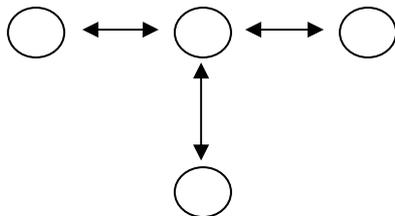
### Exercise 1

The group is divided into two groups.

One group has to complete the agility T, while the other group is performing the exercise station.

The group doing the agility T can only stop once the other group has completed the exercise station. Both groups have to complete the agility T and the exercise station.

Agility T



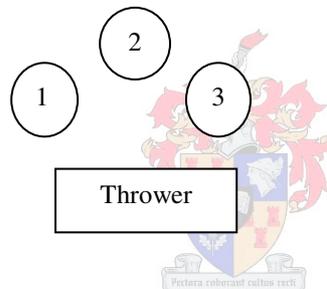
Exercise station – high knees (20sec)

- Jumping jacks (2 x 12)
- Burpees (2 x 12)
- sit-ups with ball throw/catch (2 x 12)

## Exercise 2

The group is once again split into two smaller groups.

There is one thrower and the rest of the team is positioned in a straight line, behind each other. One person shuffles between the cones and receives a pass that requires them to jump. Once the player has received the ball at all three cones, she moves to the back of the line. Every now and again, the thrower must be replaced. Every person should receive twice.



## Exercise 3

Start with all the players on the baseline. With every blow of the whistle the players will both start/stop jogging and stop/start sprinting. Vary the amount of time they spend jogging and sprinting. Perform the activity three times for approximately 1,5 minutes each.

## Cool down

**Stretch:** Hammies, quads, gluteus, triceps, biceps and rhomboids

## Week 5 – 6:

### Day 1:

#### Warm-up:

- Jog around the outdoor soccer field x 2
- Butt kicks (20m and back)
- High knees (20m and back)
- Hamstring kicks (20m and back)
- Grapevine (20m and back)
- Side shuffles (x 2 each side - 20m and back)
- Big skips (20m and back)
- Forward lunges (twist - 20m and back)
- Backward lunges (20m and back)

#### Exercise 1: Power circuit

- Power lunges 30 sec
- Sprint 10-metre, pivot, sprint 10-metre back
- Push-ups 30 sec
- Sprint 10-metre, pivot, sprint 10-metre back



} x 2

#### Exercise 2: Plyometric circuit

- Swivel jumps 30 sec
- 1-legged hops (right leg) 10m, pivot, 1-legged hops back (left leg) 10m
- Swivel jumps 30 sec
- 1-legged hops (right leg) 10m, pivot, 1-legged hops back (left leg) 10m

} x 2

#### Exercise 3: Zig Zag (on court)

Side shuffles and sprints

#### Exercise 4: Suicides

Netball court thirds

**Cool down:**

2 x around netball court

Day 2:

**Warm-up:**

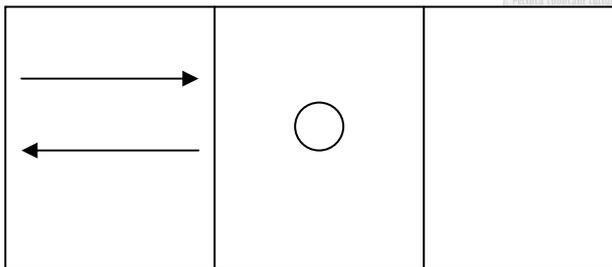
Netball training session

**Exercise 1: Various exercises**

- Single leg jumps (high knees)      2 x 10 each
- Box jumps      2 x 5 each
- Wall sits with toe taps      2 x 30 sec
- Clap push-up against wall      2 x 10



**Exercise 2: Plyometric exercises**



- 10 Star jumps – run to line of centre third line and back
- 9 Star jumps – run to line of centre third line and back
- Continue until you perform 1 star jump.

**Exercise 3: Side shuffle game:**

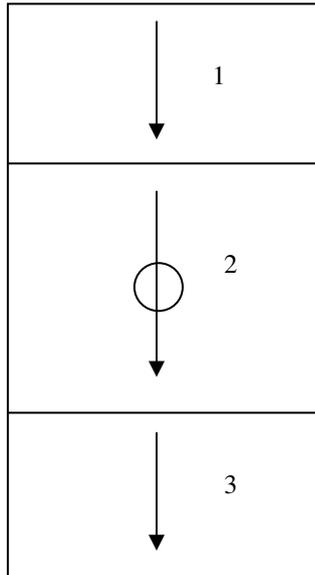
Players are on the ball of their feet, ready to move. Coach gives a signal and players need to side shuffle in the direction to which the coach has pointed. Continue this exercise for 5 minutes.

Day 3:

**Warm-up**

Netball training session

**Exercise 1: Abdominal work and endurance**



1 – Sprint forward to the centre third line, do 30 sec of skipping

2 – Jog to 2<sup>nd</sup> line and complete 15 - 1 – crunches

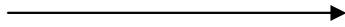
2 – Swats

3 – Ceiling crunches

4 – Single leg drops

3 – Run backwards to the last line.

**Exercise 2: Ladder work**



Do each of the following x 2

1 – 1 foot in each block at a time

2 – Both feet in each block at a time

3 – Inside, inside, outside, outside

4 – High knees, both feet in each block

5 – Diagonal – 1 foot in, 1 foot outside, change to other foot in and other foot outside

6 – Sideways (1 foot in each block at a time)

**Cool down**

Run around the netball courts x 2

