EFFECTS OF A BAREFOOT INTERVENTION PROGRAMME ON THE LANDING KINETICS AND KINEMATICS OF NETBALL PLAYERS

By

Boluwaji Gbenga Jaiyesimi

Thesis presented for the degree of Doctor of Sport Science in the Faculty of Education at the Stellenbosch University

Pectora roborant cultus recti

UNIVERSITEIT
iYUNIVESITHI
STELLENBOSCH
UNIVERSITY

100
1918 · 2018

Supervisor: Prof. Dr Ranel Venter

Co-Supervisor: Dr John Cockcroft

December 2018

DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Name: ________________________________

Date: ________________________________

ACKNOWLEDGEMENTS

First, I give glory to the Lord for all that he has done and is doing in my life. I would not have come this far if not for Him.

To my promoter, Prof Ranel Venter and her husband (Rev Willem Venter), I am eternally grateful for all the wonderful moments we shared together. Your love and parenting are worth emulating. Dr. John Cockroft, thank you for your words of encouragement and intellectual contributions. Special thanks to Prof Kidd for the statistical analysis. To staff members of CAF Neuromuscular laboratory, I am full of thanks for your technical support. Dr Grobbelaar and all the staff members of the Sports Science Department, you are indeed a family.

I want to especially thank Maties Netball Club for participation in this project. Also the leadership of the club: Karen Swart (Club manager), Zanele Modana (Head Coach), Zarko Krkeljas, Charlé and Sean Surmon. To my special team and friends on this project: Saint Sackey, JP Lombaard, Mr Tapera and all the honours students on the team; you guys are great. Mrs Michelle Woodrow, Human Kinetics Publisher distributor, thank you for the books you sent to me, I am so grateful. To Dr Azante Mtenje and Dr Bradley Fryer, thank you for editing and proofreading.

My special thanks go to the Aare and Yeye Aare Afe Babalola, the founder of Afe Babalola University, Nigeria (ABUAD) for their love and support. I am grateful for the permission and financial support. To Daddy Ajisafe (VC ABUAD), you are indeed a special father, mentor and great dad. To Pastor Modupe Babalola, you are a special mentor and spiritual father. My unreserved appreciation to the ABUAD community.

My sweetheart, Kikelomo Eunice Jaiyesimi, I am full of emotion to recount your selfless and humble sacrifices towards this journey. I am eternally grateful for your constant encouragement and understanding. You are indeed a woman of virtue. Toluwanimi, my anointed evangelist, thank you for showing love to daddy at all times. You really added fanciful moments. Moreover, to a brother and friend in a million, Toba Bamitale, a unique human being, thanks so much for the encouragement and love.

Daddy and Mummy Ariyo (ABUAD Chapel Chaplain), thank you for the prayers, counselling and guidance. You are indeed God-sent to our family. You were there with us from the beginning to the end. ABUAD Chapel family, I am grateful for your immense support. Papa and Mama Princewill Afolabi, I am full of thanks for all you have done in my life. All God's Power family, thank you so much. Daddy and Mummy Oluwatukesi, thanks for those core moments of life decisions and unconditional love. My unreserved gratitude to Pastor (Dr.) Funlola Olojede and RCCG Desire of Nation, for the love, prayer and support. And to the brethren in Every Nation Stellenbosch, you are a desired kingdom community. Sis Bimbo Fafowora and other friends in Weidenhof House, you indeed substantiated the spiritual experience of the journey.

To all my Fathers in the Department of Human Kinetics and Health Education, University of Ibadan, I cannot thank you enough for the role you have played in my academic and intellectual development. You are an exceptional family. Special thanks to my academic father and mentor at heart, Prof J.F. Babalola. A special tribute to my life coach, Late Prof A.O. Abass, you are one in a million. Your legacy of intellectual prowess and daring vision shall live on.

To my biological father, Late Chief Sunday Jaiyesimi, a model of humility and diligence: I thank God for the gift you were to us. My appreciation also goes to Mummy Jaiye (my mother), Sister Jumoke, Yemisi and Adeolu, as well as their respective families. To all Jaiyesimis and Akinlabis, home and abroad, thanks a million for the love we share and who we are in Christ Jesus.

The study would not have been possible without the funding provided by the National Research Fund (NRF) and The World Academy of Science (TWAS). The author is solely responsible for the opinions and conclusions of this study and they are not to be attributed to NRF/TWAS.

DEDICATION

I dedicate this piece of work to God the Father, the Son and the Holy Spirit for the special privilege to accomplish this task. Praise be unto His name who is able to do exceedingly and abundantly above what we think or ask according to His power that is at work in us.

ABSTRACT

Effective landings, as a component of movement tasks in many sports, have a significant role during ground contact and subsequent kinetic chain intersegmental interactions. Landings are frequently performed tasks in sports to manipulate skills, maximise mechanical functions of the body and to possibly avoid injury. The rationale of biomechanical studies on landing in netball focuses on the reduction of risk of lower extremity injuries and enhance performance. The trauma of injury to a female athlete ranges from immobility, disengagement from the team to psychophysiological stress and physical deterioration.

The primary aim of the study was to determine the acute differences in landing kinetics and kinematics between barefoot and shod conditions in netball players. The secondary aim was to determine effect of a six-week barefoot training intervention on landing biomechanics in netball players. The experimental design adopted for the study was a pretest-posttest randomized groups design. Thirty netball players were recruited for the study and randomly allocated into an experimental (EXP) (n = 15) or a control group (CON) (n = 15). The players performed jump-landing tasks (single-leg drop landing right and left) (SLR and SLL), a drop vertical jump (DVJ) and a stop-jump performance task (SJPT) in barefoot (BF), and shod (SH) conditions. The intervention for the study spanned a 6-week period with 18 training sessions over this period.

Ground reaction forces, time to peak ground reaction forces and shock attenuation were considered for kinetic variables while impact peak acceleration, initial contact angles, peak angles and range of motion were considered for kinematic variables. A 3D force plate (sampled at 1000 Hz) was used to capture force data while a wireless inertial motion capture system (sampled at 200 Hz, filtered with Butterworth 60 Hz low-pass), was used to capture kinematic data. The Subjective evaluation of the Landing Error Scoring System (LESS), Modified Lower Limb Comfort Index (mLLCI) and barefoot activity experience was adopted for qualitative assessment of the study. Mean, standard deviation, standard error of mean, and percentage differences were used in the descriptive analysis while Chi-square, independent t-tests and a mixed model ANOVA were used in the inferential analysis.

The results showed a non-significant reduction in peak resultant force and vertical ground reaction forces for the jump-landing tasks in SH condition. The mediolateral ground reaction force was significantly lower in BF condition for some of the jump-landing tasks (SLL p = 0.02; DVJ p = 0.03). It was further shown that sagittal plane kinematics increased at initial contact in BF condition but decreased at peak angle. The frontal plane kinematics increased in BF more than SH conditions at initial contact but decreased at peak angle. The EXP (p = 0.00) and CON groups (p = 0.00) had significant changes in knee shock attenuation after the intervention. However, the CON group had more shock attenuation at the knee and ankle during the jump-landing tasks. The feedback of subjective experience of barefoot activities after the intervention showed that the negative experience of injury risks and significant others did not outweigh the positive perception of neuromuscular benefits and other related factors.

In conclusion, BF training could form part of training modalities implemented to enhance safe and effective landings. Coaches need to be educated on the implementation of an injury prevention programme, including emphasis on effective landings, to possibly reduce the incidence of lower limb injuries in netball.

Keywords: Barefoot, kinetics, kinematics, shock attenuation, impact peak acceleration

OPSOMMING

Effektiewe landing, as 'n komponent van baie sportbewegingstake, speel 'n belangrike rol gedurende grondkontak en die gevolglike intersegmentale interaksies van die kinetiese ketting. Landing is 'n bewegingstaak wat dikwels uitgevoer word by die manipulering van vaardighede, om meganiese funksies van die liggaam te maksimaliseer en om moontlike beserings te voorkom.Die rasionaal vir studies in verband met landing in netball is om 'n moontlike bydrae te lewer om beseringsrisiko van die onderste ledemate te verinder en prestasie te verbeter. Die trauma as gevolg van beserings by vroue-atlete wissel van immobiliteit, verwydering van die span tot sielkundig-fisiologiese stress en fisieke agteruitgang.

Die primêre doel was om te bepaal of daar akute verskille is tussen kaalvoet- en skoenkondisies tydens landings by die netbalspelers. Die sekondêre doel van die studie was om die effek van 'n ses-weke kaalvoetintervensie op die landingsbiomeganika van netbalspelers te bepaal.

Die studie-ontwerp was 'n pre- posttoetsing met lukrake groepe. Dertig netbalspelers is vir die studie gewerf en lukraak in 'n eksperimentele- (EKS) (n = 15) en 'n kontrolegroep (KON) (n = 15) ingedeel. Die spelers het spring-landtake (enkelbeen aftree-landing links en regs EAL, EAR), vertikale spring en valsprong (VS), en 'n stop-springtaak (SST) uitgevoer in kaalvoet- (KV) en skoen- (SK) kondisies. Die intervensie was oor 'n periode van ses weke met 18 oefensessies in die tydperk.

Grondreaksiekragte, tyd tot piek reaksiekragte en skokvermindering is ingesluit as kinetiese veranderlikes, terwyl peik-impak versnelling, aanvanklike kontakhoeke, piekhoeke en omvang van beweing as kinematiese veranderlikes ingesluit is. 'n 3D kragplatform (1000 Hz) is gebruik om die kragdata op te neem, terwyl 'n koordlose inersie bewegingssisteem (200 Hz; gefiltreer met Butterworth 60 Hz lae-deurgang), gebruik is om die kinematiese date te versamel. Kwalitatiewe data is genereer deur middel van die subjektiewe Landingsfoutsisteem, die Aangepaste Onderste Ledemaat Gemaksindeks en terugvoer oor die kaalvoetondervinding. Gemiddeldes, standaardafwyking, standardmetingsfout en persentasie verskille is gebruik in die beskrywende statistiek, terwyl Chi-kwadraat, onafhanklike T-toetse en 'n gemengde model ANOVA gebruik is vir inferensiële analises.

Resultate het ‘n afname in die piek resultante krag en vertikale grondreaksiekragte met die spring-land take in SK getoon. Die medio-laterale grondreaksiekrag was laer by sommige van die spring-landtake in KV (EAL p = 0.02; VS p = 0.03).Verder was daar ‘n toename in die sagittale vlak kinematika met aanvanklike kontak in KV, maar dit het verminder met piekhoek. Frontale vlak kinematika het meer in KV toegeneem as in SK met aanvanklike kontak, maar het verminder by piekhoeke. Die EKS (p = 0.00) en die KON (p = 0.00) het beduidende veranderinge in die knee en enkelskokvermindering na die intervensie getoon. Die KON het egter meer skokvermindering by die knie en enkel gedurende spring-landtake gehad. Die terugvoer oor die subjektiewe ervaring van die kaalvoet-aktiwiteite wys dat die ervaring van beseringsrisiko en beduidende ander nie die positiewe persepsie van neuromuskulêre voordele en verbandhoudende faktore negatief beinvloed het nie.

Ten slotte, KV kan deel vorm van oefenmodaliteite wat toegepas word vir veilige en effektiewe landings. Afrigter behoort opgelei te word om beseringsvoorkomingsprogramme te implementer wat ook fokus op die leer van effektiewe landingspatrone om moontlik beserings aan die onderste ledemate te verminder.

Sleutelwoorde: Kaalvoet, kinetika, kinematika skokvermindering, impak piekversnelling

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

%	:	Percentage or percent
α	:	Cronbach Alpha
↓	:	Decrease
↑	:	Increase
→	:	No change
χ2	:	Chi-square
P	:	Significant level
n	:	Sample size
ACL	:	Anterior cruciate ligament
AGRF	:	Anteroposterior ground reaction force
AGRFtp	:	Time to peak anteroposterior ground reaction force
$Ankle_{SA}$	:	Ankle shock attenuation
ANOVA	:	Analysis of Variance
APA	:	American Psychological Association
BF	:	Barefoot
BW	:	Body weight
cm	:	centimetre
CAF	:	Central Analytical Facilities
CON	:	Control
D2E	:	Down to Earth
deg	:	degree
DVJ	:	Drop vertical jump
ES	:	Effect size
EXP	:	Experimental
$Foot_{accl}$	:	Foot acceleration
g	:	gravity
GRFs	:	Ground reaction forces
GRFtp	:	Time to peak ground reaction forces
Hip_{SA}	:	Hip shock attenuation

IPA	:	Impact peak acceleration
ICC	:	Intraclass correlation coefficient
IMCS	:	Inertial Motion Capture System
IMU	:	Inertial Motion Unit
ISAK	:	International Society for the Advancement of Kinanthropometry
kg	:	Kilogram
KNEE	:	Knee Injury Prevention for Netballers to Enhance Performance and Extend Play
$knee_{SA}$	:	Knee shock attenuation
LESS	:	Landing Error Scoring System
LLCI	:	Lower Limb Comfort Index
m	:	meter
m	:	mean
MDT	:	Multidisciplinary Team Approach
MGRF	:	Mediolateral ground reaction force
MGRFtp	:	Time to peak mediolateral ground reaction force
mLLCI	:	Modified Lower Limb Comfort Index
N	:	Newton
$Pelvis_{accl}$	:	Pelvis acceleration
PRF	:	Peak resultant force
PRFtp	:	Time to peak resultant force
r	:	reliability
REC	:	Research Ethics Committee
RE-AIM	:	Reach Effectiveness Adoption, Implementation and Maintenance
RH	:	Relative height
s	:	second
SA	:	Shock attenuation
SD	:	Standard deviation
SEM	:	Standard error of mean
SH	:	Shod
Sh	:	Standing height
$Shank_{accl}$	:	Shank acceleration

SJPT	:	Stop-jump performance task
SLL	:	Single-leg drop landing Left
SLR	:	Single-leg drop landing Right
SU	:	Stellenbosch University
$Thigh_{accl}$	:	Thigh acceleration
V	:	Cramer V
VGRF	:	Vertical ground reaction force
VGRFtp	:	Time to peak vertical ground reaction force

CHAPTER ONE

INTRODUCTION

A. OVERVIEW OF LITERATURE

Barefoot running became a global phenomenon when an Olympian (Abebe Bikila from Ethiopia) had to compete in the Olympic marathon (Rome Summer Olympic, 1960) without shoes because Adidas could not supply his shoe size (Kaplan, 2014). Through the years, many studies have been carried out to examine the biomechanical effects of running barefoot. Research has shown that barefoot running is more efficient than shod running in individuals with good running form (Nearman, 2011). Lieberman et al. (2010) reported that during barefoot running, landing impact is attenuated and joint loading is reduced as a result of the changes in the kinematic pattern of running. Meanwhile, barefoot runners tend to plantarflex into forefoot landing during the landing phase, but heel landing has been associated with shod runners. Plantarflexion has been shown to contribute to a reduction in the incidence of musculoskeletal injury during running (Rowley & Richards, 2015). Differences in kinematics and kinetics between barefoot and shod running (Nigg & Enders, 2013) are becoming a controversial topic among podiatrists and biomechanists as barefoot imitating footwear has gradually gained prominence among elite and recreational runners.

Lieberman et al. (2010) suggested that barefoot running helps to activate and increase the strength of four layers of muscles in the foot as well as greater utilization of the lower leg muscles which are underutilized in a shod condition. Jenkins and Cauthon (2011) reported that barefoot runners generated lower ground reaction forces than shod runners. Larger ground reaction forces have been found to have a positive correlation with lower extremity injuries (McNair, Prapavessis, & Callender, 2000). Running footwear is made of materials to, among other things, attenuate shock and stabilize the feet so as to control foot and ankle movement (Divert et al., 2005). Thompson, Seegmiller and McGowan (2016) added that running footwear is usually designed to reduce shock transmission during repetitive ground contact, which might contribute to the incidence of running-related musculoskeletal injuries. Despite these assumed advantages of running shoes, the frequency of running injuries has not changed over the past 40 years (Nigg, Baltich, Hoerzer, & Enders, 2015). Although barefoot running is associated with a number of positive outcomes, there are also indications of injuries among habitually barefoot runners, e.g. plantar surface injuries (Altman & Davis, 2016), Achilles and peroneal tendinitis (Arulsingh & Pai, 2015).

Coaches and athletes are faced with challenges to minimise the incidence of injury emanating from physical adaptation and conditioning of the athletes to the training regimen and diverse game situations (Anza, Denis, & Silva, 2013). Schütte (2012) pointed out the paucity of studies on the differences between kinematics and kinetics of barefoot and shod jump-landing activities even though quite a number of studies have been carried out on barefoot and shod running and walking. A number of sports such as netball, basketball, volleyball and athletic jump events are characterised by jump-landing movements. Eerkes (2012) noted that many of the reported injuries could be related to high loads in the injured joints during jumping and specifically during landing actions. Bisseling et al. (2007) identified the relationship between stiff landing and patellar tendinopathy and the need to soften landings by proper ankle plantarflexion and knee flexion. During the execution of the jump-landing task, the landing mechanics could be detrimental or complementary to the movement task (Dufek & Bates, 1992). It was however noted that the lack of a coordinated landing phase of a movement task could be detrimental (Dufek & Bates,1991) and result in injury (Bressel & Cronin, 2005). Thus, there is a need for proper landing techniques to enable the body to safely dissipate energy efficiently during movement tasks (Mothersole, Cronin, & Harris, 2013).

According to Stasinopoulos (2004), the movement effieciency technique of an athlete may cause injuries, as well as prevent them. It has been shown that teaching important game techniques to players could serve as an injury preventive measure (Forthomme, 2005). Therefore, if athletes are trained to execute the proper landing techniques that provide neuromuscular feedback for biomechanical adjustment, it could be possible to create significant changes in overall landing skill execution. The effects of barefoot as training modality have generated high interest among researchers recently (De Villiers & Venter, 2014; Mullen, Cotton, Bechtold, & Toby, 2014; Tam, Tucker, Wilson, & Santos-Concejero, 2015; Onwaree, 2015). It was suggested that barefoot running could promote running economy (Warne & Warrington, 2014), decrease risk of running-related injuries (Jenkins & Cauthon, 2011), increase musculoskeletal strength (Krabak, Hoffman, Msillet & Chimes, 2011), reduce impact forces (Azevedo, Mezêncio, Amadio, & Serrão, 2016), improve proprioceptive ability and decrease risk of foot deformities (Tam, Tucker & Wilson., 2016). However, there is still a gap in our knowledge of the effects of barefoot training on the landing biomechanics in the context of a team sport to enhance performance and reduce injuries. Tam, Tucker and Wilson (2016) affirmed that there is still a paucity of studies to prove the ecological validity of barefoot training and changes associated over time. In a study on the effect of barefoot training and biomotor performance in netball players, De Villiers and Venter (2014) reported that barefoot training could lead to improvements in ankle stability in the experimental group compared to the control group. In addition, Khowailed, Petrofsky, Lohman and Daher (2015) reported that changes in a movement pattern can be accomplished within six weeks in previously habitually shod runners. Studies are yet to be conducted on the influence of the barefoot condition on the adjustment of lower extremities biomechanics to enhance the landing performance of netball players. This raises the question, of whether barefoot training intervention could affect the landing kinematics and kinetics of netball players, with the long-term effect of reducing injury.

B. MOTIVATION AND POTENTIAL BENEFITS

Recent developments in the literature on the benefits of barefoot training to injury reduction and recovery in running sports has raised the need to explore benefits of barefoot as a training modality in jump-landing sports. According to Nigg and Enders (2013), there is an increase in the awareness of the benefits of barefoot training among coaches. Some believe that barefoot training employs more muscles during the performance which includes large (bicep femoris and gastrocnemius) or smaller muscles (soleus and peroneus longus) leading to overall strength development and injury prevention in the lower leg and ankle. The current study aims to investigate whether incorporating barefoot as a training modality promotes jump biomechanical performance and mitigate injury risk in netball players.

The testing protocols of stop-jump tasks and drop landings have been used by studies focusing on landing biomechanics and related injuries (Chappell, Yu, Kirkendall, & Garrett, 2002; Kulas, Zalewski, Hortobagyi & DeVita, 2008; Fong et al., 2014; Donohue et al., 2015). These protocols have been modified to simulate patterns of play in jumping sports and could be easily adopted by coaches and trainers for skill development. Results from the current study should help coaches and athletes understand the link between dynamic movement landing and the prevention of related injury risks. It should also provide insight into the inclusion of the barefoot condition in a training programme.

C. AIMS AND OBJECTIVES

Aims

The primary aim of the study was to determine the effect of a six-week barefoot training intervention on landing biomechanics in netball players. The secondary aim was to determine acute differences in landing kinematics and kinetics between barefoot and shod conditions in netball players.

Objectives and Hypotheses

The objectives were to determine, for a quantitative test protocol consisting of single-leg drop landing (right and left), drop vertical jump and stop-jump performance task:

1. Acute differences in lower body kinetics (ground reaction forces, time to peak ground reaction forces and shock attenuation) between BF and SH landing.

   Hypothesis (Ho: BF = SH):
   Ground reaction forces, peak ground reaction forces and shock attenuation would not be significantly different in BF when compared with SH condition.

2. Acute differences in lower body kinematics (impact peak acceleration, initial contact angle, peak angle and range of motion) between BF and SH landing.

   Hypothesis (Ho: BF = SH):
   Impact peak acceleration, initial contact angles, peak angles and range of motion would not be significantly different in BF when compared with SH condition.

3. The effect of a six-week barefoot intervention on landing kinetics (ground reaction force, impact distribution and shock attenuation) between EXP and CON groups.

   Hypothesis (Ho: EXP = CON):
   Ground reaction forces, time to peak ground reaction forces and shock attenuation would not be significantly different in EXP when compared with CON groups.

4. The effect of a six-week barefoot intervention on landing kinematics (impact peak acceleration, initial contact angles, peak angles and range of motion) between EXP and CON groups.

   Hypothesis (Ho: EXP = CON):
   Impact peak acceleration, initial contact angle, peak angle and range of motion would not be significantly different in EXP when compared with CON groups.

   Furthermore, the qualitative objectives included:
5. Determining the effect of a six-week barefoot intervention on the performance of LESS instrument.
6. Evaluating the subjective experience of netball players on barefoot intervention.
7. Evaluating the barefoot intervention adaptation by the netball players (mLLCI).

D. VARIABLES

The independent and dependent variables are shown in **Table 1.1, Table 1.2, Table 1.3, Table 1.4.**

Independent variables

Table 1.1: Independent variables

	Categories	Subcategories	
1	Treatment	Experimental (EXP)	Control (CON)
2	Conditions	Barefoot (BF)	Shod (SH)

Dependent variables

Landing kinetics

Table 1.2: Landing kinetics categories and subcategories

	Categories	Subcategories
1	Ground reaction forces (GRFs)	Peak resultant force (PRF) Vertical ground reaction force (VGRF) Mediolateral ground reaction force (MGRF) Anteroposterior ground reaction force (AGRF)
2	Time to peak ground reaction forces (GRFtp)	Time to peak resultant force (PRFtp) Time to peak vertical ground reaction force (VGRFtp) Time to peak mediolateral ground reaction force (MGRFtp) Time to peak anteroposterior ground reaction force (AGRFtp)
4	Shock attenuation	Hip shock attenuation (Hip_{SA}) Knee shock attenuation ($Knee_{SA}$) Ankle shock attenuation ($Ankle_{SA}$)

Landing kinematics

Table 1.3: Landing kinematics categories and subcategories

	Categories	Subcategories
1	Impact peak acceleration	Pelvis acceleration ($Pelvis_{accl}$) Thigh acceleration ($Thigh_{accl}$) Shank acceleration ($Shank_{accl}$) Foot acceleration ($Foot_{accl}$)
2	Initial contact angle (IC)	Sagittal plane excursion (Lumbar flexion, hip flexion, knee flexion, ankle dorsiflexion) Frontal plane excursion (Hip abduction, knee abduction, ankle inversion, ankle abduction)
3	Peak angle	Sagittal plane excursion (Lumbar flexion, hip flexion, knee flexion, ankle dorsiflexion) Frontal plane excursion (Hip abduction, knee abduction, ankle inversion, ankle abduction)
4	Range of motion (ROM)	Sagittal plane excursion (Hip flexion ROM, knee flexion ROM, ankle dorsiflexion ROM) Frontal plane excursion (Hip abduction ROM, knee abduction ROM, ankle inversion ROM, ankle abduction ROM)

Subjective Evaluation

1. Landing Error Scoring System (LESS)
2. Modified Lower Limb Comfort Index (mLLCI)
3. Subjective experience of barefoot
4. Barefoot previous experience

Jump-Landing tasks

Table 1.4: Jump-landing tasks

	Unilateral (Passive) Landing	Bilateral (Active) Landing
1	Single-leg drop landing drop right (SLR)	Drop vertical jump (DVJ)
2	Single-leg drop landing drop left (SLL)	Stop-jump performance task (SJPT)

E. QUANTITATIVE VARIABLES

Acute differences of barefoot and shod conditions

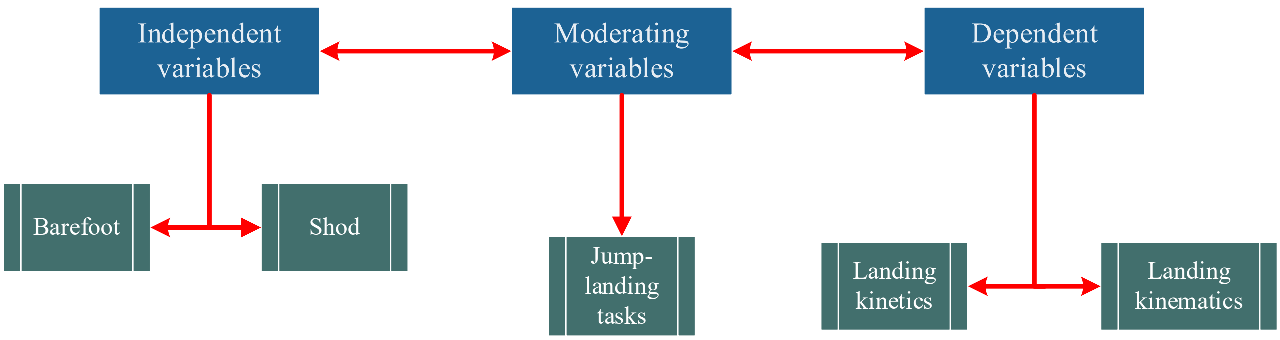


Figure 1.1: Schematic layout showing the breakdown of quantitative variables (acute differences between conditions)

Intervention groups (Experimental and/vs Control)

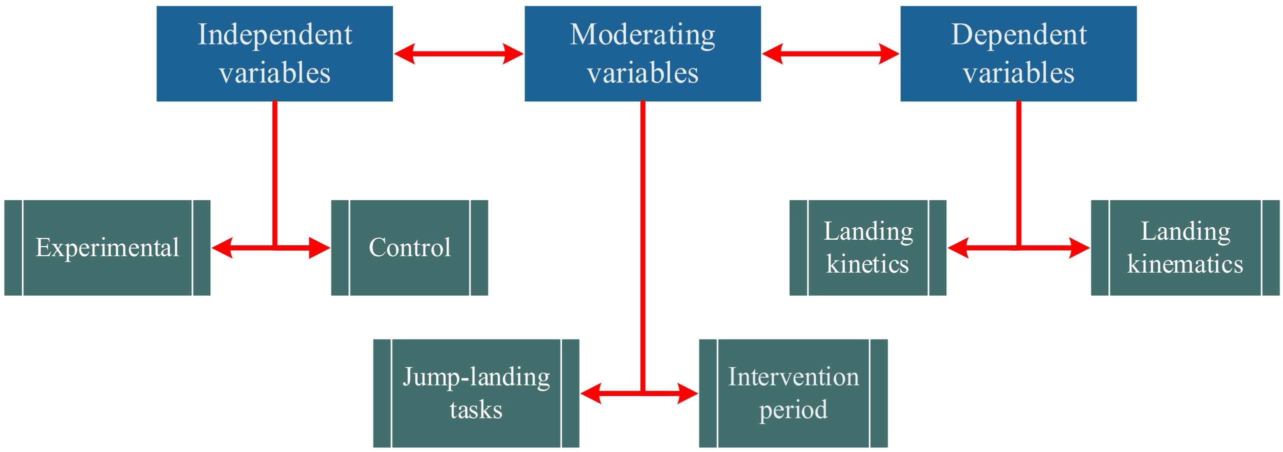


Figure 1.2: Schematic layout showing the breakdown of quantitative variables (Experimental and/vs Control)

F. QUALITATIVE VARIABLES

Subjective evaluation (LESS)

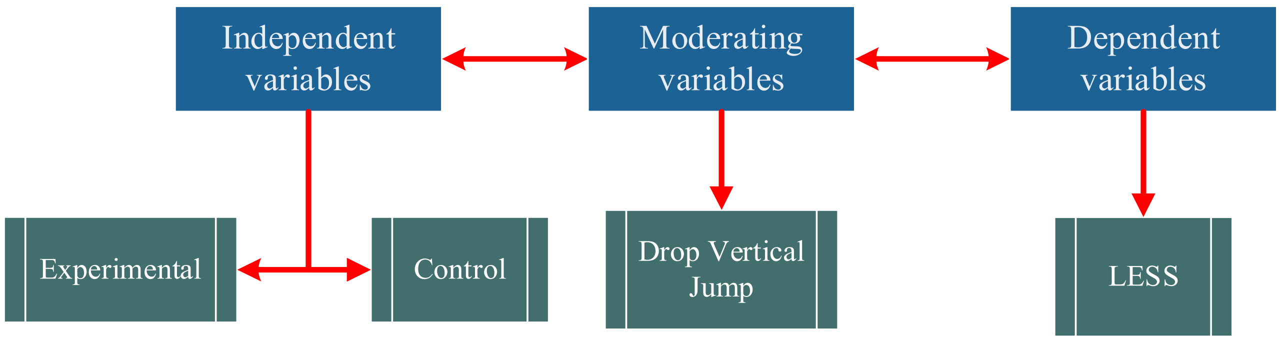


Figure 1.3: Schematic layout showing the breakdown of qualitative variables (LESS)

Subjective evaluation (mLLCI)

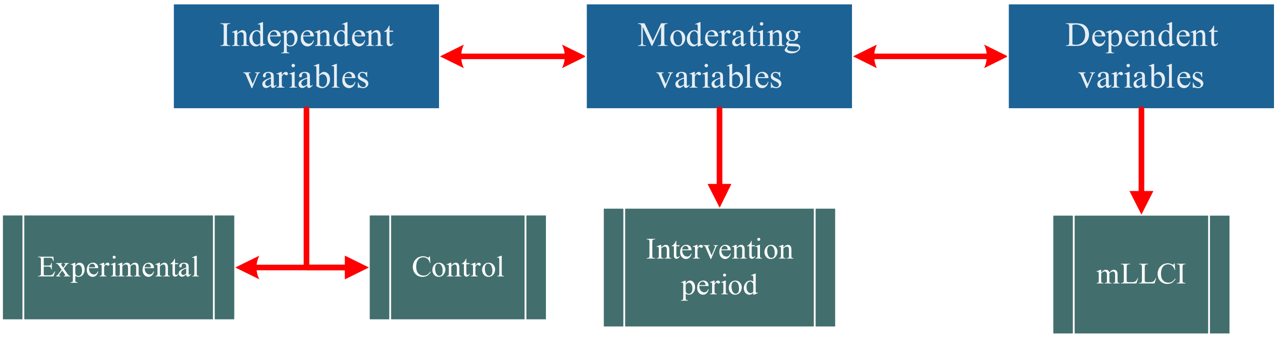


Figure 1.4: Schematic layout showing the breakdown of qualitative variables (mLLCI)

G. ASSUMPTIONS

The following assumptions were made regarding the study: (a) that participants had a sincere interest in participating in the research; (b) that the participants completed the questionnaires honestly; (c) that the participants performed the physical tests and participation in the intervention programme to the best of their abilities; and (d) that the instruments used elicited reliable responses.

H. OUTLINE OF THE THESIS

The thesis constituted five chapters. The first chapter comprised background, motivation, and statement of the problem, potential benefits, aims, objectives, and variables for the study. The second chapter featured the theoretical framework for the study. The literature review on landing kinetics and kinematics, impact peak acceleration and shock attenuation, barefoot training and footwear were presented in the second chapter. The third chapter comprised research methodology of study design, participants, inclusion and exclusion criteria, assumptions, research procedures, measurement and tests, intervention programme, training characteristics, ethical aspects and statistical analyses for the study. The fourth chapter featured the results according to the aims, objectives and research hypotheses for the study. The fifth chapter comprised the discussion of findings, study limitations and future research, practical implications and conclusion of the study. The American Psychological Association (APA) reference format was used for citations and reference guidelines for the study.

CHAPTER TWO

THEORETICAL CONTEXT

"What goes up, must come down, 'according to an old saying'. The problem is that athletes often train for the 'going up', while neglecting the 'coming down' – and all its potential for injury".

Bressel and Cronin (2005)

A. INTRODUCTION

Landing is a frequently performed task in sports to manipulate skills, maximise mechanical functions and avoid injury. Dufek and Bates (1991) broadly classified volleyball, basketball, netball, gymnastics, aerobic dance and running as jump-landing sports, which involve activities containing an airborne phase and results in a consequent need for safe landing. Over the years, netball players have adopted several landing techniques which are largely influenced by the direction of the pass, proximity of opponents in a game situation, court surface and shoe condition (Steele & Lafortune, 1989). Steele (1990) described landing as a fundamental part of netball skills which completes the final phase of a typical netball movement such as rebounding after an attempted goal, leaping to catch a pass, or steadying the body after a defensive deflection. Landing is a fundamental skill needed to perform many movements during netball training and game situations. As a component of movement tasks, it plays a significant role during ground contact and subsequent kinetic chain intersegmental interactions (Caster, 1996).

According to Caster (1996), the landing phase can be categorised into two distinct phase, namely: the preparatory phase (a phase prior to an airborne activity) and the discrete phase (a phase subsequent to an airborne activity). The performance of landing tasks in sports is important, not only for the biomechanics of landing phase analysis, but also for the prevention of lower extremity injuries (Hopper, McNair, & Elliott, 1999a; Yu, Lin, & Garrett, 2006). Landing generates magnitudes of the impact that are mainly absorbed by the lower extremities and could lead to injury if the body cannot absorb the shock transmission (Dufek & Bates, 1990; Hopper, Lo, Kirkham, & Elliott, 1992). The progression of landing mechanics could be complementary to the movement task (Dufek & Bates, 1992) or detrimental to the performer and usually results in injury (Bressel & Cronin, 2005), if not well-monitored during the performance (Dufek & Bates,1991). Thus, there is a need for proper landing techniques to enable the body to safely dissipate energy efficiently during movement task (Mothersole et al., 2013).

Several studies have been devoted to the analysis of landing patterns in sports, in an attempt to provide possible solutions to lower limb injuries (Lobietti, Coleman, Pizzichillo, & Merni, 2010; Padua et al., 2015). Significant factors which have been ientified that could influence the landing phase of a movement task include: the height of deceleration (Hewett et al., 2005), distance of a jump (DiStefano et al., 2016), landing techniques (Mcnitt-Gray, 1993) and magnitude of landing impact (Mothersole et al., 2013). In addition, good landing skills are characterised by good lower limb kinematics at initial contact (Blackburn & Padua, 2009) and forefoot to heel landing (Padua et al., 2011).

B. BIOMECHANICS OF LANDING

Landing as a component of a movement task plays a significant role during ground contact and subsequent kinetic chain intersegmental interactions. It is a phase in motion analysis that determines injury severity. The magnitude of the force generated at landing is fundamental to injury occurrence (Dufek & Bates, 1990; Hopper, Lo, Kirkham, & Elliott, 1992). The high braking force generated by a player at landing, could serve as a major contributing factor to potential injuries. This is due to the potentially excessive force placed on the stabilising ligaments of the lower limb, with the knee in particular being commonly affected (Steele, 1986). Mothersole et al. (2013) noted that excessive ground reaction forces (GRFs) experienced by the body during landing could increase the risk of lower limb injuries. In a study by Hopper et al. (1999) which contained fifteen netball players, it was found that bracing, taping and range of motion (ROM) at the foot-ankle complex would not alter vertical ground reaction forces (VGRF). Understanding the dynamics of landing mechanics for injury prevention and performance enhancement would require profiling all the components of GRFs (Mothersole, 2013).

C. LANDING KINETICS AND SPORTS PERFORMANCE

Generally, landing kinetics includes the magnitude and direction of force or impact at landing. Landing kinetics does not only involve magnitude of force generation but also rate of loading and impact attenuation. According to Mothersole (2013), landing kinetics play significant roles in sports performance and injury prevention especially in movements that require jump-landing tasks. Van Der Worp, Vrielink and Bredeweg (2016) in a systematic review, affirmed that high GRFs are found to be associated with a history of injuries among previously injured athletes. Yin et al. (2015) confirmed the findings of the other studies that landing with a high impact could put the knee at risk for injury. It is important to design landing strategies in netball that conform to the on-court landing conditions and mitigate against the risk of injury. The landing kinetics for this study includes GRFs, time to peak ground reaction forces (GRFtp) and shock attenuation (SA).

D. LANDING PERFORMANCE AND GROUND REACTION FORCES

According to Bartlett (2007), the measured force acting on the performer has the same magnitude as, but opposite direction from, the reaction force exerted on the performer by the force plate (law of action-reaction). Every form of dynamic movement leverage on the properties of GRFs. Divert et al. (2005) described GRFs as forces generated when the body segment makes contact with the ground. GRFs are commonly measured with a force plate and are expressed in Newtons (N = 1kg) or relative to body weight (BW), which is quantitatively derived from force equals mass times acceleration (F = ma) (Edwards, 2000; Bressel & Cronin, 2005). Headon and Curwen (2001) noted that when the vertical ground reaction force is normalized to body weight, the resultant time-series is the acceleration profile of the movement. The vertical, anteroposterior and mediolateral planes represent the three component vectors (x, y and z) in measuring ground reaction forces (**Figure 2.1**). Encouragingly, Hood, McBain, Portas and Spears (2016) noted that the recent availability of portable force plate has made field assessment of GRFs possible and ecologically viable in comparison to laboratory-based assessments.

In 1986, Julie Steele embarked on a project that influenced the course of biomechanical research in netball. The objectives of the project included examining forces generated at landing; characteristics of netball landing techniques and the influence of different footwear (Steele, 1986). Vertical ground reaction force (VGRF), time to peak vertical ground reaction force (VGRFtp), peak braking force (PBF), time to peak braking force (BFtp), peak resultant force and time to peak resultant force were the main force variables adopted for the study. Steele (1988) described VGRF as the largest force experienced in the vertical direction at landing. PBF as the largest braking force (horizontal force) which enabled a player to stop moving forward at landing and peak resultant force (maximum total force) as the combination of vertical and horizontal and mediolateral forces experienced at landing.

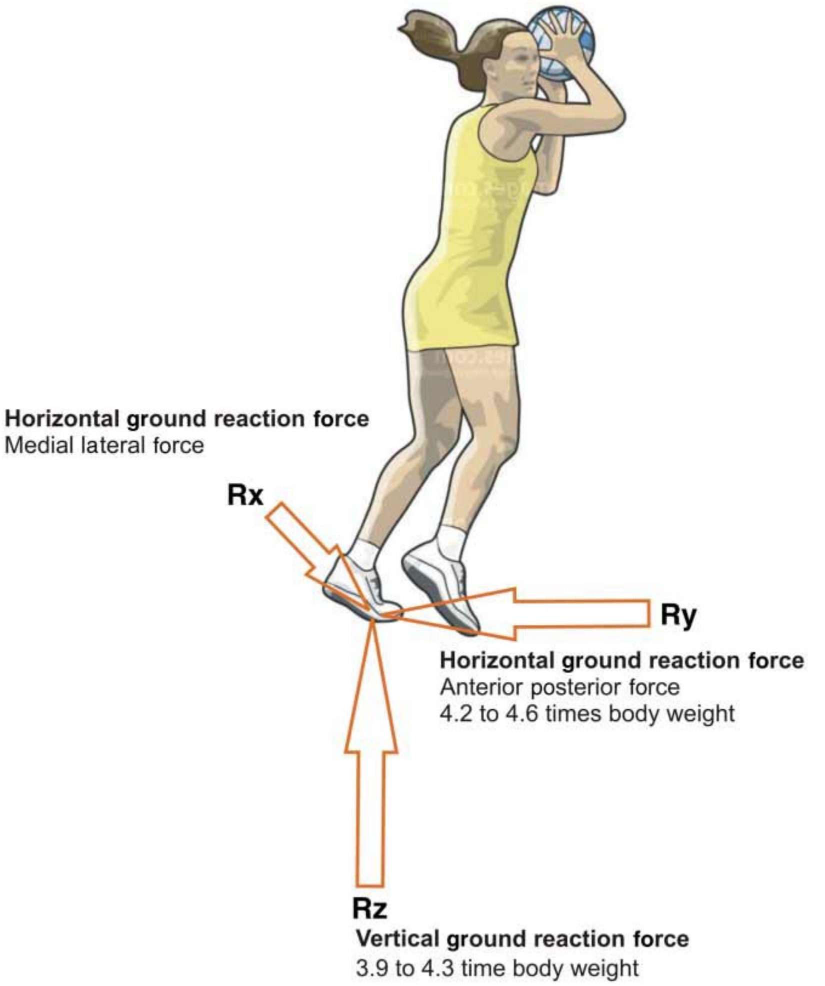


Figure 2.1: The arrows pointing at the three components of the GRFs on a netball player about to pass the ball (Source: Walker & Subic, 2010)

GRFs in barefoot and shod conditions

GRFs elucidate the intensity and duration of force that is experienced by the various body segments during ground contact (Bressel & Cronin, 2005), which can be in barefoot, barefoot-inspired or shod condition (Sinclair, 2014). The shock absorbing properties of footwear and ground surface condition can influence the magnitude of impact forces (Hart & Smith, 2008). Two studies revealed that the degree of magnitude can vary between 2.53 and 3.09 times a person's BW, depending on the type of footwear as well as exercise intensity (Logan et al., 2010; Phan et al., 2017). In the study by Steele (1986), it was speculated that high braking force generated by a player at landing, could serve as a major contributing factor to potential injuries by putting the ligaments of the lower limb, especially the knee, under undue stress. Therefore, it could be speculated that the greater the braking force, the higher the risk of ACL injury.

Steele (1986) reported on the analysis of netball landing techniques, and the implication for injury prevention and shoe design. The study involved 21 centre court players, with an age range of 15.2 to 21.6 years (18.59 ± 2.29). Peak VGRFs (3.9 to 4.3 BW) of the netball players in her study were compared with VGRFs generated during running. It was concluded that forces generated after catching a ball in netball were considerably higher than values reported in running. This claim was supported by a study on distance running, where peak VGRFs varied between 2.2 – 2.8 times a person's body weight in instances where runners were rear-foot strikers (Cavanagh & Lafortune, 1980).

In a further study conducted by Steele (1988), it was found that higher vertical forces and lower horizontal forces experienced at landing, could lower the incidence rates of knee ligament injury, although would increase the likelihood of damage to the internal structures within the knee joint as a result of the compression of the musculoskeletal structures. In addition to these findings, it was reported that the rate at which load is applied to the lower limb, as well as the size of the force and point of application are additional factors contributing to the likelihood of injury (Steele, 1990). A study by Nigg (2001) corroborated the observations pointed out by other authors that increases in GRF at landing, could result in ligament damage, articular cartilage degeneration, osteoarthritis and/or musculoskeletal disorders. In order to adequately mitigate the risk of injury, athletes are advised to modify their landing techniques in an effort to minimize the GRFs, and thereby decrease stress on the musculoskeletal structures (Steele, 1988).

Training adaptation to GRFs and jump-landing activities

Netball players are constrained by the rules of play, in that they are only allowed to take only a single step after landing from a jump, which necessitates a rapid deceleration of the body, thereby increasing landing impact forces (Hopper, McNair, & Elliott, 1999). Dai et al. (2015) suggested that a soft landing would decrease peak posterior GRF in stop-jump and side-cutting tasks compared with the natural landing. In addition, the soft landing would decrease the knee extension moment at peak posterior GRF during stop-jump tasks. The study also noted that the decreased peak posterior ground reaction force during soft landing would decrease the sagittal plane loading, potentially leading to ACL injury. In addition to the injury risk, Mothersole et al. (2013) found that landing softly may result in a slow progression of skill execution. Therefore, as much as greater hip and knee flexion during landing is widely reported in the literature, athletes need to be trained to simultaneously absorb landing impact forces, and increase performance goals necessary for individual and team success.

Stuelcken, Greene, Smith and Vanwanseele (2013) further stressed the need for the absorption of GRFs by the distal segments of the lower limbs. For instance, Tsang (2000) reported that GRFs for drop jumps and countermovement jumps (average five times a person's BW) were higher than that of jumping jacks (3.5 times a person's BW) for children. In a study which involved 10 female gymnasts and ten female recreational athletes, higher VGRF in drop landing were reported for female gymnasts at a box height of 60cm and 90cm, than female reactional athletes (Seegmiller & McCaw, 2003). McNair and Prapavessis (1999) in a study that involved 234 adolescents, reported peak VGRF at 4.6 times a person's BW for athletes in jump-landing related sports and 4.4 BW for athletes in non-jumping sports. In a cross-sectional level 2b controlled laboratory study, Wernli, Leo, Phan, Davey, and Grisbrook (2016) found that a reduction in landing sound is linked to a reduction in drop landing VGRF, which is influenced by lower limb kinematics.

Several studies have reported the positive implication of reduced lower limb impact forces in injury prevention and rehabilitation (Wernli et al., 2016). Bates, Ford, Myer and Hewett (2013b) suggested that the second landing from a drop vertical jump may provide more biomechanical details on lower injury risk. This is due to the unstable body posture during the flight phase of the second landing which could lead to increased stiffness and greater landing perturbation. Bates et al. (2013b) reported no significant differences in first and second landing drop vertical jump VGRF, although side-to-side asymmetry was greater for the second landing. GRF values reported by Dufek and Bates (1990) ranged from 9.33 times a person's BW to 10.55 times a person's BW for athletes who performed three series of landings from different distances (40 cm, 70 cm, 100 cm) and heights (40 cm, 60 cm, 100 cm) using different landing techniques.

In a study examining the differences in lower extremity kinetics during drop landings from three different heights (0.32, 0.72, 1.28m), Mcnitt-Gray (1993) reported GRFs of between 3.9 - 11.0 times a person's BW for gymnasts and between 4.2 - 9.1 times a person's BW for recreational athletes. Although landing softly and landing with greater knee flexion at initial ground contact might reduce ACL loading during stop-jump and side-cutting tasks, the performance of these tasks decreased, as indicated by increased stance time and mechanical work as well as decreased jump height and movement speed (Dai et al., 2015). In addition, Hopper et al. (1999a) reported peak VGRF 3.37 BW for a normal landing, 3.12 BW for braced landing, 3.33 BW for taped landing of netball players. In another study, Hopper et al. (2017) reported VGRF at 2.4 times a person's BW for drop vertical jump and 1.9 times a person's BW for single-leg landing. Following neuromuscular training intervention in this particular study, the experimental group significantly reduced landing impact in the drop vertical jump by 1.3 times a person's BW, and single-leg drop landing by 1.2 times a person's BW.

Summary

Landing kinetics do not only involve the magnitude of force generation, but also rate of loading and impact attenuation. Every form of dynamic movement leverages on the properties of GRFs. The shock absorbing footwear and ground surface condition will influence the magnitude of impact forces. Netball players are constrained by the rules of play, whereby they are only permitted to take one step after landing from a jump, which has the propensity to generate high landing impact forces (Hopper, McNair, & Elliott, 1999). Athletes should therefore be trained to simultaneously absorb landing impact forces, while still being able to accomplish performance goals necessary for individual and team success.

E. LANDING PERFORMANCE AND TIME TO PEAK GRFS

Steele (1988) described time to peak VGRF as the time range from initial contact with the ground, until peak VGRF. Time to peak resultant force was described as the time from initial contact with the ground, until peak resultant force. Time to peak VGRF provides a mechanism for the evaluation of limb dominance and symmetry (Bates et al., 2013a). The duration of the landing phase during movement tasks may impact on the change in time to peak VGRF. In a study by Steele (1988), it was reported that shortened time to the peak resultant force, and a greater magnitude of force, are contributory factors which increase total stress placed on the lower extremity, thereby increasing the likelihood of injury. Steele and Milburn (1987) reported that time to peak vertical and braking forces (31.2 ms and 30.5 ms) was greater in heel-strike landing compared to fore-foot landing (30.6 ms and 23.9 ms). When examining the effects of pass height, Steele (1988) reported longer average time to maximum vertical force for high pass landing in comparison to standard pass landing.

McClay et al. (1994) noted that decreases in time to peak force is proportionate to the magnitude of shock transmission experienced by the body. Carcia, Kivlan and Scibek (2012) found that there was a strong relationship between time to peak force and frontal plane kinematics at initial contact, and 100 ms post-contact during a unilateral squat. It was observed that longer time to peak force may lead to poor landing kinematics. Time to peak VGRF has been associated with increases in the magnitude of knee and hip flexion (Steele, 1988). Furthermore, players who demonstrated increases in the time to peak VGRF also increased the degree of inward lean flexion at the ankle and hip.

Time to peak in barefoot and shod condition

Steele (1986) noted in her study that even though shoe selection did not alter the magnitude of the VGRF, there was an increase in time to peak GRF. Furthermore, the rate of force loading at landing, could largely be affected by shoe selection and any orthotic device contained within the shoe itself. Therefore, players should be encouraged to wear footwear capable of attenuating force at landing during training or competition. When assessing the differences between dominant and non-dominant limb landing, there were no significant differences reported for time to peak VGRF (18 – 32 ms) at landing. According to the study of Steele and Milburn (1987), where landing barefoot (BF) was compared with shod (SH) conditions (using three different types of footwear), time to peak force (BF = 18.0 ms; SH = 28.3 - 32.3 ms) and braking forces (BF = 4.23 BW; SH = 4.50 ± 4.61 BW) were found to be lower, while the vertical forces were greater (BF = 4.26 BW; SH = 3.92 ± 4.02 BW) in barefoot players. Time to peak recorded for the barefoot condition was significantly shorter than the time recorded for the three footwear conditions used for the study.

Training adaptation to time to peak GRFs and jump-landing activities

Dai et al. (2015) reported that a decrease in GRFS was possible due to the range of motion of the lower extremities which allowed subjects to dissipate landing force over a longer period of time. Caster (1996) suggested that an increase in knee flexion might be a strategy to absorb landing momentum. In a study on the effect of bracing and taping when landing from a jump, Hopper et al. (1999) reported time to peak vertical ground reaction forces of 43.71 ms for a normal landing, 34.56 ms for braced landing and 37.97 ms for taped landing. Bates, Ford, Myer and Hewett (2013a) examined timing differences in between the first and second landing of drop vertical jump performed by 239 adolescent female basketball players and reported that time to peak GRFs increased during the second landing. They noted that a rapid increase in time to peak GRF may impact on injury risk of the lower limb ligaments, and increase joint loading commonly associated with higher incidence of ACL injury. No significant differences were found in left leg time to peak VGRF between landings but right leg increased between landings. However, they reported a reduction in the duration of time to peak between landings, although time to peak VGRF increase between landings on the right leg.

Summary

Steele (1988) reported shortened time to the peak resultant force and increased the magnitude of force as contributory factors to the increase in total stress placed on the lower extremity, which could lead to increase in the likelihood of injury. It was noted that an extended time to peak force would lead to poor landing kinematics and that the rate of force loading at landing could mostly be affected by shoes and shoe inserts. Therefore, players should be encouraged to wear footwear capable of attenuating force at landing during training or competition.

F. LANDING PERFORMANCE AND SHOCK ATTENUATION

Applequist (2012) defined shock attenuation (SA) as the process by which the impact shock caused by the collision between the foot and ground is reduced. Measurement of the magnitude of attenuation can be achieved by calculating impact acceleration from two anatomical segments of the body (Derrick, 2004). Shorten and Winslow (1992) noted that impact can be categorised into impact force (peak GRF), impact shock and impact shock wave (propagation of shock in the body). Impact force measured by a force plate is a homogenous quantification of whole body impact, which is proportionate to the net force acting on the centre of mass. The segmental acceleration of the open kinetic chain is not measured by force plate. Derrick (2004) argued that impact forces travel through the whole body in an extended position with the reduced acceleration of the lower limb, while a flexed knee will reduce the magnitude of impact and increase segmental acceleration (**Figure 2.2**). Therefore, it could be concluded that the increase in segmental acceleration of the lower limb will influence the reduction of impact forces that could possibly predispose the body to injury.

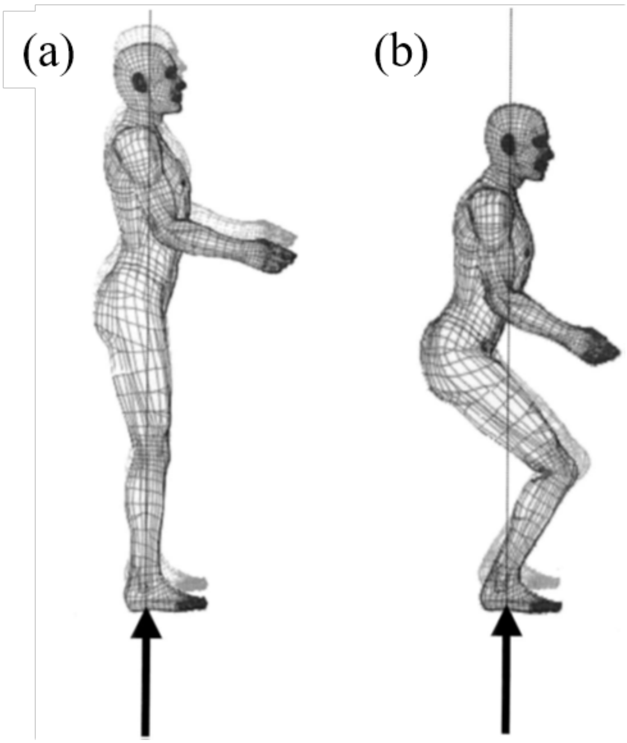


Figure 2.2: (a) Pointed upward showing the line of action of impact force (b) pointed upward arrow showing the flexed knee and the reduction of the magnitude of impact force (Source: Derrick, 2004)

The interaction of musculoskeletal tissues naturally influences the magnitude of shock transmission. A shock wave usually travels through the musculoskeletal system during rapid deceleration in ground contact (Hamill, 1999). Bishop et al. (2006) however, argued that shock absorption and acceleration at the shank and head could not provide detailed information on transmission of impact acceleration in the body. In a study conducted by Coventry et al. (2006), it was found that the presence of fatigue in the muscles of the lower limbs did not impact on their ability to attenuate the forces placed on them during landing. In contrast to this, Gross and Nelson (1988) earlier concluded that the asymmetrical landing pattern of a fatigued athlete when performing a vertical jump, generated higher impact forces and lower levels of SA in the ankle. In supporting this argument, Bishop et al. (2006) found that the rate at which shock is attenuated in the lower limb, could be affected by muscle fatigue.

The properties of footwear extrinsically determine shock attenuation (Hamill, 1999). Due to the variance in the magnitude of force experienced in different sports by athletes, the shock-attenuating mechanism cannot be the same. The cushioning properties of sport footwear is designed to attenuate impact forces of varying magnitude (Edwards, 2000). Footwear that is not mechanically designed for a specific sport may be subjected to a displacement limit or bottom out if the repetitive impact force exceeds the shock-absorbing capabilities(Edwards, 2000). Force transmission and moments are experienced by the lower extremities during landing which facilitates the acceleration and deceleration of joint kinematics. Therefore, a safe landing would involve positive contribution of lower extremities muscles to absorb the shock and eliminate the velocity of the body (Yeow et al., 2011).

Shock attenuation in barefoot and shod conditions

Tibial acceleration has been widely reported as a reliable method of measuring shock absorption (Hamill, 1999). Accelerometer placement at the medial aspect of the calcaneus and distal antero-medial tibia revealed 31.3 % shock attenuation, regardless of surface landing with barefoot from a countermovement jump (Gross & Nelson, 1988). Sinclair et al. (2013), in a study on the influence of barefoot and barefoot-inspired footwear on the kinetics and kinematics of running in comparison to conventional running shoes, reported that the shock-absorbing materials of conventional running shoes are superior to barefoot or barefoot-inspired shoes. Yeow et al. (2011) reported in their study, which compared barefoot and shod landing, that greater knee joint range of motion increased the shock absorption and reduced the landing impact in shod condition compared with the barefoot landing. The study further associated the greater knee joint kinematics during shod landing to the counter movement produced by the knee extensor muscles. The study concluded that landing height could influence landing knee energetics in shod condition and also contribute to dissipation of forces on the knee joint. It was therefore suggested that landing on a hard surface should be performed in shod condition to stimulate greater shock attenuation through an efficient range of motion and reduced knee joint stiffness.

Training adaptation to shock attenuation and jump-landing activities

There is a higher incidence of stiff landings in female athletes compared with male athletes, which has been reported to increase the propensity for reduced hip shock attenuation and elevated load at the ankle and knee. Stiff landing is characterised by greater joint extensions (Edwards et al., 2012) which is often linked with knee injuries, greater VGRF, quadriceps and hamstrings muscle activation (Shultz et al., 2012). Coventry et al. (2006), in their study on the effect of lower extremity fatigue on shock attenuation during single-leg landing, reported that there were no significant changes to shock absorption despite the increase in hip and knee flexion and a decrease in ankle plantar flexion in the presence of fatigue. Derrick (2004) observed that impact attenuation might be compromised during knee extension due to the minimal movement at the joint complex and reduction in elasticity of the muscle-tendon relationship. The study further identified the greater capacity of the hip joint to absorb energy transmission especially in the frontal plane with an increase in elevation.

Yeow, Lee and Goh (2009) in a study on the effect of landing height on frontal plane kinematics, kinetics and energy dissipation on the lower extremity joints, concluded that the hip and knee joint play significant roles in shock absorption to attenuate impact force at landing. When examining relative absorption of energy at the hip and ankle joint when performing a drop jump and jump landing, it was found that hip relative absorption was greater for the drop jump (41.6 %) compared to the drop landing (35.4 %), whereas the converse was found with the ankle, with absorption of 46.9 % and 42.1 % for the drop landing and drop jump, respectively (Shultz et al. 2012). The rate of energy absorption at the knee was relatively similar for the two landing tasks. Yeow, Lee and Goh (2011) observed that the absorbent materials of footwear could directly influence the extent to which shock is attenuated at the ankle joint, although this does not necessarily extend to the knee joint. The study concluded that increases in landing height will increase the tendency for shock absorption, regardless of footwear condition (barefoot or shod), however shod condition might contribute more to the lower limb shock absorption through knee motion.

Shock attenuation in drop landings and drop jumps occurs in opposite directions, whereby the attenuation strategy tends to be more proximal in drop jumps and distal in drop landings (Shultz et al., 2012). Gross and Nelson (1988) investigated the perceived role of the footfall pattern on shock attenuation, and long-term prevention of lower limb injuries. It was noted that only a single peak acceleration transient was present in 89 % of the non-heel contact landing trials, which accounted for the reduction in the peak transient experienced by the lower limb. Gross and Nelson (1988) added that a more controlled lowering of the heel compared to heel contact landing significantly reduced the maximum force by 22 %, and decreased peak loads in the lower extremity. Of interest was that an ankle joint with an average range of motion of 50 degree contributed largely to shock attenuation.

Summary

The magnitude of shock transmission is naturally influenced by the interaction of bone, ligament, tendon and muscle. An increase in the segmental acceleration of the lower limbs could influence the reduction of impact forces line of action, which could possibly predispose the body to injury. Due to the variation in the magnitude of the forces experienced in different sports by athletes, shock-attenuating mechanisms should be approached on a sport-specific basis. Force transmission and moments are experienced by the lower extremities during landing, which facilitates the acceleration and deceleration of joint kinematics. It is therefore suggested that landing on a hard surface should be performed in shod condition to stimulate greater shock attenuation through an efficient range of motion and reduced knee joint stiffness.

G. LANDING KINEMATICS AND SPORTS PERFORMANCE

The kinematics of lower extremity control involves the trunk, hip, knee and ankle. Mendiguchia et al. (2011) described the core of the body as the trunk to the hip system, which explains the dynamics of the relationship between the trunk, hip and knee joint, and their control of the lower extremity during a movement task. For instance, the muscles in the lumbopelvic region, which stabilizes the trunk and the hip distally, contributes to the knee joint control and enables the neuromuscular coordination and balance of the lower extremity in any form of movement (Mendiguchia et al., 2011). According to Ericksen et al. (2016), increasing the kinematics of the hip and knee joint in the sagittal plane, and reducing impact forces, are the primary goals during jump-landing tasks. A study by Yeow et al. (2011) described how greater joint kinematics are experienced during bilateral landing from a significant height, in an attempt to absorb shock propagation and minimise the risk of injury to the lower limbs. The current study would adopt the kinematic variables of impact peak acceleration (IPA), initial contact angle (IC), peak angle and range of motion (ROM) to measure and monitor changes in jump-landing tasks after a barefoot intervention.

H. LANDING PERFORMANCE AND IMPACT PEAK ACCELERATION

Wireless sensors or inertial measurement units attached to the body have grown in popularity due to their ability to measure landing impact in a field setting compared to the traditional laboratory-based setting with an imbedded force plate. (Bleser et al., 2013). McMaster, Gill, Cronin and McGuigan (2013) noted that the use of force plates in the measurement of impact only captures ground reaction forces along the acceleration of centre of mass. However, the use of accelerometers focuses on the change in velocity of the anatomical segment in the attachment area. Accelerometers used in the field of human movement are made of different components such as strain gauge, piezoelectric as well as piezo resistive and capacitative components (Kavanagh & Menz, 2008). Hooke and Newton's second law of motion has been described as the foundational principle for the measurement of acceleration, also known as a mass spring system. The mechanism by which an accelerometer generates an acceleration value during movement involves the control and compression of the degree of force generated by the stretching of the mass spring system (Kavanagh & Menz, 2008).

The accelerometer are useful device for measuring impact between ground and physical contacts (Brewer, 2016). The sensors are economical and portable making it easy for capturing meaningful data outside of a laboratory setting (Sell, Akins, Opp & Lephart, 2014; Plowman & Smith, 2014). The sensors have evolved from uni-axial (accelerometer) to tri-axial (accelerometer, gyroscope and magnetometer) capacity to measure acceleration and angular orientation (Elvin, Elvin, & Arnoczky, 2007). Sensors are characterised by functional capacity which includes selectivity (signal response capacity), sensitivity (signal to output change), range (lowest and highest signal detection point) and stability (rate of sensitivity to signal within range) (Patel, Anastassiou, & O'Hare, 2006). The accelerometer measurement of impact takes net force, body mass and centre of mass (COM) into consideration (Derrick, 2004) and may have a linear relationship with force (Tran, Netto, Aisbett & Gastin, 2010). Nagano, Sasaki, Higashihara, and Ishii (2016) agreed that acceleration and other related variables could be measured and monitored using the accelerometer. Derrick (2004) identified that acceleration of a specific anatomical segment could be determined by calculating the amount of force transmitted through the segment. The study defined impact transmission as the magnitude of acceleration that travels through the first unit of the accelerometer relative to the second unit placed along the musculoskeletal system. Peaks in the time domain of the acceleration signal have been used to quantify shock wave (Shorten & Winslow, 1992).

Cho et al. (2009) observed that landing impact depends on environmental conditions, biomechanical factors, footwear style and spatiotemporal body position which are necessary for understanding impact distribution in the body. The acceleration of the anatomical segment could be impacted by anthropometry of the segment, joint movements, mass, segment deformation and moments of inertia (Derrick, 2004). In the same vein, Nagano et al. (2016) found that impact distribution across the body, positively correlated with the peak acceleration of the anatomical segment. In this regard, it is possible that the distance between the anatomical segment and impact force initialization influences the segment acceleration. The farther the impact force from the centre of mass, the lesser the segment acceleration (Thompson, Seegmiller and McGowan, 2016). As a counter to this, Bishop et al. (2006) suggested that shock absorption and acceleration at the shank and head cannot provide detailed information on transmission of impact acceleration in the body.

Whilst the use of accelerometery in the field of biomechanics has a number of benefits, there have been some technical issues which have been raised. Thompson, Seegmiller and McGowan (2016) noted that unwanted movement of tissue artefacts could exaggerate acceleration signal. Tran, Netto, Aisbett and Gastin (2010) in a study on the validation of accelerometer data for measuring impacts during jump-landing tasks, noted that the low sampling frequency might not be adequate in measuring impact accurately. The study further emphasized that internal vibration and sensitivity to change in position might be responsible for increased peak values with the accelerometer. The authors also noted that poor adhesion of the accelerometer sensor to the point of interest may also increase noise in the captured data, leading to a misrepresentation of the biomechanical findings. Despite the technical and methodological issues involved in the use of accelerometery in sports biomechanics, Sell et al. (2014) recommended the use of tibial acceleration during game conditions as a means to monitor risk of knee injury. It is imperative that a balance is found between the safety and comfort of the players, and the accuracy of the data collection, when planning to use accelerometery for biomechanical studies.

Impact peak acceleration in barefoot and shod condition

Thompson, Seegmiller and McGowan (2016), in a study on impact accelerations in barefoot and shod running, reported that increases in GRF and decreases in impact acceleration were associated with midsole absorption of force in the shod conditions and modified stride length with forefoot ground contact in barefoot conditions. The runners demonstrated lowest impact peak values (1.58 ± 0.21 BW) in BF condition, followed by heel strike in barefoot condition (1.81 ± 0.25 BW) and highest peak values in shod condition (1.91 ± 0.21 BW). The study observed reductions in impact acceleration and peak magnitude due to shorter stride length, and a plantarflexed position at ground contact in barefoot running. In contrast to this, greater magnitude of impact peak force and lower impact acceleration were observed in shod running. It was suggested that the plantar flexion ground contact may lead to the reduction of impact transmission.

Training adaptation to impact peak acceleration and jump-landing activities

In a study on the effects of knee contact angle on impact forces and acceleration, Derrick (2004) emphasized the need to clarify the influence of kinematics of knee movements on segmental acceleration and the impact forces. It was noted that a change in impact forces and peak acceleration might have a negative linear relationship, which is possibly influenced by a change in mass resulting from knee joint motion. In a study on the relationships between trunk and knee acceleration and the GRFs during single-leg landing, Nagano, Sasaki, Higashihara and Ichikawa (2016) found a strong correlation between peak VGRF and trunk peak acceleration although there was no correlation between the knee acceleration and GRFs. Sell et al. (2014) also reported no correlation between proximal anterior tibial shear force and acceleration, even though there was a significant correlation between acceleration data and peak posterior GRF.

Summary

Wireless sensors or inertial measurement units attached to the body are being widely used more in the measurement of landing impact, particularly in field-settings. Despite its benefits, the use of accelerometery in the field of biomechanics does have some technical issues. It is important that a balance exists between athlete safety and comfort and the accuracy of data measured through accelerometery. Lastly, changes in impact forces and peak acceleration might have a linear relationship.

I. LANDING PERFORMANCE, INITIAL CONTACT AND PEAK ANGLES

Several studies have reported the need to investigate the kinematics of jump-landing and injury risk at initial contact and peak angles (Lin, Liu, Garrett & Yu, 2008; Krosshaug et al., 2016; Leppänen et al., 2016). McLean et al., (2005) noted that initial contact measurements could help to identify individuals who are at risk of injury before the intervention. Increased energy utilization in drop landing and with drop jumps is characterised by increased hip and knee flexion at initial contact and peak muscle activation levels (Shultz et al., 2012). Padua et al., (2009) included initial contact in a subjective evaluation rating scale which was designed to identify athletes at risk for ACL injury. The instrument included initial contact measurements for ankle flexion, knee flexion, trunk flexion, foot contact, foot position, knee valgus and lateral knee flexion. In a study on the expert versus novice interrater reliability and criterion validity of the landing error scoring system (LESS), Onate, Cortes, Welch and Van Lunen (2010) recommended the need to improve clinical assessment of knee flexion and the valgus angle at initial contact, which was considered essential to the prevention of ACL injury risk.

A study by Steele (1986) showed that there were greater peak vertical forces at initial contact with less flexion of the ankle, hip and greater backward or inward lean of the trunk. Slower ankle flexion-extension and a more rapid lateral movement at the ankle, were responsible for higher VGRF seen in some trials. When investigating the lower extremity biomechanics during landing from the stop-jump task, it was found that those athletes with lower hip and knee flexion at initial contact, and greater knee flexion at maximum landing, had greater impact forces (Yu et al., 2006). The study further showed a significant correlation between hip and knee flexion-extension angular velocities and peak GRF at initial contact.

In contrast to these findings, Caster (1996) reported that maximum knee flexion plays only a minimal positive role as the increase in landing height is influenced by impact velocity changes. Their point of reference supposedly leads to an emphasis on the greater kinematics of the lower extremities kinetic chain during static and dynamic task movement and not the isolation of anatomical segment. In addition, Powell et al. (2012) found that increasing knee flexion positively correlated with ankle joint mobility in the landing phase of a drop landing task. However, landing performance (jump height, stance time and movement speed) could be negatively impacted, in an attempt to land softly, with greater knee flexion at initial contact angle in the stop-jump task and side-cutting tasks, and thereby reduce ACL loading (Dai et al., 2015).

Leppänen et al. (2017) noted that ACL injury risk increases in young female athletes with a reduction in knee flexion and increases in the VGRF during the DVJ task. The study reported knee flexion at initial contact (30.2 deg), knee valgus at initial contact (0.9 deg) and peak knee flexion (81.5 deg) for ACL-injured knees, while the uninjured knees had lower knee valgus (-1.8 deg), lower knee flexion at initial contact (27.6 deg) and greater peak knee flexion (84.6 deg). Steele (1988) recommended that in order to reduce the VGRF, players should be encouraged to land with flexed knees thereby avoiding stiffness of the knees at landing. The author further suggested that in order to reduce the size and rate of loading of vertical ground reaction forces at landing, players should be encouraged to eliminate excessive inward lean of the ankle and ensure adequate flexion of the hip (33 deg at initial contact and 45 deg peak resultant force) and knee (17 deg at initial contact and 40 deg peak resultant force) at landing.

Initial contact and peak angle in barefoot and shod condition

Bonacci et al., (2013) reported that ankle dorsiflexion was lower at initial contact for BF compared to SH running. Powell, Hanson, Long and Williams (2012), in their study on the frontal plane landing mechanics in high-arched compared with low-arched female athletes (in which athletes performed five trials of bilateral drop landing from 30 cm in barefoot condition), reported that lower limb joint angles of high-arched athletes were different from low-arched athletes. However, high-arched athletes had significantly lower ankle inversion at initial contact than low-arched athletes. Knee abduction angles at initial contact and peak joint abduction ankles were not significantly different between the two groups. Franklin et al. (2015) in a systematic review study on barefoot vs common footwear, reported shorter stride length, contact time, greater foot contact, greater knee flexion and lower peak VGRF at initial contact when walking barefoot.

Training adaptation to initial contact and peak angle jump-landing activities

Trunk lean during landing may lead to reduced knee flexion, and an increase in the hamstrings moment in combination with reduced quadriceps moments (Mendiguchia et al., 2011). The study concluded that a lack of trunk motion control during landing, would negatively affect the neuromuscular control of the hip and the knee. Mendiguchia et al. (2011) noted that the dynamics of lumbopelvic control may increase risk of injury more than the knee complex mechanism, even though several findings have established evidence of knee joint loading and ACL injury in female athletes.

The ability to maintain core stability and neuromuscular control after either static or dynamic movement, is achieved through co-ordinated activation of the muscles attached at the lumbopelvic region. Mendiguchia et al. (2011) summarized from other studies, that increasing trunk lean may be associated with a reduction in risk for ACL injury. However, the manipulation of the gluteal muscles moments by the kinematics at the hip joint, could create a neuromuscular imbalance at the hip, which may impact on the knee.

The dynamics of hip movement was further noted in Steele (1988), who reported an average 33.7 deg greater flexion of the hip at foot-ground contact after receiving a standard pass, compared to an average of 25.1 deg for a high pass. At the point of maximum resultant force, hip flexion increased to 45.2 deg for a standard pass, and 32.1 deg for a high pass. Furthermore, the players demonstrated external rotation of the hip at initial contact (15.7 deg) and maximum resultant force (10.1 deg) during a high pass. As a result of these findings, the author recommended that a greater degree of hip flexion when receiving a standard pass would enhance stability at landing, and limit the magnitude of the GRFs. Steele (1986) earlier reported 2.7 deg for trunk lean at initial contact, and 0.8 deg for maximum resultant force, which is assumed to enhance stability of the player when the centre of gravity is within the limits of supporting base.

Steele (1988) reported that increased knee internal rotation, lateral movements, and greater lateral lean of the trunk, were associated with higher peak VGFR at the moment of peak resultant force. There was a significant negative relationship between VGRF and foot-strike closer to the midline of the body. Players who landed by striding out, demonstrated lower peak VGRF than those with a foot-strike closer to the body. The degree of ankle eversion and hip flexion-extension at initial contact and peak resultant force, showed odd relationship with the occurrence of high peak VGRF. Lower peak VGRF was associated with a greater ankle inversion at initial contact, and greater flexion of the hip throughout the landing action. Blackburn, Norcross and Mcgrath (2011) identified that the degree of knee displacement during landing determines impact forces and influences ankle (ankle-dorsiflexion) and knee (knee-valgus) mobility.

Steele (1986) found that lower levels of dorsiflexion, and higher levels of ankle eversion, combined with greater lateral lean of the trunk, reduced braking forces. Lower braking forces were also associated with lower ankle inversion at foot-strike. Reduction in ankle eversion was associated with peak resultant force. Steele (1988) reported that backward inclination of the trunk when receiving a high pass was on average 6.9 deg at initial contact and 5.3 deg at the peak resultant force. When assessing trunk rotation, these values were on average -15.4 deg at initial contact and -14.8 deg at the peak resultant force. Hopper et al. (2017) in a randomized control study which involved teenage netball players, reported greater hip and knee flexion and lower hip and knee abduction at initial contact and peak angles for DVJ after the intervention. Greater hip and knee flexion and lower hip and knee abduction at initial contact and peak angles were also reported for single-leg landing. The study concluded that significant positive changes for injury prevention could occur in landing kinematics after six weeks of neuromuscular intervention.

Summary

The biomechanical analysis of the lower extremity control involves the trunk, hip, knee and ankle. Onate, Cortes, Welch and Van Lunen (2010) recommended the need to improve clinical assessment of knee flexion and the valgus angle at initial contact, which is essential to the prevention of ACL injury. The results of Steele (1986) showed that there were greater peak vertical ground reaction forces at initial contact, when the ankle and hip flexion were reduced and the trunk inward or backward lean was increased.

J. LANDING PERFORMANCE AND RANGE OF MOTION

The range of motion (ROM) is defined as the amount of segmental motion permissible within a joint (Levangie & Norkin, 2011). The degree of the ROM is determined by the musculoskeletal structure of the joint. The concerns regarding lower limb injury risk have been consistently connected to the kinetics and kinematics of the interplay between the hip, knee and ankle joint (Pefanis et al., 2009). For instance, the hip joint is made up of the femoral head and the concave surface of the pelvis (acetabulum). It provides a greater range of motion in the anteroposterior, sagittal and longitudinal axes relative to the lower limbs so as to enhance locomotion, coordination and balance (Levangie & Norkin, 2011). Gomes, de Castro and Becker (2008) proposed in their study that decreased hip range of motion was associated with a higher incidence of ACL injury. Dufek and Bates (1991) noted in their study that lower levels of knee flexion and impact velocity may lead to an increase in peak force, therefore increasing the risk for lower extremity injury. Given the large body of evidence available on peak joint moments of force and mechanical power, it is possible to determine the tolerable joint stress threshold for successful landings. It is however important to note, that the model can only be applied on a subject-by-subject basis to identify critical components of performance. In addition, it was concluded that quantifiable performance factors during submaximal landing activities, could provide additional insight into identifying absolute criteria, which might predispose an athlete to landing injuries.

Range of motion in barefoot and shod condition

Bonacci et al. (2013) found in a study that barefoot running alters the kinetics and kinematics of the knee and ankle complex, and these changes may pose therapeutic and performance challenges to the runner. Due to the critical role the ankle joint plays in netball, a study by Steele (1993) recommended a comprehensive strength and conditioning programme to mitigate the risk of lower extremity injury. It was found that ankle injuries, which are very common among netball players, could be prevented through proper conditioning of the peroneal muscles of the lower leg. Zhang, Paquette and Zhang (2013), in a study on a comparison of gait biomechanics of different footwear conditions (flip-flops, sandals, barefoot and shoes), reported that ankle plantarflexion ROM in barefoot condition was lower when compared with shod conditions. Ankle eversion ROM was not significantly greater in shod conditions when compared with barefoot. However, knee flexion ROM was significantly greater in the shod conditions than barefoot conditions, which was confirmed in a study by Yeow et al. (201). Sinclair, Atkins, Richards, and Vincent (2015) observed greater plantarflexion of the ankle joint during running in barefoot conditions in comparison to shod conditions. Levangie and Norkin (2011) suggested that optimal movement efficiency depends on greater range of motion and responsive muscle contractions with adequate firing rates.

Training adaptation to range of motion and jump-landing activities

In a study in which five different landing heights (30 cm, 45 cm, 60 cm, 75 cm and 90 cm) were adopted for ten active males, it was reported that knee ROM did not differ significantly across the landing heights (Zhang, Derrick, Evans & Yu, 2008). Zhang, Clowers, Kohstall and Yu (2005), in a study on the effect of various midsole densities and mechanical demand of landing height, reported hip, knee and ankle ROM for the various footwear midsole densities (soft, normal and hard) and relative variation of landing patterns, as determined by the potential energy equation. The ROM reported for the study increased with the lower limb potential energy for shock absorption, even though the differences were not significant across the landing heights. Qu (2016) also identified the positive role of ROM on the interaction between synthetic turf, shock pad and impact attenuation. This was confirmed with drop landing protocol on five different surfaces ranging from force platform surface to synthetic turf. Greene et al. (2014) also found that when making use of an ankle support device by a netball player, there was a reduction in sagittal plane ankle ROM during the side-cutting task, although this did not impact on the loading of the ankle joint. According to the study, the knee and ankle sagittal and frontal ROM reported for the standard netball shoe was greater than ankle brace and high shoe. The study revealed the extent of ROM variations according to footwear design. Landing phase characterised by knee valgus displacement has been associated with a limited ROM especially at the ankle (Blackburn et al., 2011) as well as muscle atrophy and tightening.

Summary

The magnitude of ROM is determined by the musculoskeletal structure of the joint. Structural deformation of the knee and hip joint influence the joint disposition of the ankle. (Sinclair et al., 2015). There is possibility for muscle atrophy and limited flexibility to place limitations on the ROM of the lower extremities. Ankle injury, which is common among netball players, could be prevented through proper conditioning of the peroneal muscles of the lower leg.

K. JUMP-LANDING TASKS

Jump-landing is a form of movement pattern frequently experienced in active sports, such as basketball, volleyball, netball and handball (Sinsurin, Vachalathiti, Jalayondeja, & Limroongreungrat, 2016). The eccentric phase of a jump-landing task utilizes the stored muscle energy to enhance the work output during the concentric phase of movement (Shultz, Schmitz, Tritsch, & Montgomery, 2012). Studies have adopted jump-landing tasks to monitor performance (Liu & Heise, 2013; Aerts, Cumps, Verhagen, & Meeusen, 2010), biomechanics of movement (Etnoyer et al., 2013; Ericksen et al., 2016), injury risk (Aerts et al., 2013; Liu, Dierkes, & Blair, 2016) and recovery (Bell, Smith, Pennuto, Stiffler, & Olson, 2014). Performance variables such as reactive strength index, contact time, flight time, leg power and the rate of force development are commonly used by various studies to monitor and evaluate changes through the performance of jump-landing tasks (Mulcahy & Crowther, 2013; Kobal et al., 2017). It is quite evident from these studies that lower limb injury risks are associated with faulty jump-landing techniques, with lateral jump-landing exposing an athlete to a greater risk of lower extremity injury than forward jump-landing (Aerts et al., 2013).

Examples of jump-landing tasks commonly used include, but are not limited to: single-leg drop landing (Coventry et al., 2006; Ali, Rouhi, & Robertson, 2013), drop vertical jumps (Mok, Petushek, & Krosshaug, 2016), stop-jump, (Wang, 2011) countermovement jumps, (Gathercole, Sporer, & Stellingwerff, 2015) and vertical jumps (Pupo & Detanico, 2011). Mothersole, Cronin and Harris (2014) suggested that successful jump-landing training should involve systematic progression. The progression model should enhance the musculoskeletal capacity and tolerance level to be able to adjust to landing impact stress. Athletes who are involved in sports characterised by jump-landing activities should be specifically trained in multi-dimensional landing to reduce incidents of lower limb injuries (Sinsurin et al., 2016).

Drop landing

Several studies have adopted drop landing as an experimental landing task to understand the biomechanics of landing (Mcnitt-Gray, 1993; Cordova et al., 2010; Edwards, Steele & McGhee, 2010, Yom, Simpson, Arnett & Brown, 2014; Hackney, Clay & James, 2016). A typical drop landing task represents an exclusive landing model without jump phase and it is often adopted in experimental studies and performed in a laboratory environment (Edwards et al., 2010). During the performance of a drop landing task, there is an increased tendency of the lateral motion of the trunk due to the unilateral concentration of the mass of the body, resulting in a high impact force and knee abduction load (Shultz, Schmitz, Tritsch & Montgomery, 2012). The use of drop landing as a benchmark to understand the dynamics of lower limb injury risks is yet to be adequately answered, due to the inability to isolate the critical factors that are related to the whole phase of jump-landing tasks (Edwards et al., 2010). The objectives of drop landing and drop jump performance are centred on the reduction of body momentum to gain stability and increase shock absorption, in order to reduce injury incidence (Shultz et al., 2012).

Studies have adopted drop landing unilaterally (single-leg landing) or bilaterally to monitor kinetics and kinematics of the lower limb. Laughlin et al. (2011), in a study on single-leg drop landing and ACL loading in a group of female participants, reported that verbal instruction on landing technique could significantly reduce ACL loading and improve landing performance. In another study on single-leg drop landing and non-contact ACL injury risks, Ali, Gordon, Robertson and Rouhi (2014) observed that understanding the kinetics and kinematics of non-contact ACL injury risks in vertical and horizontal landing patterns would contribute to injury prevention in their cohort of male athletes. Coventry et al. (2006), in a study on fatigue and SA in unilateral landing, reported that SA was not significantly influenced by the presence of muscle fatigue, despite increased work efficiency in the proximal muscles through greater sagittal kinematics. In another fatigue study monitoring loading post-anterior anterior cruciate ligament (ACL) reconstruction, Lessi and Serrão (2017) reported that greater hip kinematics and increased activation of the lower body muscles (*vastus lateralis, gluteal maximus and biceps femoris*) reduced distal joint loading of the lower limb and ACL.

Drop vertical jump

The first phase of the drop vertical jump (DVJ) involves a maximum horizontal jump to a pre-determined distance from a 30 cm stationary box or platform, followed by a maximal vertical jump to complete the second phase of the task (Bates, Ford, Myer, & Hewett, 2013a). Neuromechanical adaptation of the lower limb to the DVJ poses a unique demand on the body (Shultz et al., 2012). Peak activation of lower limb muscles was reported to be greater in the DVJ than drop landing, although activation time to peak was similar (Shultz et al., 2012). Smith et al. (2012) noted that the assessment of DVJ in multiple dimensions help to detect biomechanical risk factors for lower extremity injuries. The landing error scoring system (LESS), a subjective evaluation to monitor lower limb injury risks utilises the DVJ as its primary assessment tool (Padua et al., 2009; Smith et al., 2012; Cameron et al., 2014).

The DVJ has also been used in intervention studies to monitor kinetics and kinematics changes in landing performance. In a four-week intervention study by Pfile et al. (2013) on landing biomechanics, they reported greater sagittal kinematics at the hip and knee of the experimental groups (plyometric and core stability), and therefore recommended these programmes as a lower limb injury prevention tool. In another intervention study on neuromuscular training and the biomechanics of jumping tasks, Chappell and Limpisvasti (2008) reported that neuromuscular training has the potential to correctly recondition movement pattern and reduce injury risk. A six-week study of core stability training by Araujo, Cohen and Hayes (2015), reported significant reduction in landing forces, thereby also contributing to reduced injury risk. Ford et al. (2005), in a cross-sectional study on the effect of overhead goal performance and landing biomechanics, reported increased vertical jump height and lower limb biomechanical changes. The study, therefore, recommended the use of overhead targets to stimulate maximal explosive effort during DVJs.

Stop-jump

According to Herman et al. (2008), a stop-jump task consists of a four-step approach, a fast self-paced run, double-footed landing and maximum jump. In a cross-sectional study, Chappell, Yu, Kirkendall and Garrett (2002) classified the stop-jump-landing phase into three different forms (backward, forward and vertical jump-landing tasks) to study the kinetics of knee motion in recreational athletes. Another study including athletes investigated the biomechanics of stop-jump landing phase and associated injury risk factors between male and female athletes (Yin et al., 2015). The stop-jump has also been used as a fatigue protocol to investigate lower limb injuries in female athletes (Quammen et al., 2012). A study by Edwards et al. (2012) which compared the influence of horizontal and vertical landing in a stop-jump task on patella tendon loading found that horizontal landing increases the patellar tendon loading more than the vertical landing. A reliability study by Milner, Westlake and Tate (2011) confirmed that the stop-jump is a reliable task for the assessment of knee biomechanics during landing in laboratory-based biomechanical studies.

L. RECOMMENDED LANDING TECHNIQUES

Hopper, Elliott and Lalor (1995) noted that injury incidence in netball usually increase with the level of competition and high incidents of netball injuries are associated with incorrect landing techniques (Hopper, Haff, Joyce, Lloyd, & Haff, 2017). Successful jump-landing training would require a systematic progression of physical conditioning to minimise landing impact (Mothersole, Cronin, & Harris, 2014). Successful execution of correct landing techniques require guidelines (**Table 2.1**), which the coach and athletes could adopt to movement patterns in the pre-season training programme in an attempt to reduce landing related injuries.

Table 2.1: Recommended guidelines for landing

Correct landing	Incorrect landing
Head facing forward	Head facing down
Shoulder parallel	Shoulder asymmetry
Firm trunk control	Lean forward
Greater hip flexion	Hip extension at a peak angle
Knee flexion > 45 deg at a peak angle	Knee extension < 45 deg at a peak angle
Feet apart in alignment with the shoulder	Feet closer than knees
Toes and knees aligned	Knees over toes
Quiet landing without perturbation	Landing with high sound

Source: (Mcgrath & Ozanne-Smith, 1998; Mothersole et al., 2013; Netball Australia, 2015)

M. BAREFOOT VS SHOD

From a historical perspective, the means of survival for early men was to hunt for food by chasing and hunting down animals for food without wearing shoes. It was noted that they could cover a longer distance at the speeds of between 4 - 6.5 m/s on barefoot (Krabak et al., 2011). Interestingly, running barefoot is gradually gaining popularity among runners more especially recreational and long distance runners (Jenkins & Cauthon, 2011). According to studies in anthropology and mechanics of human movement, the human foot is naturally designed to initiate movement and provide support for the bony framework of the body (Wright, Ivanenko, & Gurfinkel, 2012). The composition of the human foot is a complex interaction between ligaments, tendons, muscles and bones, which together give rise to the strong arches that underpin its optimal functioning. This anatomical structure allows pliability and propulsion which is enhanced by elastic energy storage in the muscles (Wright et al., 2012). Two different methods are usually adopted in the evaluation of properties of footwear. The first is the assessment by mechanical impact and the second is the assessment of the shoe during movement (Hamill, 1999).

The use of improper footwear over the short- or long-term may significantly impact on proper development of the foot (Franklin et al., 2015). The kinematics of the ankle joint as well as the arch and toes determine the progression of movement tasks which help to maintain the gravitational factor and movement dynamics (Wright et al., 2012). Considering the foot structure and developmental process, Onwaree (2015) noted that foot structure and anatomy differed significantly between habitually barefoot and shod individual. Structural and functional gait differences are noticed overtime in habitually barefoot walkers when compared with habitually shod walkers across age groups (Franklin et al., 2015). Moreover, Oeffinger et al. (1999) stressed that the degree of flexibility of a footwear determines the extent of stride and step length reduction during walking. This could be explained when examining the interplay of two important factors, which namely; the weight of the footwear and the pendulum-lengthening during the swing phase of gait (Franklin et al., 2015) with the swing phase possibly influencing the joint inertia loading. In contrast to this, research by Tsai and Lin (2013) contradicted the findings that weight of the footwear is a contributing factor to the step and stride length reduction during barefoot walking.

It is widely known that the purpose of footwear is to attenuate impact transmission and minimise the incidence of injury (Thompson et al., 2016). The fundament design of footwear tends to influence the ground reaction forces with stiffness modulation (Shultz et al., 2012), with the dynamic movement characteristics of the foot being altered by the properties of footwear (Onwaree, 2015). A number of studies have challenged the exaggerated cushioning system of traditional footwear, initially thought to prevent injury by reducing impact forces when landing. These studies found that that the cushioning system contributed to the gradual loss of foot proprioceptive motor control and contributed towards an increased risk of injury (Robbins & Hanna, 1987; Robbins & Gouw, 1991; Richards et al., 2009). In addition to these findings, footwear with excessive cushioning has been shown to impact on the biomechanics of natural movements by contributing to an unnatural movement pattern during the push-off phase of gait (Morio et al., 2009). The question of whether the shock-absorbing properties and mobility control mechanism of footwear have been able to prevent foot-related injuries, is yet to be fully answered biomechanically and pathologically (Richards et al., 2009).

Barefoot conditions, barefoot-inspired footwear (Sinclair et al., 2013; Sinclair, 2014; Sinclair, 2016) and minimalist shoes (Schütte, Miles, Venter & Niekerk, 2011; Warne et al., 2014; Hollander et al., 2015) are often used synonymously with one another; a misrepresentation that Nigg (2009) pointed out in his study. He argued that the minimalist shoe only mimics the physical properties of barefoot conditions, but lacks the sensory orientation and functional capacity of the natural condition. The introduction of the barefoot shoe has drawn a number of runners to the diverse experience of running in a pseudo-barefoot modality. Nonetheless, this terminology should be adopted for the market promotional strategy of modern footwear, rather than functional biomechanical terminology for movement science. Till date, a number of potential confounding factors challenge the modern footwear market, namely; the influential mechanism of market positioning, consumer interest, cultural preference and biomechanics of injury risk (Onwaree, 2015).

Scientific evidence of barefoot and shod running

There are divergent schools of thought on the potential benefits of barefoot compared to shod running. Some believe that barefoot running does not belong in modern life, despite it being prominent in the ancient times. A study by Sinclair et al. (2013) in support of this argument, found that the impact generated during running barefoot at 4.0 ms^{-1} could increase the risk of injury. A significant methodological weakness of the study was that all the participants were non-habitual runners, and therefore could not make accurate inferences regarding the risk of barefoot running. Azevedo, Mezencio, Amadio and Serrao (2016) in a 16-week barefoot intervention study for habitual shod runners which involved 20 male and female runners (29.5 ± 7.3), reported a 20.1 % VGRF reduction in shod runners after the intervention. The post-test comparison of barefoot vs shod showed a 22.6 % reduction in the barefoot group. Unfortunately, the study recorded a 70 % dropout rate during the intervention due to fear of injury, incidence of injury and the time requirements. It was concluded that a barefoot intervention could provide potential biomechanical benefits for both habitually barefoot and shod runners in terms of shock absorption, efficient impact distribution, and improved muscle activity.

Warburton (2001) warned that shod runners are constantly exposed to the risk of ankle sprains due to the lack of foot orientation during running. Moreover, shod running increases the risk of plantar fasciitis and other related injuries due to greater shock transmission to the distal muscles of the lower limb. Shod runners have been reported to have a 4 % higher energy cost during running. Even though this reduction may be insignificant to recreational runners, a competitive runner would benefit immensely from energy cost reduction (Warburton, 2001). Oeffinger et al. (1999), in a study on the comparison of gait with or without shoes in children, established that gait analysis in barefoot condition would be adequate for clinical evaluation of orthoses, without the need to include the normative values from the shod condition. The recommendation was based on the close uniformity in the result of their study between barefoot and shod conditions, apart from spatiotemporal variables. Furthermore, peak plantar pressures were also reported to be lower in habitual barefoot walkers, and higher in habitual shod walkers who walked barefoot (Franklin et al., 2015).

There are some populations that should exercise caution when evaluating barefoot running option, as outlined by Warburton (2001). He advised that runners who suffer from conditions that result in poor plantar sensation or peripheral neuropathy in the foot region should be discouraged from barefoot running. Altman and Davis (2016) concluded in their prospective study with 201 barefoot and shod runners, that increases in injury rate among runners is not necessarily associated with barefoot conditions in and of themselves. In some cases, barefoot running might be therapeutic for injured runners and hold protective benefits against complex knee injuries for habitual runners, if properly engaged. However, harshness of weather and environmental debris should be carefully considered when running barefoot due to plantar sensitivity, which might expose the runner to injury (Altman & Davis, 2016). Warburton (2001) identified relative factors that may cause an athlete to train or compete in either barefoot or shod conditions. The first factor was that athletes in developing countries might choose barefoot conditions over shod due to poverty or cultural influences. The second factor was that an athlete who is habitually shod, might not be interested in barefoot training or conditions. The third factor was that the increasing incidence of footwear-associated injury risk might influence the decision of shod runners who are interested in barefoot running.

Barefoot training

Barefoot training could be described as an intervention to stimulate and possibly recondition movement deficiency, musculoskeletal inhibitions and improve motor performance. Despite a large number of studies on barefoot running, there is a paucity of information on barefoot training specifically. Zifchock et al. (2011) proposed that barefoot training for the habitually shod could increase the tendency for reduced levels of lower limb acceleration during movement tasks. Tam, Tucker and Wilson (2016), in a descriptive laboratory study on a barefoot running intervention, reported significant changes among positive responders after an eight-week intervention. The study included 29 habitually shod runners and concluded that implementation of a barefoot program with conscious instruction could reduce running-related injury risk.

Nigg (2009), in a critical review of barefoot biomechanics and related footwear, pointed out that barefoot training could increase the mechanical properties of small and large muscles surrounding the ankle joint. The *Tibialis Anterior* and *Triceps Surae* were identified as large muscles which could respond to flexion-extension movements in the sagittal plane faster than inversion-eversion movements in the transverse plane. In addition to this, the smaller and intrinsic muscle within the foot, stabilize the unstable ankle during dynamic movement with minimal energy dissipation, which is assumed to be beneficial to the performance of athletes. Moreover, it is important to note that barefoot training may recondition the neuromuscular feedback mechanisms, through proprioceptive facilitation initiated from ground contact, to adjust for kinematic error margin at the lower extremities (Robbins & Hanna, 1987; Lieberman, 2012).

The questions of optimal intensity, duration, mode, and type of exercise training that should constitute barefoot training are yet to be scientifically established (Du Plessis, 2011; Mullen, Cotton, Bechtold, & Toby, 2014). However, there are pockets of anecdotal information on transitioning into barefoot running and the specifics of barefoot training related to this transition. Warburton (2001) made a few recommended guidelines for the transition to barefoot activity. In the initial stages, daily barefoot conditions should not exceed 30 minutes. The mode of activity should progress from walking, to jogging, and lastly running, if the progressive adaptation is void of injury. The duration of progression or complete adaptation depends on the individual response to the barefoot condition or training. The period of transition is critical to injury reduction in the barefoot transition process (Lohman, Balan Sackiriyas, & Swen, 2011). According to Warburton (2001), adaptation to barefoot training or running should include structured ankle and foot strengthening exercises to reduce mobility discomfort. This has been supported by a number of studies which confirm that it is advisable not to engage in barefoot activity, without any form of structured barefoot training including a transitioning component (Altman & Davis, 2012; Bonacci et al., 2013; Fredericks et al., 2015).

In his study, Rothschild (2012b) designed a potential training template for the barefoot running transition. According to the study, the first four-weeks should focus on power limb-specific exercises, and 30- minutes low-intensity barefoot activities. The following two-weeks should involve running (almost a mile) at least twice a week. The running surface should be natural or synthetic grass or a rubberized running track. The running distance could be increased by 10 % based on lower limb adaptation, and absence of plantar soreness. Subsequent weeks could follow the same pattern of increase in running distance and intensity. In addition, the study suggested activities and exercises that could enhance the successful transition to barefoot running. The barefoot conditioning activities could involve: walking and running indoor and outdoor on soothing surfaces; drills on running gait; proprioceptive exercises with resistive bands and wobble boards; flexibility exercises involving calf stretches; and strengthening exercises of the foot musculatures and plyometric exercises.

Advantages and disadvantages of the barefoot condition

Despite numerous studies establishing scientific evidence and some clinical boundaries for barefoot and shod conditions, there is no common consensus on the advantages and disadvantages of barefoot conditions. Most of the available information in this regard takes the form of personal experiences, anecdotal reports and cross-sectional studies, rather than longitudinal and controlled laboratory studies which may substantiate the popular claims of the potential benefits of barefoot training. A study by Hollander et al. (2017) in a systematic review of habitually barefoot runners reported reduced ankle dorsiflexion, increased knee flexion, increased foot length and reduced foot width in habitually barefoot compared to shod runners. The study lacks substantial clinical evidence to generate adequate effect sizes for robust conclusions to be drawn on barefoot and shod pathology. Moreover, habitually barefoot has been defined in different studies as a minimum of three years barefoot experience (Arulsingh & Pai, 2015), no shoe experience (Sim-Fook & Hodgson, 1958; Rao & Joseph, 1992; Echarri & Forriol, 2003; Mei et al., 2015) and more than 50% running and walking barefoot (Lieberman et al., 2010; Goss & Gross, 2012; Lieberman et al., 2015), which makes it somewhat difficult to standardize.

Foot pathology and morphology

As for foot pathology and morphology, Sim-Fook and Hodgson (1958) reported a lower incidence of fallen arches (flat feet), bunions and hallux rigidus in habitually barefoot Chinese fishermen (n = 107) who had never worn shoes. A study by Rao and Joseph (1992) which corroborated these findings also reported a lower incidence of fallen arches among habitually barefoot children (n = 745, 4 – 13 years). Arulsingh and Pai (2015) in a study which involved male and female runners, observed that habitually barefoot runners (n = 51, 19.4 ± 2.6) had a lower incidence of lower limb deformities, but a higher rate of foot pathologies when compared with habitually shod runners (n = 177, 21.9 ± 3.5). Thompson and Zipfel (2005) in a cross-sectional study (n = 60) on barefoot practice from childhood to adulthood among women from different racial background in South Africa, observed that increases in foot width could not be solely attributed to barefoot condition. The study suggested that genetics could also account for the foot morphology. However, Shu et al. (2015) in a study which involved habitually barefoot male and female runners (n = 168) who had been running barefoot from childhood, reported a reduction in foot length but increase in foot width, suggesting that foot morphology is not only genetically determined. D'Aout, Pataky, De Clercq, and Aerts (2009) also observed similar results in self-reported habitually barefoot walkers. They were of the opinion that walking barefoot might be more beneficial for healthy individual than for athletes, who need shoe for training and performance. However, they suggested barefoot training for athletes and the use of footwear that is non-stiff and comfortable for performance.

Gait retraining

Studies have shown the potential of barefoot training in improving the mechanics of both walking and running gait (Rothschild, 2012b). Spatiotemporal variables of step length (Lythgo, Wilson, & Galea, 2009; Moreno-Hernández et al., 2010), stride length (Oeffinger et al., 1999), stride time (Wolf et al., 2008; Lythgo et al., 2009), stance time (Zhang, Paquette, & Zhang, 2013) and double support time (Lythgo et al., 2009) have been shown to be reduced in barefoot conditions. Conversely, swing time (Moreno-Hernández et al., 2010) and cadence (Wolf et al., 2008; Wirth, Hauser, & Mueller, 2011) increase in barefoot conditions. Further support for these findings was presented by Tam, Tucker and Wilson (2016) who reported improvements in running gait and performance following a barefoot training intervention. Zhang, Paquette and Zhang (2013), in a study comparing the effect of different types of footwear (flip-flops, sandals, barefoot and shoes) on gait biomechanics, reported that ankle plantarflexion ROM in the barefoot condition was lower when compared with shod conditions. Forefoot landing and plantarflexion angle at contact have also been commonly reported among runners in barefoot interventions.

Impact force reduction

Lieberman et al. (2010) reported that during barefoot running, landing impact is attenuated and joint loading is reduced as a result of the changes in the kinematic pattern of running. A later study supported these findings, where it was reported that barefoot runners generated lower ground reaction forces than shod runners during landing (Jenkins and Cauthon, 2011). Thompson et al. (2016) added that traditional footwear used by runners are designed to reduce shock transmission as a result of repetitive ground contact, which might contribute to the incidence of running related musculoskeletal injuries. Sinclair et al. (2013), in a study on the influence of barefoot and barefoot-inspired footwear on the kinetics and kinematics of running in comparison to conventional running shoes, reported that the shock absorbing materials of conventional running shoes are superior to barefoot or barefoot-inspired shoes

Decreased incidence of injury

Hryvniak et al. (2014) in a descriptive study which involved 509 runners, reported that most of the participants perceived barefoot running as a mode of correcting running mechanics and a means to improve performance. Some of the participants confirmed seeing improvements on the deficits present from previous lower extremity injuries, whilst most of the participants reported no acute or chronic injuries after adopting barefoot running. An ethnographic study conducted by Warnock (2013) on barefoot running reported that some barefoot runners transitioned from shod running to barefoot running due to health issues or injury. The study added that other runners transitioned from minimalist to barefoot running due to a sensational need, connecting with nature or satisfaction derived from running unshod. Although barefoot running is associated with a number of positive outcomes, there are also indications of injuries that have occurred among habitually barefoot runners, which includes plantar surface injuries (Altman & Davis, 2016), Achilles and peroneal tendinitis (Arulsingh & Pai, 2015).

Other

Lieberman et al. (2010) found that barefoot running helps to activate and increase the strength of four layers of muscles in the foot as well as greater utilization of the lower leg muscles, which are underutilized in a shod condition. However, barefoot running or intervention has been reportedly characterised by minor discomfort at the initial stage (Tam, Tucker & Wilson, 2016). For instance, lower limb muscle pain or soreness were linked with the adverse reaction after barefoot running (Rothschild, 2012a; Schütte, 2012; Kaplan, 2014). Rixe, Gallo, and Silvis (2012) in a review study, anecdotally proposed that there was a possible tendency for runners to adapt to running surfaces in barefoot more than shod condition. In a way, this claim was supported earlier by Robins and Waked (1997), but was later considered as an injury risk by Nigg (2009) and Saxby (2011). Nonetheless, it was claimed that barefoot training could recondition the neuromuscular feedback through proprioceptive facilitation initiated from ground contact (Robbins & Hanna, 1987; Lieberman, 2012) to adjust for kinematic faulty movement at the lower extremities. Rixe, Gallo, & Silvis (2012) also identified that plantar sensory stimulation during ground contact could increase the feeling of running rhythm and soft landing.

N. SUBJECTIVE EVALUATION

Subjective evaluation is drawn from the theory of subjectivity which expounds on the reality created through perception (Mathison, 2005). Over the years, biomechanical studies have adopted qualitative assessment to: broaden general knowledge or perspective on subject-matters; validate clinical findings from philosophical standpoints; and provide hands-on easy to use tool derived from proven quantitative findings, as an alternative to controlled laboratory study. For instance, the perception of barefoot running has been studied with thematic analysis (Walton & French, 2016) and ethnography research design (Warnock, 2013). In the same vein, landing error scoring system (LESS) has been adopted by several studies, as a clinical assessment tool to identify athletes at the risk of injury (Padua et al., 2009; Smith et al., 2012; Cameron et al., 2014).

Landing Error Scoring System

The risk factors associated with lower limb non-contact injuries tend to occur in more than one plane of movements. Therefore, a well-designed clinical assessment of jump-landing tasks needs to be all-encompassing, involving quantitative and qualitative assessments of lower limb injury risks (Padua et al., 2009). Different studies have adopted various subjective tools to evaluate lower limb risk of injury (Kinchington, 2010; James et al., 2016; Zazulak et al., 2016; Venter, Masterson, Tidbury, & Krkeljas, 2017). In line with this, LESS was designed as a two-dimensional clinical subjective landing technique assessment tool with biomechanics related items to identify potential for non-contact ACL injury risk through drop vertical jump-landing task (Padua et al., 2009; Kowata, 2014; DiStefano et al., 2016). Items on the instrument are formulated to identify kinematics that could predispose an individual to lower limb injuries (Kowata, 2014). In a clinical setting, the instrument could be used to distinguish between individuals who are susceptible to the risks of lower limb injuries (Padua et al., 2011). It could also be used to monitor and design effective injury prevention and rehabilitation programme. The video analysis and subjective evaluation of the drop vertical jump are characterised by a two-dimensional assessment of trunk and lower limbs movement at initial contact and peak flexion, as well as range of motion (Smith et al., 2012).

The LESS as a clinical tool has been reported to be valid in a cohort study conducted by Padua et al. (2009). The study concluded that the LESS could be used to monitor the risk of the ACL injury, and for the development of injury prevention programmes for an athlete or a sports team. The study associated high LESS scores with poor landing style, which is characterised by minimal flexion of the knee, hip and trunk, increased knee valgus and hip internal rotation in two-dimensional planes. Due to the clinical relevance of LESS, it has been modified as a musculoskeletal assessment tool in different studies as LESS-RT (Padua et al., 2011) and iLESS (Cortes & Onate, 2013) for more suitable application to the methodology of the respective studies.

Padua et al. (2009) reported excellent inter-rater (0.84) and inter-rater (0.91) reliability with two raters for LESS. The study concluded that LESS is a valid and reliable non-contact injury risk assessment tool. These finding were supported by Kowata (2014) who reported high intra-rater (0.96) and inter-rater (0.97) reliability with two raters (1 expert and 1 novice). Smith et al. (2012) in a case-control level three evidence study, which involved 5 047 male and female high school and college students, reported high intrarater (0.97) and interrater (0.92) reliability with two raters. The study did conclude however, that ACL injury could not be reliably predicted by the LESS instrument (**Table 2.2**).

Table 2.2: Reliability of LESS

Authors	Rater and Reliability	Statistical Procedure and Result
Padua et al. (2009)	2 raters Interrater reliability: $ICC_{2,k}$ (0.84 ± 0.71) Intra-rater reliability: $ICC_{2,1}$ (0.91± 0.42)	Quartile: 4 quartiles, representing excellent (LESS score, < 4), good (LESS score > 4 to ≤ 5), moderate (LESS score > 5 to ≤ 6), and poor (LESS score, > 6) One-way analysis of variance: $\chi 2$ = 116.80, df = 3, P < .001.
Padua et al. (2015)	2 raters Interrater reliability (Ref Padua, Marshall, Boling, Thigpen, Garrett & Beutler, 2009)	Fisher test and Confidence Intervals ROC had five as the optimal cut point with sensitivity of 86 % (95 % CI = 42 %, 99 %) and a specificity of 64 % (95 % CI = 62 %, 67 %). Uninjured participants had lower LESS scores (4.43 ± 1.71) than injured participants (6.24 ± 1.75; t_{1215} = -2.784, P =.005).
Root et al. (2015)	1 rater (Reliability values not reported)	ANOVA and CI Group significance difference for the LESS score ($F_{2,83}$ = 3.48, P =.04). IPPs resulted in a greater improvement in LESS score than the SWU (group difference (-0.83 ± 0.33; 95 % CI = 1.47,-0.18) and the DWU (-0.67 ± 0.337; 95 % CI = -1.34,-0.002)
Smith et al. (2012)	2 raters Interrater reliability: $ICC_{2,k}$ (0.92 ± 0.59) Intra-rater reliability: $ICC_{2,1}$ (0.97 ± 0.45)	Conditional logistic regression: No significant relationship between LESS and risk of ACL as a continuous variable (combined group, p =.32). No significant relationship between LESS and risk of ACL as a categorical variable (combined group, p =.35).
Kowata (2014)	2 raters Interrater reliability: $ICC_{2,k}$ (0.97 ± 0.99) Intra-rater reliability: $ICC_{2,1}$ (0.96 ± 1.00)	Repeated measure ANOVA The LESS scores on each task were significantly different (p < 0.001; F = 53.94) between the DVJ and JS (effect size (ES) = 1.94), DVJ and RB (ES = 0.95), and JS and RB (ES = 1.45)
Onate, Cortes, Welch and Van Lunen (2010)	2 raters (1 expert, 1 novice) Interrater reliability: ($ICC_{2,1}$ = .835, P < .001)	Phi correlation coefficient analysis and Kappa statistical analysis
Wesley, Aronson and Docherty (2015)	Not reported	2 X 2 Repeated measure analysis of variance LESS scores: No significant test-by-sex interaction ($F_{1,34}$ = .25, P = .62). Women scored significantly higher on the LESS (6.3 ± 1.8) than their male counterparts (4.9 ± 2.2), regardless of time. Overall, post-exercise scores were significantly higher than Pre-exercise scores (mean difference = 1.3, 95 % CI = 0.8, 1.8).

ICC = *Intraclass Correlation Coefficient,* χ^2 = *Chi-Square*, **df** = *Degree of freedom,* **ROC** = *Receiver Operating Characteristics,* **IPP** = *Injury Prevention Programmes*, **DWU** = *Dynamic Warm-Up,* **SWU** = *Static Warm-Up,* **ACL** = *Anterior Cruciate Ligament,* **DVJ** = *Drop Vertical Jump,* **RB** = *Rebounding,* **JS =** *Jump Stop-jump Shot*, **ES** = *Effect Size*

Barefoot subjective experience

Studies have shown that physical activity participation in barefoot conditions still requires further scientific clarification with respect to injury risk and its impact on healthy living (Robbins & Hanna, 1987; Hart & Smith, 2008; Nigg & Enders, 2013). In majority of the cases, participation in barefoot running or barefoot interventions, results in some minor discomfort at the initial stages. In a barefoot intervention study, Du Plessis (2011) adopted a four-item open-ended questionnaire to evaluate the perceived level of discomfort after participation in barefoot intervention programme by well-trained university netball players. The study reported that most of the participants experienced initial discomfort which later diminished in the course of the intervention. In another study, Rothschild (2012a) adopted 26-item of an open and closed-ended questionnaire to examine 785 runner's interest and participation in barefoot and shod running. Even though the study reported lower limb muscle pain or soreness after barefoot running, most of the young elite runners had increasing level of interest in barefoot or minimalist running. Hryvniak et al. (2014) in a descriptive study, which involved 509 runners and used 10-item barefoot running questionnaire, reported that most of the participants perceived barefoot running as a modality to correct running mechanics and improve performance. Surprisingly, most of the participants experienced no injury or injury risk while transitioning to barefoot running.

Lower limb comfort index

The lower limb comfort index (LLCI) is a relatively new subjective clinical instrument concept designed for football players (Kinchington, 2010), and which has been adopted for rugby players (Kinchington, Ball, & Naughton, 2011) as well as recreational runners (Schütte & Venter, 2013) and recreational distance runners (Dreyer, 2014). The instrument is a subjective monitoring tool for players or athletes to assess lower limb adaptation (pain or comfort zone) during training or exercise. The instrument specifically monitors anatomical segment of the foot, ankle, shin, knee, calf-Achilles complex and the footwear. A high LLCI score could be a very good predictor of lower limb injury risk reduction (Kinchington, 2011). The LLCI is based on a clinical standpoint that pain is a stimulus response to the interaction between the sensory neuron (nociceptive) and the brain (cerebral cortex). The relevance of LLCI is based on the need to create a record for monitoring the multiple anatomical site comfort of the lower limb over a possible period of injury occurrence (Kinchington, Ball & Naughton, 2010). Therefore, it is important to give adequate attention to pain occurrence during training or the intervention programme to avoid the progression of an acute condition to a chronic injury or deformity. Kinchington, Ball and Naughton (2010) proposed that data collected through the instrument could be integrated into injury prevention and recovery programmes. However, Dreyer (2014) reported limitation in some of the items of the LLCI. For instance, the athletes for the study perceived pain related to the foot region (the foot and footwear) as non-specific to the point of origin. In the same vein, the pain which occurred between calf and Achilles was not specified as a point of interest in the instrument.

Summary

Subjective evaluation was drawn from the theory of subjectivity. Involving the perception of athletes in the design of an injury prevention programme is pertinent to the success of the programme. Injury prevention tools should be adopted based on the needs of the sport or the team. Even though participation in physical activity in the barefoot condition is characterised by minor discomfort at the initial stage, physical adaptation to the condition is possible. However, care needs to be taken, if the environment is not barefoot-friendly or there is health challenge that could be aggravated.

O. NETBALL

Netball is one of the most prominent sports among the Commonwealth nations (Thomas, Comfort, Jones, & Dos'Santos, 2017), mostly played by women. It is an explosive, high-intensity female team sport (Hopper, Lo, Kirkham, & Elliott, 1992), which involves a change of direction with leaps and hops to beat the opponent and aim at making a goal (Hopper, Haff, Joyce, Lloyd & Haff, 2017). The duration of the game includes four quarters of 15 minutes each, with three minutes rest after each interval (Thomas et al., 2017). A break of five-minutes rest is given for the half-time. The game is played by two teams, with seven players on the court from each team throughout the game. The players, tactically and technically, play from different specific positions on the court, which include centre court, goal shooting and defensive players (**Figure 2.3**). The centre (C), wing attack (WA) and wing defence (WD) are centre court players. The goal attack (GA) and goal shooter (GS) are goal scoring players. The goalkeeper (GK) and goal defence (GD) are defenders (Thomas et al., 2017).

The rationale for biomechanical studies in netball, is to reduce injury risk and to enhance performance. Studies on netball have focused on the kinetics of foot deceleration (Steele & Lafortune, 1989), factors which impact on landing GRFs (Mothersole et al., 2013), biomechanical factors influencing performance (Steele, 1993) and knee joint loading sequence (Stuelcken, Greene, Smith, & Vanwanseele, 2013). Pass variation, ball trajectory, ball delivery (two hands, right, left), landing pattern (right, left, bilateral symmetry, bilateral asymmetry), movement pattern (hop, leap, jump, skip/run, planted), footfall (fore, hind, out, plant) and other related factors informed biomechanical questions in netball (Hopper, Lo, Kirkham, & Elliott, 1992; Mcgrath & Ozanne-Smith, 1998).

Risk factors for injuries in netball

The game conditions in netball are characterised by movements which are commonly associated with injury risks for female athletes (Mcgrath & Ozanne-smith, 1998). Generally, female athletes are at higher risk of anterior cruciate ligament injury than male athletes due to the unique female anatomical features (Mendiguchia et al., 2011). In addition, they are more prone to greater trunk displacement, hip flexion, hip adduction and hip internal rotation during movement tasks (Mendiguchia et al., 2011). The trauma of injury and potential loss to a college female athlete range from immobility, disengagement from the team, absence from classes and unstable academic experience, to psychophysiological stress and physical deterioration (Mcgrath & Ozanne-smith, 1998).

Hopper, Elliott and Lalor (1995) noted that injuries in netball usually increase with the level of competition, and a high incidence of injury is associated with incorrect landing techniques (Hopper, Haff, Joyce, Lloyd, & Haff, 2017). Hopper and Elliott (1993) earlier identified that there appears to be a relationship between back problems and foot pathomechanics in netball players. There is a greater tendency for the musculoskeletal framework of the lower back to be exposed to injury (Hopper & Elliott, 1993) if the high magnitude of impact generated during ground contact is not well-attenuated by the lower-limb joint complex. In addition, Steele (1986) stressed that strains or tears to the tissues of the joint during a game would be a significant contributor to lower limb injuries.

Generally, the ankle (58 %) and the knee (22 %) are regarded as the most common sites of injury in netball (Hopper & Elliott, 1993). This finding was corroborated by Greene et al. (2014) who observed that knee and ankle injuries, with the accompanying painful losses, are a common phenomenon in the game of netball. Steele (1986) identified excessive ankle inversion, which is caused by strain to the lateral ligaments of the ankle, as the most common cause of ankle injury in netball. It was added that excessive knee rotation in a weight bearing condition could also lead to the damage of tissues and ligaments of the knee joint. Steele further stressed that the anatomical design of the knee is to flex and extend, with only a very limited capacity for rotation. Knee rotation beyond anatomical limits may cause the cruciate ligaments (anterior or posterior) to rupture. Hip abduction and knee joint loading have been associated with a high incidence of ACL injury in female athletes (Ford & Mclean, 2005).

In a five year descriptive epidemiological study of netball injuries during competition, which involved 11,228 netball players, Hopper et al. (1995) reported 84 % ankle injuries (67 % of the injuries were classified as lateral ligament sprains) and 8.3 % knee injuries (1.8 % were classified as ACL ruptures). The categories of the injury reported by the study were ankle related injuries (peroneal tears, fracture lateral malleolus, fracture medial malleolus, fracture of cuboid/1st metatarsal and fracture base of 5th metatarsal); knee related injuries (ACL, lateral and/ or medial meniscus, medial collateral ligament, lateral collateral ligament and patella subluxed or dislocated); muscle related injuries (lower leg muscle strain, lower back muscle strain and quadriceps haematoma); upper limb related injuries (shoulder joint-rotator cuff and elbow ligament/dislocation/fracture) and finger-related injuries (digital joint sprain/fracture). Figure 2.3 shows that most of the injuries occurred at the defensive zone followed by the attacking zone.

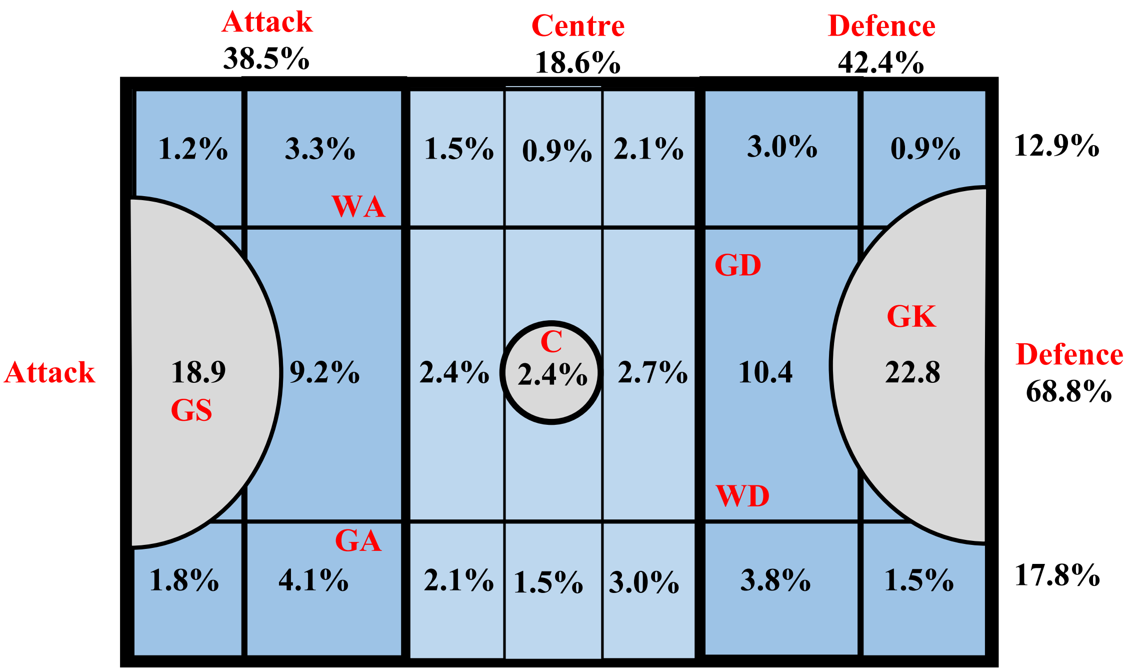


Figure 2.3: Location of netball injury on the court and player positions (in red) (Source: Hopper et al., 1995)

Intrinsic and Extrinsic factors of injuries in netball

Injuries in netball are multifactorial, with research by Hewett, Lindenfeld, Riccobene, & Noyes (1999) examining the multifactorial interaction between hormones, musculoskeletal components, and years of sports participation, and how this interaction could lead to a high incidence rate of knee injuries in female athletes. In the context of the current study, the researcher will elaborate on the surface selection, footfall pattern, footwear, footwork rules, pass variations, ankle bracing and footwear as extrinsic factors, as well as fatigue, pre-season conditioning, rehabilitation and recovery and neuromuscular technique as intrinsic factors (**Table 2.3**).

Table 2.3: Intrinsic and extrinsic factors of injuries in netball

	Extrinsic factors	Intrinsic factors
1	Footfall pattern	1. Fatigue
2	Surface selection	2. Pre-season conditioning
3	Footwork rules	3. Neuromuscular technique
4	Pass variations	
5.	Ankle brace	
6.	Footwear	

Source: Mcgrath & Ozanne-smith (1998)

Footfall pattern

Steele (1988) noted that players landing on the heel of the foot generated more initial peak vertical forces than players landing on the forefoot, which tends to increase the risk of injury to musculoskeletal structures. According to the study, footfall pattern did not influence the vertical force experienced seeing that no significant differences were reported in the magnitude and/or timing of VGRF, or initial peak VGRF, of players who landed on the heel versus those that landed on their forefoot. Players who landed on the forefoot after receiving a high pass showed significantly lower maximum vertical forces, maximum vertical force rates of loading, initial peak vertical forces and braking forces. However, there was no significant difference in maximum braking forces for both conditions (forefoot and heel landing) after landing. Even though, there were no significant differences among the force variables in footfall conditions, a number of studies have confirmed greater vertical forces in heel landing (Shih, Lin & Shiang, 2013; An, Rainbow & Cheung, 2015, Thompson, Seegmiller & McGowan, 2016).

Surface selection

Like most other sports, netball has evolved over the years from its primitive beginnings to a technically and scientifically complex sport, where natural elements are controlled in an attempt to reduce the risk of injury (Mcgrath & Ozanne-smith, 1998). In recent times, netball has been played on synthetic rubber, concrete, bitumen, synthetic grass and timber surfaces (Mcgrath & Ozanne-smith, 1998). There is a link between surface selection and the incidence of injury, despite the rise in biomechanically modified footwear and orthotics manufactured for the specific surfaces (Mcgrath & Ozanne-smith, 1998). In a recent study, Schütte et al. (2016) reported that surface variability has the potential to alter spatiotemporal stability of the trunk during running. Langeveld, Coetzee, and Holtzhausen (2014) observed a higher incidence of netball injuries occurred on concrete rather than synthetic surfaces, even when controlling for the fact that more games are played on synthetic surface. In addition, 15 % of the 1 280 players from the three tournaments in South Africa that participated in the study, sustained one or more injuries during the season. Walker and Subic (2010) confirmed that the composition of sports surfaces, which commonly consists of multilayer structures, has the unusual ability to interfere with players' behavioural disposition during the game situation. Mcgrath and Ozanne-smith (1998) noted that there is greater tendency for increased shock transmission and greater joint loading, when netball is played on concrete which would reaffirm the findings of the studies above.

Footwork rules

The technique for receiving a pass in netball is governed by footwork rules, which constrains the players to sudden bilateral or unilateral landing (Stuelcken et al., 2013), being restricted to no more than one and half steps before pass delivery (Hopper, Lo, Kirkham, & Elliott, 1992). A player in possession of the ball would not take another step with the pivot or landed foot to avoid a footwork rule violation (Mcgrath & Ozanne-Smith, 1998). The rule has been found to subject the netball players to increasing braking force and muscle activity (Walker & Subic, 2010), which increases the magnitude of the loading on the lower limbs. Furthermore, the rules subject the players to rapid pass distribution and quick movement, thereby increasing the intensity of the game (Thomas et al., 2017).

Pass variations

Hopper et al. (1992) identified four different passes in netball, which include; straight, loop, bounce and rebound. Otago (2004) observed that pass variation could influence the force acting on the body and the landing pattern (**Figure 2.4 and Figure 2.5**). In a study on the effects of a change in passing height on the mechanics of landing in netball, the players demonstrated significantly lower braking forces when receiving a high pass (2.7 times a person's BW) compared to standard pass (3.1 times a person's BW) (Steele, 1988). The study reported no significant differences in time to maximum braking forces. The magnitude of the average peak VGRF reported was 4.5 times a person's BW when receiving a standard pass and 5.4 BW for a high pass. There were significant differences between the force formation and techniques used at landing from both passes, which in turn influenced the ground reaction forces generated at landing. The high pass technique was therefore recommended by the study to prevent injury associated with high braking forces. Otago (2004) recommended more running and passing in a game situation than leg planting and bilateral landing, considering it places less load on the joints of the lower extremities.

Figure 2.4: Bongiwe Msomi (Spar Proteas captain) receiving a high pass (Source: <u>www.bona.co.za/bongiwe-msomi-love-netball/</u>)

Figure 2.5: Erin Burger (Proteas Netball Club Centre) landing on the heel unilaterally while receiving a pass (Photo credit: Caldecott, Reg)

Ankle bracing

Hopper, McNair and Elliott (1999), in their study on landing in netball noted that biomechanics of landing pattern, could not be influenced by bracing the ankle joint. In contrast, Greene, Stuelcken, Smith and Vanwanseele (2014) reported that ankle bracing can reduce range of motion, without altering the loading on the joints of the lower limb. Mason-Mackay, Whatman, Reid and Lorimer (2016) in their study on the effect of ankle bracing on landing biomechanics in female netballs, concluded that ankle bracing increases joint stiffness, and may increase injury risk in netball players. Brizuela, Llana, Ferrandis, and Garcia-Belenguer (1997) noted that ankle protection could increase the tendency of limited ankle mobility and increased shock transmission to the body, which would impact on injury risk. Contradictory evidence was provided by Hopper et al. (1999) in their study with fifteen netball players, where it was reported that bracing, taping and range of motion at the foot-ankle complex did not alter vertical ground reaction forces. Janssen, van Mechelen, and Verhagen (2014) reported that ankle bracing has more potential than neuromuscular training in lower limb injury reduction of non-injured athletes. Therefore, the use of ankle brace requires more controlled trial studies to clarify the clinical implications.

Footwear

The composite and mechanical properties of footwear intricately influence shock attenuation (Hamill, 1999). Footwear that is not mechanically designed for a specific sport may be subjected to a displacement limit or bottom out, if the repetitive impact force exceed the shock absorbing system (Edwards, 2000). Shock absorbing footwear and ground surface condition influence both the magnitude of impact forces (Hart & Smith, 2008) as well as the rate of loading (Steele, 1986). Footwear has the capacity to influence the ground reaction forces with the aid of stiffness modulation (Shultz et al., 2012). Richards, Magin, Callister and Richards (2009) questioned the assumption that the exaggerated cushioning system of traditional running footwear reduces the level of impact and thereby prevents injuries. The rate of force loading at landing could largely be affected by shoes and shoe inserts. Therefore, players should be encouraged to wear footwear capable of attenuating force at landing during training or competition (Steele, 1986) without biomechanical constraints to subsequent movement. Finally, Onwaree (2015) noted that dynamic movement characteristics of the foot can be altered by the properties of footwear.

Fatigue

According to Bishop et al. (2006), the rate at which shock is attenuated by the lower limbs could be affected by muscle fatigue. Tamura et al. (2016) reported that during a single leg landing, there is a greater tendency to increase angular velocity within the knee to attenuate landing shock at the onset of fatigue. The study revealed an inverse relationship between fatigue and shock attenuation. Bishop et al. (2006) observed that the activity of the muscles involved in landing cannot be isolated in understanding the biomechanics of shock absorption at a joint, and need to be seen as an integrated system. Gross (1988) earlier reported in a study on the shock attenuation role of the ankle during landing from a vertical jump, that asymmetry in landing pattern of a fatigued athlete has the potential to generate higher impact forces. Research by Coventry et al. (2006) disputed this fact, with their research showing that even though the lower limbs play a major role in the attenuation of forces generated at landing, this role cannot be said to be altered by the presence of fatigue in the muscles of the lower limbs.

Pre-season conditioning

Physical conditioning is a prerequisite for the game of netball due to the high level of physical demand and game techniques required by the players (Thomas et al., 2017). It has been widely reported that conditioning programmes for athlete could lead to a reduction in injury risk (Heidt et al., 2000; Dollard, Pontell, & Hallivis, 2006; Thomas et al., 2017). According to the recommendation by Faigenbaum (2001), players should be encouraged to adopt lifestyle-related physical activities during the pre-season period as the foundation for conditioning, in addition to other components which culminate to physical readiness for sports participation. The components of field-based physical fitness conditioning for netball could consist of skinfold assessment, stop jump, countermovement jump, drop jump (0.3m), single hop, 5- and 10-m sprint, modified 505 change of direction speed (CODs), isometric mid-thigh pull, 1 RM back squat and $30\text{-}15_{IFT}$ (Intermittent fitness test) (Thomas et al., 2017). Mothersole (2013) noted that a strength and conditioning programme should not only focus on performance improvement, but also injury prevention.

Neuromuscular technique

Neuromuscular control plays a significant role in the prevention and reduction of ACL injury (Ericksen et al., 2016). The ability to derive benefit from the adaptations in neuromuscular control in order to reduce the risk of injury, requires neuromuscular training. Neuromuscular training is a form of injury prevention, which has the potential to biomechanically reduce landing impact forces and physiologically increase hamstring to quadriceps ratios (Hewett, Lindenfeld, Riccobene, & Noyes, 1999). The potential of neuromuscular training in injury prevention and management has been widely reported (Myer, Ford, Palumbo, & Hewett, 2005; Myer, Chu, Brent, & Hewett, 2008; Myer, Sugimoto, Thomas, & Hewett, 2013; Suglmoto, Myer, McKeon, & Hewett, 2014).

Injury prevention programme

Training programmes and the competitive demands of netball need to be evaluated to adequately measure the risk of injury (Hopper & Elliott, 1993). Langeveld, Coetzee and Holtzhausen (2014) were of the opinion that coaches need to be educated on the implementation of injury prevention programmes in order to reduce the number of ankle and knee joint injuries in netball. Programme design should not only focus on performance improvements, but also on injury prevention (Mothersole, 2013). Effective injury prevention programmes should be designed to identify individuals in the team who may be susceptible to injury (Smith et al., 2005). The programme should be designed to allow for gradual progression an appropriate adaptation to training stimuli (Mothersole, 2013). Nessler, Denney and Sampley (2017) identified age, biomechanics, compliance, dosage, exercise variety and feedback as cardinal principles of injury prevention programmes.

The components of training programmes need to adequately cater for the athletes' needs with respect to performance and prevention of injury, as well as preserving the collective responsibility of the team. Hewett, Lindenfeld, Riccobene and Noyes (1999) reported a reduction in the incidence of knee injuries after a six-week plyometric injury prevention training programme which involved 366 female athletes. The study showed that untrained female athletes are more likely to experience knee injury than trained female athletes. It was claimed that dynamic stability of the knee joint after the intervention might be responsible for the reduction in injury incidence among the trained female athletes. Understanding the dynamics of landing mechanics for injury prevention and performance enhancement, would require profiling all the components of ground reaction forces (Mothersole, 2013).

Neuromuscular training is a form of injury prevention, which has the potential to biomechanically reduce landing impact forces and physiologically increase hamstring to quadriceps ratios (Hewett et al., 1999b), and is associated with the prevention and reduction of ACL injury (Ericksen et al., 2016). Hopper et al. (2017) emphasized that a well-designed neuromuscular injury prevention programme will lead to improved knee kinematics and decreased landing forces. Neuromuscular training programmes designed to reduce trunk, hip and knee joint loading and control for knee abduction, can significantly reduce the incidence of injury (Mendiguchia et al., 2011). A randomized study conducted by Hopper et al. (2017), showed that the inclusion of resistance and plyometric training in neuromuscular injury prevention programmes, can significantly influence the attenuation of landing impact in young netball players (Nessler et al., 2017).

Elphinston and Hardman (2006) evaluated injury prevention programmes from a multidisciplinary team approach (MDT), which involved collaborative efforts from the players, sports medicine personnel, coach and other stakeholders. MDT significantly increased players' compliance to injury prevention programmes, reduced rate of injury in commonly reported sites (neck, shoulder, lower back, knee and ankle) and assisted with the players' ability to manage interpersonal conflicts. Down to Earth (D2E) is another injury prevention programme designed to teach safe landing techniques (Saunders et al., 2010). The programme was implemented with a RE-AIM (Reach Effectiveness

Adoption, Implementation, and Maintenance) approach framework. The training programme was accepted as a valid and reliable injury prevention programme by 85 % of the junior netball coaches who participated in D2E. Aside from injury prevention, components of D2E also enhance athletic performance and safe execution of fundamental skills. The coaches agreed that young and upcoming players would benefit more from the programme as an injury preventative measure. The KNEE (Knee injury prevention for Netballers to Enhance performance and Extend play) programme was designed and adopted by Netball Australia as injury prevention programme in the game of netball (Netball Australia, 2015).

P. SUMMARY

Landing is a fundamental skill in netball. Good landing skills are characterised by well-coordinated lower limb kinematics and kinetics, therefore evaluating biomechanical dimensions of landing is essential to movement dynamics. The rationale of biomechanical studies of landing in netball is to prevent the occurrence of common injuries and to enhance performance. There is a greater tendency for the musculoskeletal framework to be affected, if the high magnitude of impact generated during ground contact is not attenuated by the lower extremities. Integration of neuromuscular training and correct landing technique with an injury prevention programme have the potential of preventing injuries which could be traumatic, devastating and performance-threatening.

CHAPTER THREE

METHODOLOGY

A. INTRODUCTION

This chapter describes the study design, participants, research procedures, measurements and tests used in the study. Details on the research study intervention, as well as the statistical analyses of the data, are also presented in this chapter.

B. STUDY DESIGN

The experimental design adopted for the study was a pretest-posttest randomized groups design, in accordance with the research objectives and hypotheses. The sample size was determined by using the GPower® 3.1 software program (Kiel, Germany). Based on a priori analysis, a potency of 0.80, $\alpha = 0.05$ was adopted (means of two independent groups, non-sphericity correction of one and an effect size of 0.95). The analysis of statistical power was conducted to reduce type II error probability, and to determine the minimal number of subjects necessary for this investigation. Therefore, 30 participants were found to be sufficient and recruited to participate in the study to mitigate the effects of an experimental drop-out rate. All participants who met the inclusion criteria were randomly assigned to the experimental (EXP) and control (CON) group (**Figure 3.1**).

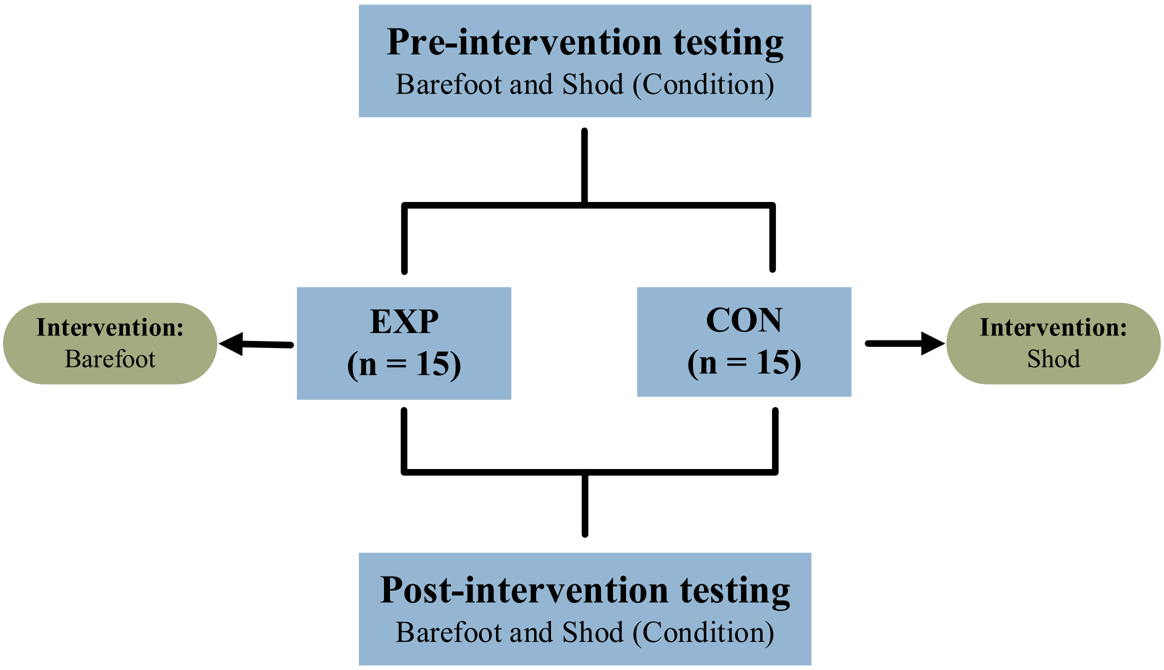


Figure 3.1: Study design flow chart. EXP represents Experimental and CON represents Control

C. PARTICIPANTS

Participants were recruited from the netball club of Stellenbosch University (SU). All the participants for the study were part of the same high-performance group and have previous league experience. Participants were included in the study if they (a) were within the age range of 18 to 24 years old; (b) had completed the pre-season strength and conditioning programme of the club; (c) had played in the national league or regional competitions. Participants were excluded from the study if they (a) had any known history of metabolic, neurological, or cardiovascular disease; (b) had any confirmed diagnosis of patellar tendinitis; (c) had any recent (~ 6 months prior) barefoot training experience; (d) had a confirmed diagnosis of a balance disorder.

D. RESEARCH PROCEDURES

Permission to conduct the study was obtained from the Chief Director of Sport at SU as well as the club manager and the head coach of the Maties netball squad. Participants volunteered to be part of the study of their own volition. Prior to the commencement of the intervention, the participants were thoroughly briefed on the protocol in two sessions at club meetings. The testing procedures were explained, described and demonstrated to the participants by the researcher. Written consent to participate in the testing was completed and submitted by each participant (**Appendix A**). A personal information sheet (**Appendix F**), physical activity readiness questionnaire (**Appendix C**), pre-participation health and history screening questionnaire (**Appendix D**) and previous barefoot experience questionnaires (**Appendix E**) were completed by each participant before the commencement of the intervention. A timetable was drawn up, in collaboration with the netball manager, to accommodate each participant's free time for testing.

The pre- and post-testing took place at the CAF Neuromechanics laboratory, Tygerberg Campus, Stellenbosch University (**Figure 3.2**). On arrival at the Neuromechanics laboratory, the participants were informed about the general rules of the laboratory for safety and precaution. Anthropometric measurements of standing height and body mass were taken as part of the baseline measurements. After a 5-minute netball-specific dynamic warm-up, a wireless inertial motion capture system (IMSC; MyoMotion Research Pro, Noraxon USA Inc.) was firmly attached with a fixation strap, double-sided adhesive tape and elastic straps to the lower body of each participant (**Figure 3.4**). An additional three sensors were attached to the upper thorax, lower thorax and pelvis to capture the movement of the upper body as well as lumbopelvic region (**Figure 3.5**). Prior to testing with the IMCS, the participants were briefed on the data capturing protocol which involved calibration (synchronisation of the IMCS) after the completion of each trial and instant feedback if any of the sensors accidentally dislodged or the device malfunctioned. The calibration procedure involved standing upright on a platform, with feet equidistant to shoulder width, and palms facing forward, in the standard anatomical position. The participant was asked to maintain this position without moving until the calibration process was completed. The calibration process was monitored by the researcher through the IMCS graphic user interface (GUI). The successful initialization of IMCS synchronises any movement by the participants with the IMCS avatar (animated skeleton).

Following the successful calibration of the IMSC, participants performed both unilateral and bilateral jump-landing tasks on the force plate (FP9060 model, BERTEC® Corp, Worthington, USA). The jump-landing tasks involved a single-leg drop landing right (SLR), a single-leg drop landing left (SLL), a drop vertical jump (DVJ) and the stop-jump performance task (SJPT). All the participants, irrespective of their group, went through the pre-testing in barefoot (BF) and shod (SH) condition. The pre-testing conditions were randomized, with a 5-minute rest period in-between (change over condition) to avoid carryover and fatigue effect (**Figure 3.3**)

Once all participants had completed the pre-testing procedures, they took part in a six-week intervention programme, consisting of three sessions per week (18 sessions). The volume of the training sessions was progressed in time from 10 minutes to 45 minutes per session. Both groups went through the same intervention programme which consisted of a strength and conditioning programme with netball-specific drills. The EXP group performed the sessions in BF conditions, whereas the CON group used their usual netball training shoes. Further details on the training sessions for both groups including the netball-specific drills are described later in this chapter.

All the players in the research squad performed their usual pre-competition netball training. The research had to be conducted within the timeframe and functioning of the club without causing too much disruption. At the commencement of the intervention period, the head coach requested the CON group to perform a single additional weekly strength and conditioning training session in the gymnasium at SU. Being part of a club setting for research adds to the ecological validity of the study, although the additional training of the CON group was an unforeseen development. Following the completion of the intervention period, the participants underwent post-testing for the same outcome variables that were obtained in the pre-testing. In order for participants to be eligible for post-testing, they needed to have attended at least 70% of the training sessions (~15 training sessions out of 18 training sessions). The participants completed the mLLCI questionnaire to determine their adaptability to barefoot training. The participants were also given a questionnaire on their personal experience of the intervention.

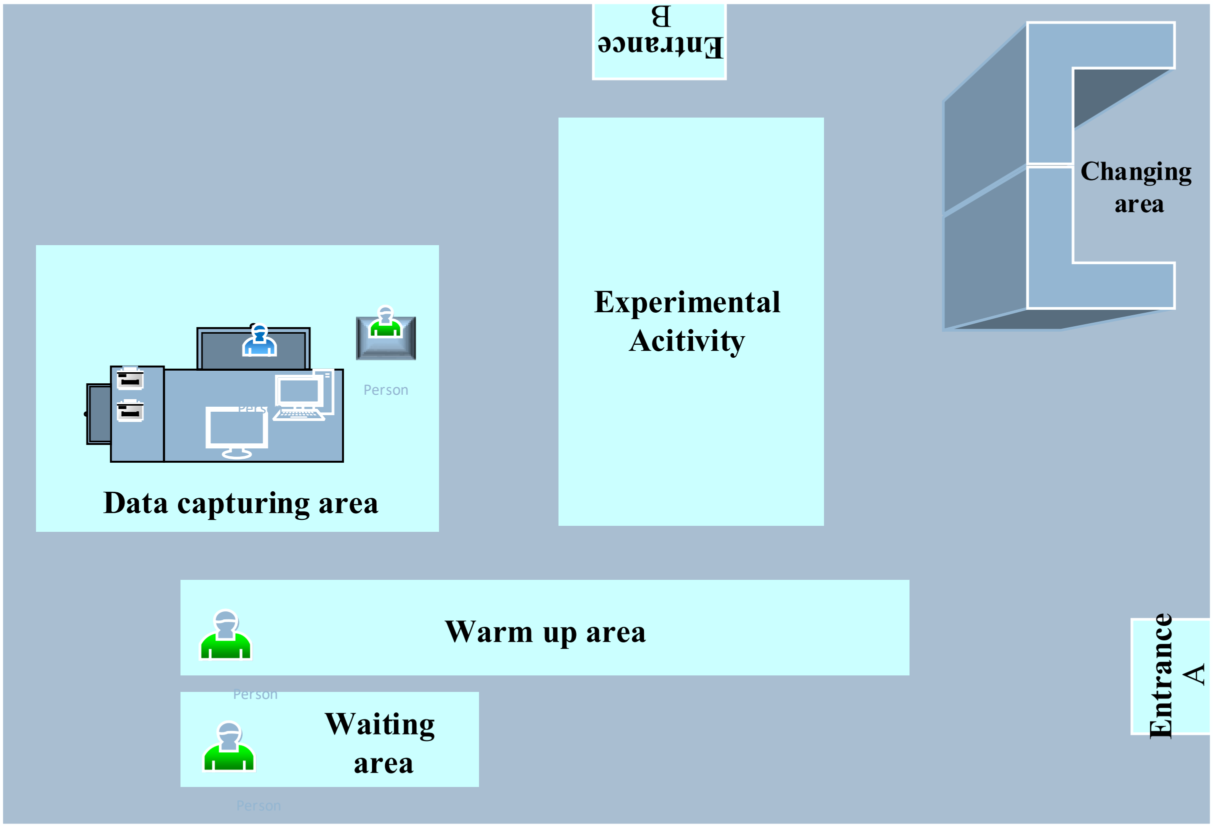


Figure 3.2: The laboratory layout for data collection

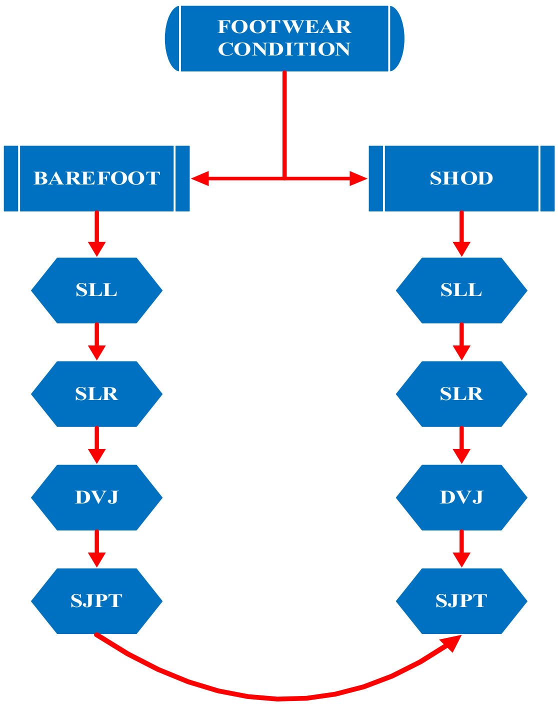


Figure 3.3: Schematic layout showing one of the randomized order of jump-landing tasks in both conditions

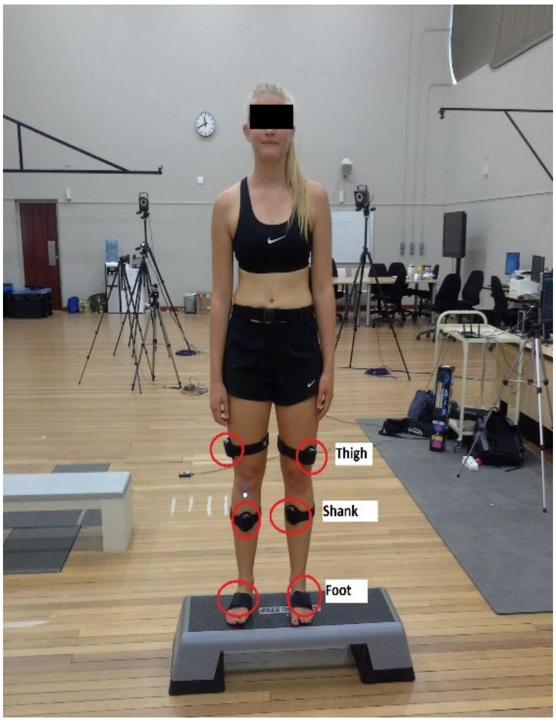


Figure 3.4: Anterior view of a participant with sensors (thigh, shank and foot) ready for calibration on 30 cm box (Photograph by Jaiyesimi B.G)

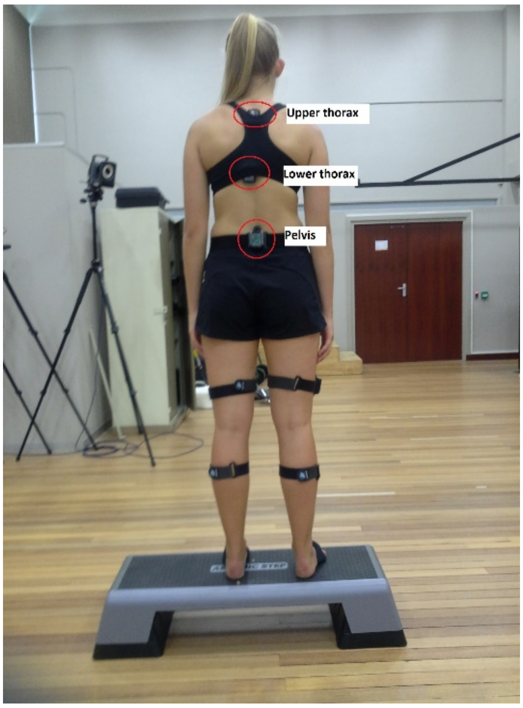


Figure 3.5: Posterior view of a participant with sensors (upper thorax, lower thorax and pelvis) ready for calibration on a 30 cm box. (Photograph by Jaiyesimi B.G)

E. MEASUREMENTS AND TESTS

Anthropometry

Basic anthropometry measurements of standing height and body mass were obtained as baseline measures in the study. The measurements were taken according to the recommendations of the International Standards for Anthropometric Assessment (ISAK) (Stewart, Marfell-Jones, & Olds, 2011) by a qualified Biokineticist with experience in anthropometric assessments. The standing height measurements were taken with each participants standing erect with the heels together and buttocks touching the stadiometer (Seca®, model 213, Germany). Once aligned in Frankfort plane with the orbitale and tragus on the horizontal plane, the participants were asked to inhale maximally, with the measurement being taken at the highest point of the skull (vertex). The measurement was recorded to the nearest whole number in centimetres (cm). The body mass measurements were taken with each participants standing erect, with light-weight clothing, with body mass equally distributed, and looking straight ahead. Measurements were taken with a calibrated electronic scale (Salter®, model 9106, Kent, UK) rounded off to 0.1 kilograms (kg).

Jump-landing tasks

The jump-landing tasks consisted of unilateral and bilateral landing patterns. The unilateral landing patterns included a single-leg drop landing right (SLR) and a single-leg drop landing left (SLL). The bilateral landing patterns included a drop vertical jump (DVJ) and the stop-jump performance task (SJPT). The platform from which all participants performed the various jumps was set at 30 cm (Thompson et al., 2017). A total of 24 jumps were performed by each participant. The breakdown of the jump-landing tasks is presented in **Table 3.1.**

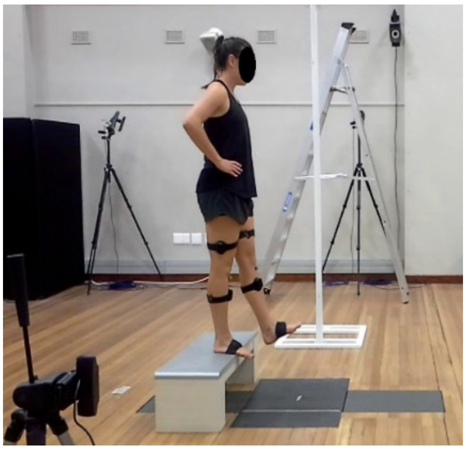
Table 3.1: Jump-landing tasks

	Conditions	SLR	SLL	DVJ	SJPT	Total	Overall
1	BF (trials)	3	3	3	3	12	24
2	SH (trials)	3	3	3	3	12	

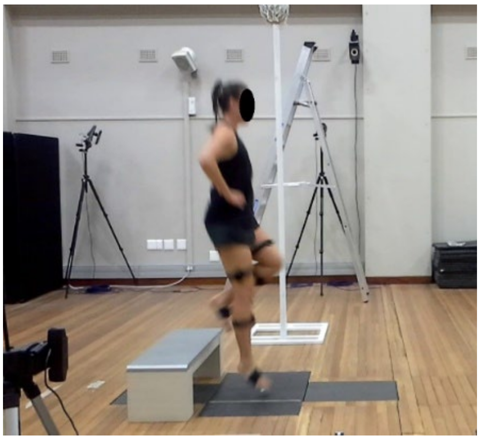
BF represents Barefoot, SH represents Shod, SLR represents, single-leg drop landing right, SLL represents single-leg drop landing left, DVJ represents drop vertical jump, SJPT represents stop-jump performance task

Single-leg drop landing

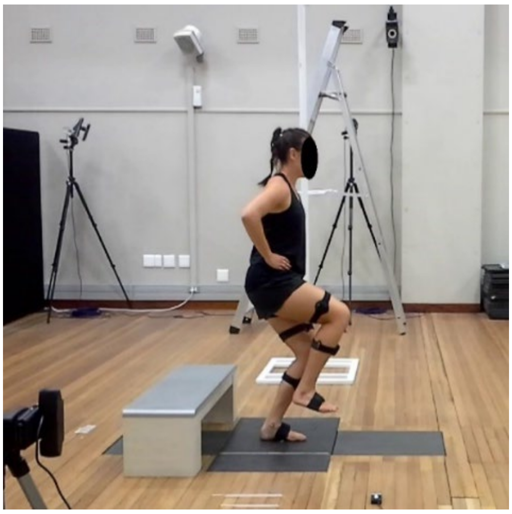
Single-leg drop landing, also known as unilateral landing involves moving the body completely away from the base or platform of support and landing on either the left or right leg (**Figure 3.6**). Lavipour (2009) reported unilateral landing as the most common form of jump-landing in netball, accounting for 67% of the cases. Fransz, Huurnink, de Boode, Kingma and van Dieen (2016) described single-leg drop landing as a test for static and dynamic abilities in landing. During the trials, the participants were instructed to stand on the platform with hands on their hips, shift the lead landing leg off the base of support, drop from the platform onto to the force plate, maintain balance for 10 seconds and avoid contact with the contralateral limb (Wernli, Leo, Phan, Davey & Grisbrook, 2016; Nordin & Dufek, 2017). Each of the participants in both groups performed three trials per leg, randomizing the order between BF and SH conditions (Thompson et al., 2016). Munro, Herrington and Carolan (2012) reported an ICC of 0.75 for single-leg drop landing reliability.



(a)



(b)



(c)

Figure 3.6: Participant executing single-leg drop landing (a) ready position (b) flight phase (c) landing phase (Photograph by Jaiyesimi B.G)

Drop vertical jump

For the drop vertical jump (DVJ), participants were required to perform a forward jump from the platform, landing with both feet simultaneously on the force plate, with an immediate transition into a countermovement jump with maximal effort and vertical velocity. The movement ended with a bilateral landing on the force plate (**Figure 3.7**). The distance from the edge of the box to the force plate was set as 50% of each participant's standing height (Smith et al., 2012). This type of jump has been adopted by several studies to monitor, validate and evaluate biomechanics of jump-landing in related sports (McNair, Prapavessis, & Callender, 2000; Fox, Bonacci, McLean, Spittle, & Saunders, 2016). Each participant in both groups performed three trials of the DVJ in BF and SH conditions. Munro, Herrington and Carolan (2012) reported an ICC of 0.88 for DVJ reliability. The DVJ was also used in the evaluation of the landing error scoring system (LESS).

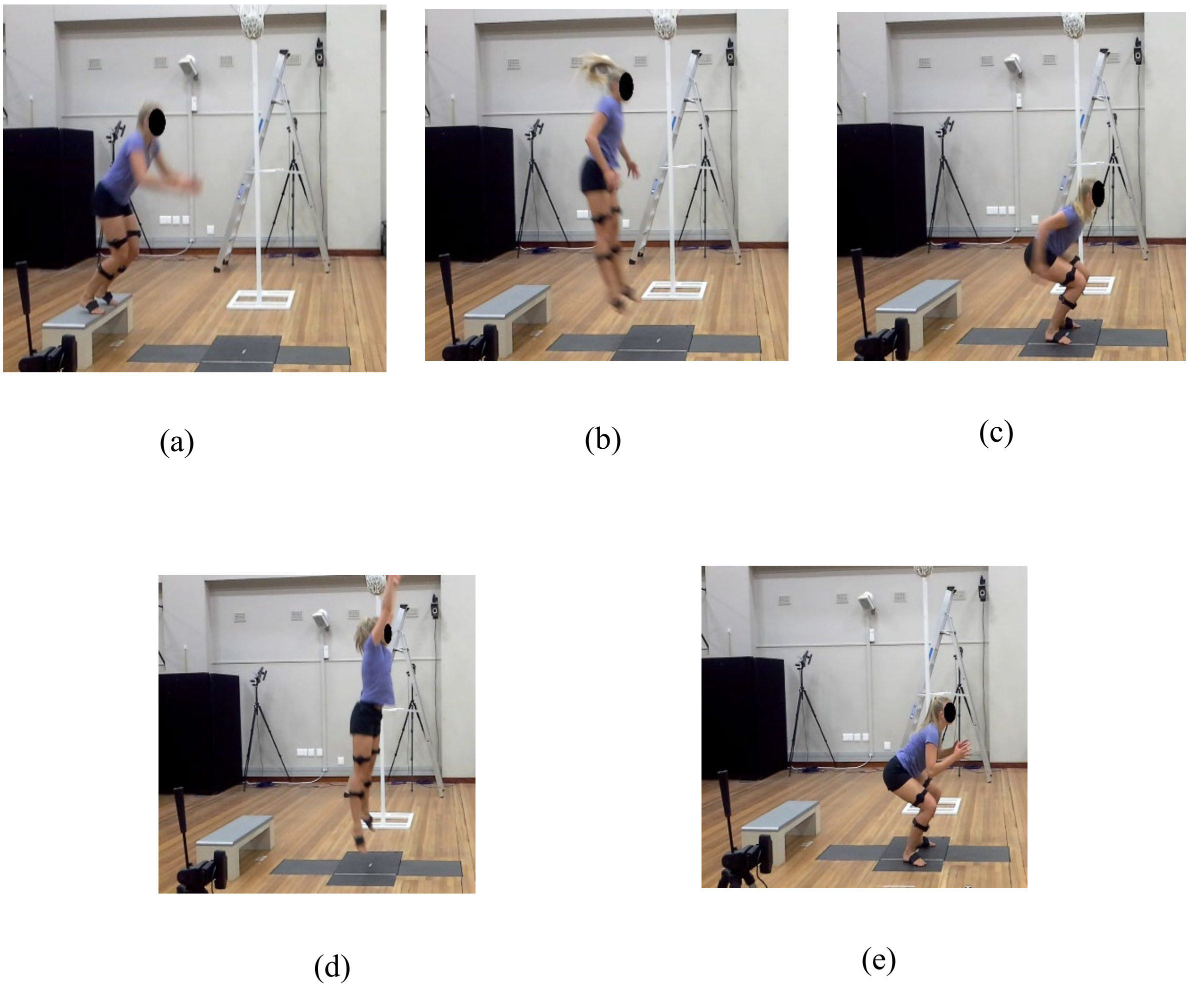


Figure 3.7: Participant executing drop vertical jump at the beginning of different phases (a) take off phase (b) first flight phase (c) first landing phase (d) second flight phase (e) and second landing phase (Photograph by Jaiyesimi B.G)

Stop-jump performance task

Stop-jump performance task (SJPT) was designed to simulate game-like conditions that involve dynamic movements such as acceleration to receive a high pass and landing. The SJPT is a modified form of the stop-jump (Chappell, 2005; Fong et al., 2014). According to Herman et al. (2008), the stop-jump task consisted of a four-step approach, a fast self-paced comfortable run, followed by a double-footed landing. Milner, Westlake and Tate (2011) confirmed that the stop-jump is a reliable task for the assessment of knee biomechanics during landing in laboratory-based biomechanical studies with between-session ICC of 0.69 – 0.96 and within-session of 0.63 – 0.88. The SJPT for this study involved self-paced acceleration, as well as the jump, flight and landing phase (Lin et al., 2008).

The task required the participant to land either unilaterally on their preferred leg, or bilaterally, to reduce the tendency of an unnatural landing style in response to sport-specific movement.

Each participant accelerated on an 8 m runway, decelerated and stopped on the force plate, jumped to contact the suspended ball with two hands, and landed on the force plate once again (**Figure 3.8**). Each participant in both groups performed three trials of the SJPT in the BF and SH conditions. Trials, not well-captured due to the dislodgement of the sensor, wrong execution of the jump or improper landing on the force plate were discarded and repeated until the correct movement was performed. An adjustable upright netball apparatus was used for the suspension of the ball (**Figure 3.9**). The height of the upright was 3.2 m with a ring circumference of 5 cm. The height of the suspended ball was set relative to the submaximal explosive jump of each athlete. The following equation was derived by the researcher to calculate relative height (RH):

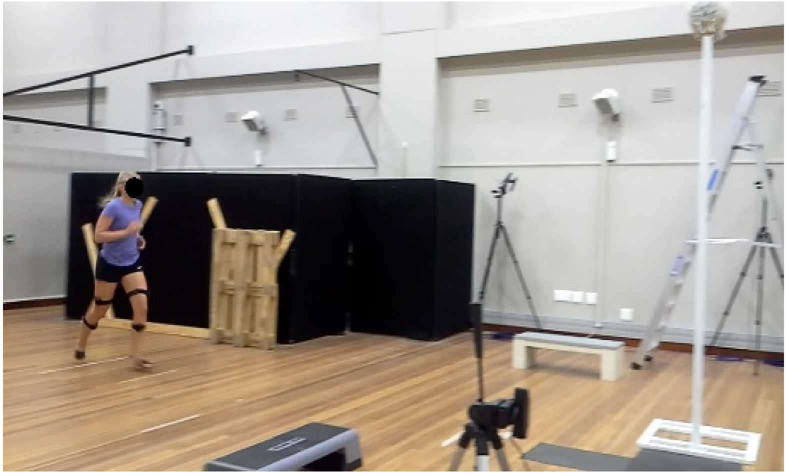
$$RH = \left[Sh\ (cm) + \frac{Sh(cm)}{2}\right] - 10\ cm \qquad (1)$$

RH represents Relative Height; Sh represents Standing Height; cm represents centimetre

This equation was derived by the researcher to account for jump height differences of the participants since no study was found with the equation for stop-jump with a target goal. Four volunteers were used to collect pilot data for the equation. After the equation was derived, the reliability was calculated using SJPT pre-test flight time data to test for internal consistency. The reliability was high as calculated by Cronbach Alpha (α = .70). **Table 3.2** was generated with Relative Height (RH) values and placed in categories. The RH data values were categorised into 10cm interval in four categories and each category was tested for reliability.

Table 3.2: Stop-jump performance task categorized into the relative height

	Categories	Values (cm)	α	Qualitative outcome of α
1	Low	< 245	.71	High
2	Medium	> 245 ≤ 255	.63	Moderate
3	High	> 245 ≤ 265	.67	Moderate
4	Super high	> 275	.46	Low



(a)

(b)

(c)

(d)

Figure 3.8: Participant executing stop-jump performance task at the beginning of different phases (a) approach run (b) first landing phase (c) flight phase (d) and second landing phase (Photograph by Jaiyesimi B.G)

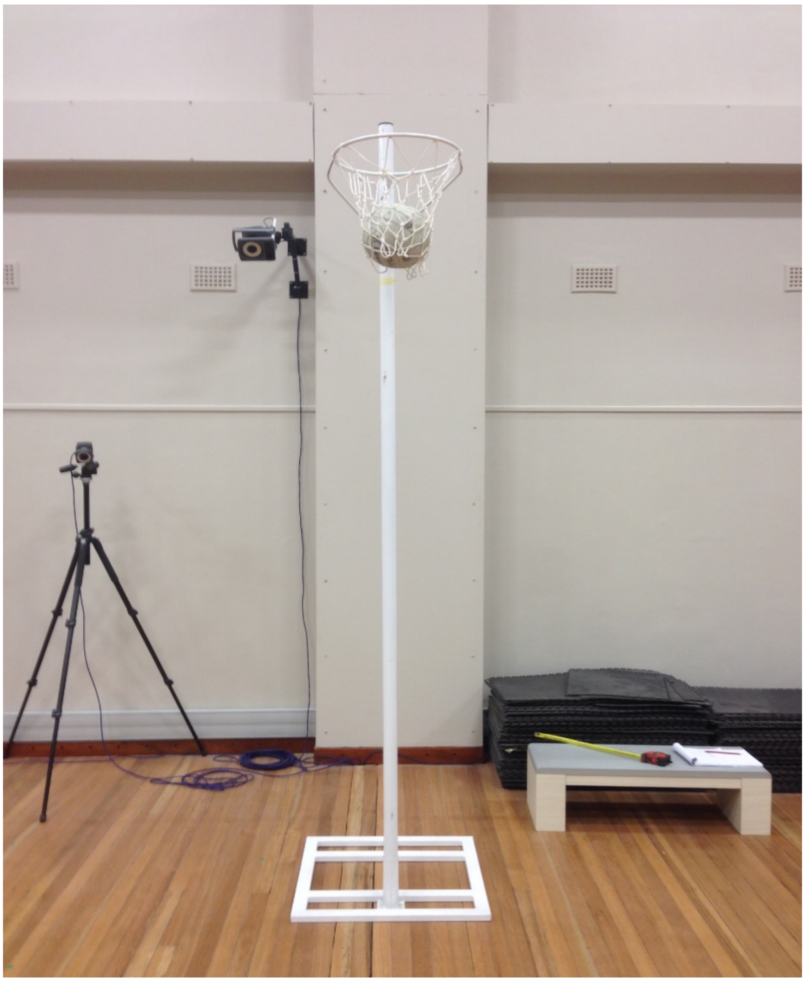


Figure 3.9: The adjustable netball upright with the movable base, netball ring and netball suspension net (painted in white) (Photograph by Jaiyesimi B.G).

Kinetic variables

Kinetic variables for the study included ground reaction forces, time to peak ground reaction forces and shock attenuation (SA).

Ground reaction forces and time to peak

Ground reaction forces (GRFs) are commonly measured with a force plate (Yeadon & Challis, 1994; Divert et al., 2005). Generally, it is described as the force generated when the body segment makes contact with the ground. The force plate sampling at 1000 Hz was used to measure components of GRFs and time to peak ground reaction forces (GRFtp) with the Analogue & Digital Amplifier AM6800. The analogue data were digitally converted using the analogue input board AIS. The force plate was permanently fixed and flushed with the floor surface to ensure safe landing and reliable data capturing. Active peak force was considered for each of the force-magnitude variables (x, y, z). Force-time was taken from the signal rise to the active peak under the force curve. The vertical, anteroposterior and mediolateral planes represent the three component vectors (x, y, z) in measuring ground reaction force. GRFs for landing are expressed in terms of body weight (BW). The magnitude of the following force components was extracted for the study: peak resultant force (PRF), vertical ground reaction force (VGRF), mediolateral ground reaction force (MGRF), anteroposterior ground reaction force (AGRF). The time to peak components of these variables was also extracted (PRFtp, VGRFtp, MGRFtp, AGRFtp).

Shock attenuation

Shock attenuation (SA) is the process by which the magnitude of the impact caused by the collision between the foot and ground is reduced (Applequist, 2012). Mathematically, it is the measure of the reduction of the impact peak acceleration between two segments. Shock attenuation was measured at 200 Hz with a multi-segment IMCS (Myomotion Research Pro, Noraxon USA Inc.) (**Figure 3.10**). The SA for the current study focused on the lower extremities and lower back and was measured at the hip (hip_{SA}), knee ($knee_{SA}$) and ankle ($ankle_{SA}$). The following formula by Applequist (2012) was used to calculate SA:

$$SA\ (\%) = 100\left[1 - \frac{Peak\ segment\ A}{Peak\ segment\ B}\right] \quad (2)$$

The peak segment is defined by the position of the IMCS sensor on the anatomical segment of the body. According to Gross and Nelson (1988), the use of accelerometers for non-invasive shock attenuation is widely supported with a high level of validity and reliability (0.74 - 0.96).

Figure 3.10: Single unit of myoMotion IMU sensor

Kinematic parameters

Kinematic parameters of impact peak acceleration, initial contact angle, peak angle and range of motion were measured for the study. The anatomical angles were recorded in real-time by the IMCS system. The IMCS system software (MR3 3.10.64) was utilized for data collection and pre-processing. Kinematic data were displayed in real-time using a 3D avatar to monitor the experimental procedures (**Figure 3.11**).

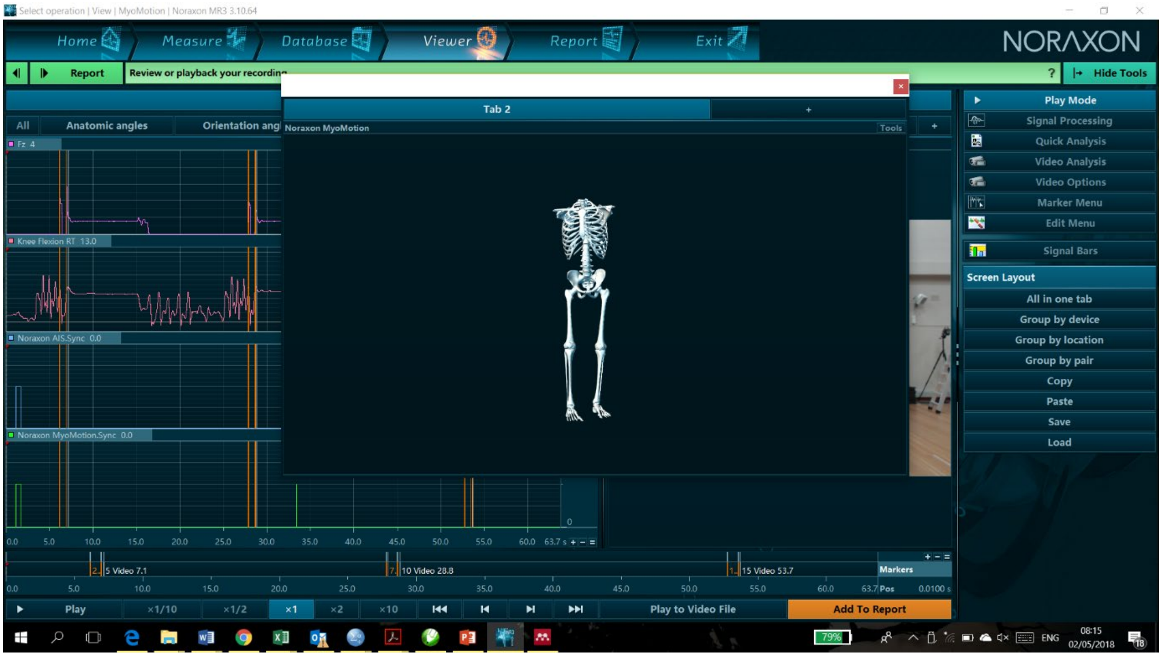


Figure 3.11: MR3 software graphic user interface displaying the 3D avatar and the signal reading of motion capture (Screenshot captured by Jaiyesimi B.G)

Impact Peak Acceleration

The impact peak acceleration was obtained at the pelvis ($pelvis_{accl}$), thigh ($thigh_{accl}$), shank ($shank_{accl}$) and foot ($foot_{accl}$). The signal processing was set to low-pass Butterworth at 60 Hz cut off frequency (Zhang et al., 2008). Choukou, Laffaye, and Taiar (2014) reported a tri-axial accelerometer with a high level of validity and reliability (0.74 - 0.96) (**Figure 3.12**).

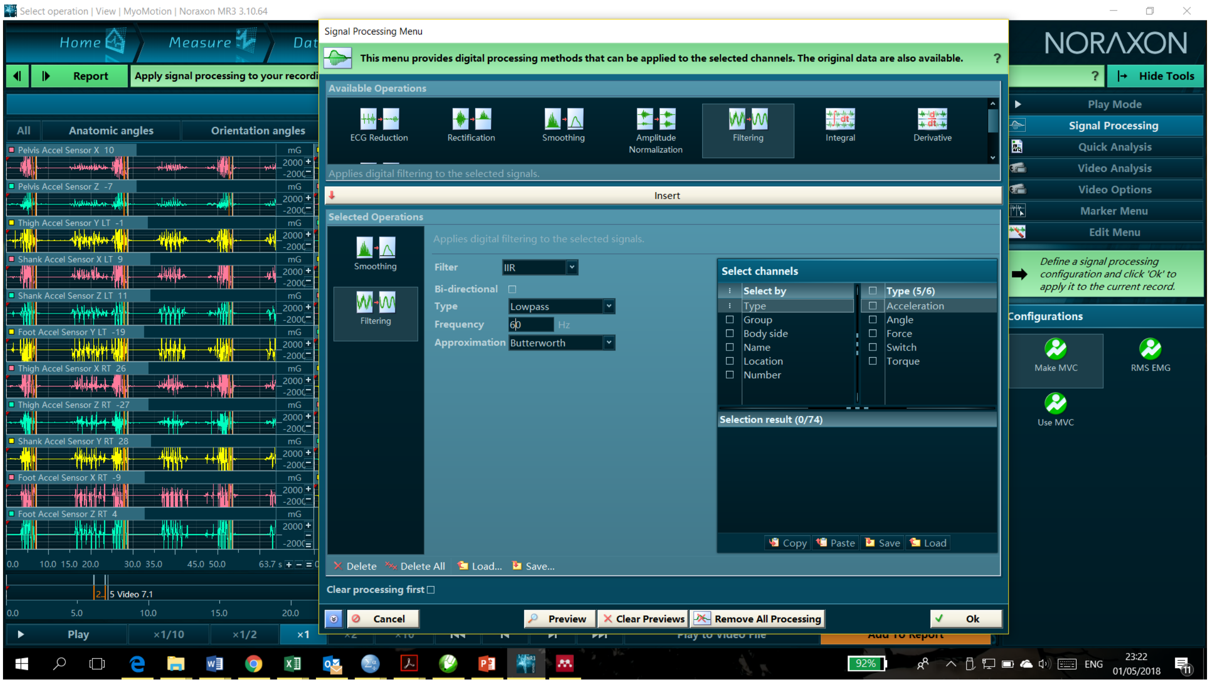


Figure 3.12: MR3 software graphic user interface for signal processing (Screenshot captured by Jaiyesimi B.G)

Initial contact angle

To determine the time of landing for identifying the initial contact angles, a rise in the VGRF (z) of above 10 N was used (Mitchell et al., 2008). Lumbar flexion, hip flexion, hip abduction, knee flexion, knee abduction, ankle dorsiflexion, ankle inversion and ankle abduction were measured and extracted at the initial contact from the jump-landing tasks for the study.

Peak angle

The peak angle was defined as the angle at which the VGRF reached the maximum true peak which is between the initial contact and 50 % of the stance phase (Quammen et al., 2012). Lumbar flexion, hip flexion, hip abduction, knee flexion, knee abduction, ankle dorsiflexion, ankle inversion and ankle abduction were measured and extracted at the peak angle.

Range of motion

The range of motion (ROM) was defined as the difference between an initial contact at touchdown, and maximum angle during the landing phase (Zhang et al., 2005). Hip flexion, hip abduction, knee flexion, knee abduction, ankle dorsiflexion, ankle inversion and ankle abduction were measured and extracted for the study.

Subjective Evaluation

Landing Error Scoring System

The Landing Error Scoring System (LESS) is a subjective evaluation instrument designed for injury risk assessment and to identify individuals with poor jump-landing technique (Padua et al., 2009). The instrument focused on foot orientation, trunk, hip and knee displacement in the sagittal and frontal plane and the overall landing performance. The scoring system is used for evaluating landing errors in the DVJ (Padua et al., 2009).

The LESS provides a relatively easy and inexpensive method of risk assessment. It has been shown to have a high level of validity and reliability (0.72 - 0.81) in identifying faulty movement patterns (86% sensitivity and 64% specificity) (Padua et al., 2011; Dai et al., 2015). Two video cameras (Logitech c920 cameras, 800 x 600 resolution, 30 FPS) were positioned to record jump-landing performance in the sagittal and frontal planes. The cameras were placed perpendicular to the frontal and sagittal planes. They were time-synchronised with the IMCS and force plate data to capture the experimental activities in real-time for post-analysis. Reflective markers were placed on the anterior superior iliac spine, patella and medial malleolus for 2D measurement analysis. The post-analysis videos of three trials of DVJ in BF and SH conditions were extracted from MR3 software. The video files were imported into the 2D motion analysis software (Kinovea ® 0.8.15) to be used by trained raters for the LESS analysis procedure.

LESS is usually scored by trained raters (Onate, Cortes, Welch, & Van Lunen, 2010; Smith et al., 2012). For this study, four novice raters (postgraduate Sport Scientists) were divided into two groups (two raters in a group). The raters were trained (two sessions of one hour each) on the kinematic analysis of movement with the 2D motion analysis software (**Figure 3.13**). They were also trained (two sessions of one hour each) on the interpretation and scoring of the LESS instrument. The scoring was categorised into various categories, namely: excellent (≤ 4), good (> 4 to ≤ 5), moderate, (> 5 to ≤ 6) and poor (> 6) (Smith et al., 2012). The scoring evaluates the quality of the landing kinematics and the code is between 0 and 3 (**Appendix H**). The lower the score the better the landing performance. Cohen's Kappa coefficient ($_k$) was used to report the ICC. Intra-rater reliability was reported as moderate (0.67).

Figure 3.13: A training session for the raters

Subjective experience of barefoot activities

Following the completion of the intervention, the participants completed a customized 3-item open-ended questionnaire, providing subjective feedback on their barefoot intervention experience (**Appendix I**). The questionnaire contained questions on their best and worst experience of the barefoot intervention. The participants were also asked if they would be interested in future barefoot intervention.

Modified Lower Limb Comfort Index scale

The risk of barefoot activity was monitored with the Modified Lower Limb Index Scale (mLLCI). Hart and Smith (2008) recommended that the implementation of barefoot training programme should be supported with an injury monitoring journal to compare current progress and incidence of injury frequency with the previous history. The scale was adapted from the Lower Limb Comfort Index scale (LLCI) by Kinchington (2011). The LLCI is a subjective scale designed to monitor lower limb comfort and rehabilitation progress of an athlete in the case of injury. It was originally designed and validated for football players (Kinchington, 2011) and was adapted for endurance runner transitioning to minimalist shoes (Schütte, 2012). Each item on the scale represented the average of both left and right side.

The mLLCI was completed by each participant independently to avoid group influence and bias (Schütte, 2012). The instrument was completed after the first eight sessions (March), the following eight sessions (April) and the last two sessions (May). The comfort descriptor was used to monitor the barefoot transition programme. Each anatomical segment (feet, ankle, Achilles, calves, shins, knees, hip and lower back) was scored between 0-6. According to Kinchington (2011), the scores were classified into three zones. The red zone score of 0, 1 or 2 represented rest, which translated into no further barefoot activity until recovery. The black zone score of 3 or 4 indicated that a 0 – 20 % increase in activity was possible. The blue zone score 5 or 6 indicated that a 20 - 40 % increase in activity was reasonable. A graphical representation of the zones is shown in **Table 3.3** below. In this study, the comfort index reported by the EXP group fell within the black zone more than 80 % of the time, which would have had a direct impact on the rate of progression of the barefoot intervention.

Table 3.3: Zone classification for mLLCI

Description/Score	Rest/0-2	Increment 0-20%/3-4	Increment 20-40%/5-6
Zone			

F. INTERVENTION PROGRAMME

The intervention programme was characterised by a six-week strength and conditioning programme performed in BF conditions, for a total of 18 training sessions. The introduction of the BF conditions as part of the intervention was done gradually to minimise the risk of lower limb injury. The participants in the EXP group underwent the barefoot intervention programme with netball-specific strength and conditioning drills. The CON group engaged in the same strength and conditioning programme in their usual netball training shoes and an additional training session in the gym (once a week). Both programmes were structured in such a way as to minimise the disruption of the usual training days of the participants and accounted for the two-week university holiday period. The first training session involved 10 minutes of barefoot activity. Over the course of the 18 training sessions, the time spent in BF conditions was increased from 10 minutes to 45 minutes (**Figure 3.14**). To be eligible for post-intervention testing, participants were required to attend at least 13 of the 18 training sessions (70 %). Of the 30 participants initially enrolled in the study, 22 were eligible for post-intervention testing.

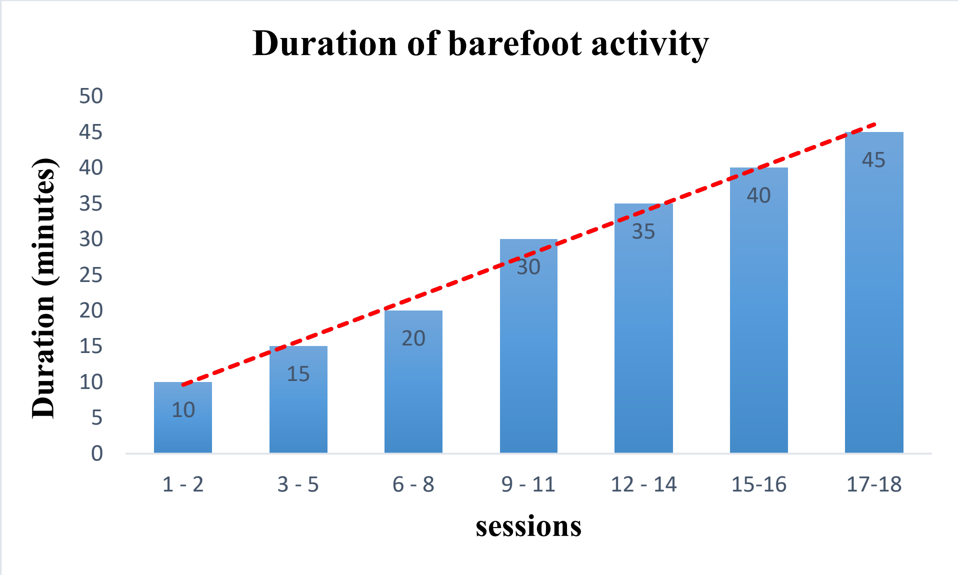
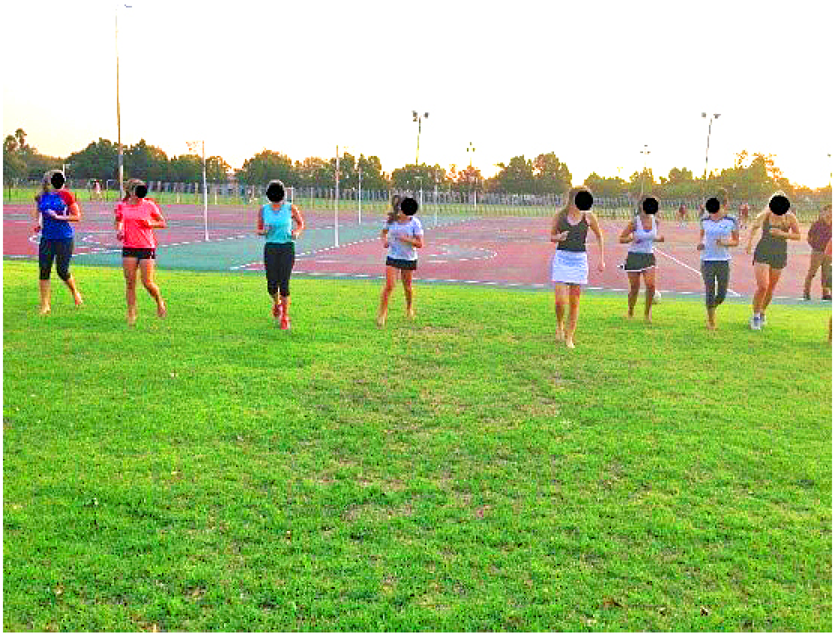


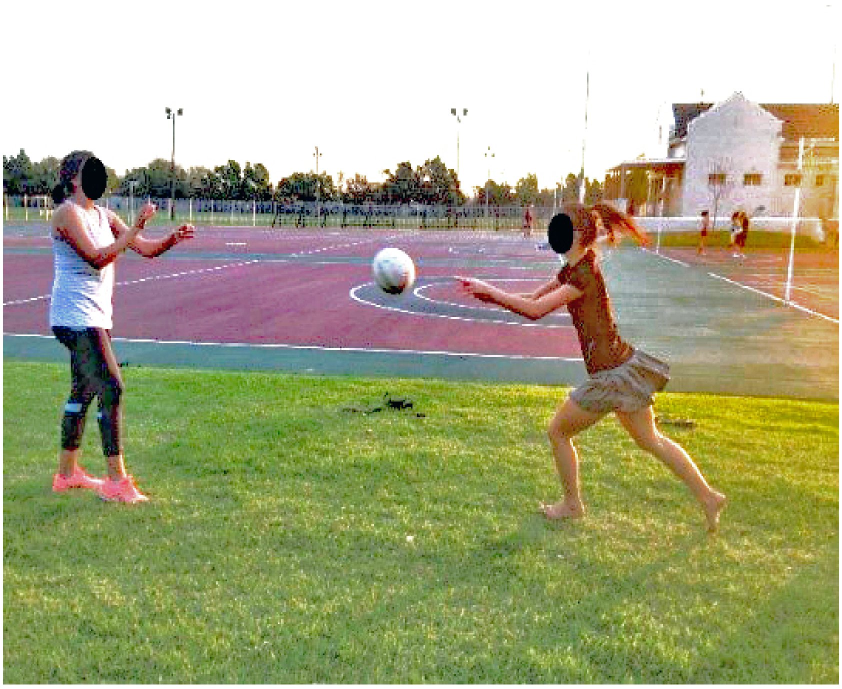
Figure 3.14: Duration and progression of barefoot activity

Selection of training surface

The implementation of a barefoot training programme requires careful selection of the terrain upon which activities take place (Hart & Smith, 2008). Terrain variability is among the most important factor for successful implementation of a barefoot training programme. A gradual increase in time of participation should be determined by training response and surface comfort (Du Plesis, 2011). Saxby (2011) suggested that the likelihood of injury occurrence is higher on hard surfaces compared to soft surfaces. However, high level of training surfaces softness can reduce the efficiency of the elastic recoil thus increasing muscular activity and risk of injury (Saxby, 2011). The familiarisation and transitioning to BF condition for this study took place on grass and traditional concrete netball court, to enhance proprioceptive feedback and gradual neuromuscular adaptation (**Figure 3.15**)



(a)



(b)

(c)

Figure 3.15: (a) Participants in EXP group doing warm-ups on grass surface (b) Participants in EXP group doing netball-specific drill on grass surface (c) A participant in CON group sprinting across 10 m runway at a relative pace on concrete surface. (Photograph by Jaiyesimi B.G)

Motivation for intervention duration

Khowailed, Petrofsky, Lohman and Daher (2015) reported that changes in a movement pattern can be accomplished within six weeks in previously habitually shod runners. Rezaimanesh, Amiri-Farsani and Saidian (2011), in a four-week study on plyometric training and EMG change in futsal players, reported significant changes in bicep femoris and gracilis during squat movement. Hauschildt (2018) suggested that motor learning could take place within three to six weeks. Hammett and Hey (2003) noted that stimulus enhanced by training specificity could initiate neuromuscular adaptation in the first two weeks of intervention. However, the study was carried out for four weeks with high school students (average age = 16 years).

G. TRAINING CHARACTERISTICS

The training programme was designed in collaboration with the strength and conditioning coach who was appointed by the club for the duration of the season. Every session started with a 10-minute warm-up, including activities like slow jogging, butt kicks, single-leg squats, to name a few. The session continued with drills like one-legged, regular plank hold, hurdle jump and elastic band run. The training sessions concluded with ball drills. **Appendix N** contains more detail about the training programme.

H. STATISTICAL ANALYSIS

Descriptive and inferential statistics of the variable of interests were utilized in the data analysis. Microsoft Excel (Microsoft Office Professional®, 2016; USA), SPSS 25 (SPSS® Inc., Chicago, USA) and STATISTICA® 13 "VEPAC" module (Statsoft, Inc; 2013 USA) were used for data processing and statistical analysis. The descriptive data for the study were reported as means, standard deviation, standard error of mean and percentage differences. The inferential statistics were reported with Chi-square, independent T-Test and a mixed model ANOVA. The variables "treatment", "time", "footwear" and "activity" were included as fixed effects. The subjects nested in treatment was included as random effect. Fisher least significant difference "LSD" was used for post-hoc testing though the outcome is not reported in the result chapter to avoid ambiguity.

The three valid trials for each jump were extracted and averaged for statistical analysis (Ford et al., 2005; Pouliot-Laforte, Veilleux, Rauch, & Lemay, 2014). The first four objectives were statistically analysed with mixed model ANOVA. The baseline data from the pre-intervention testing were used for the first and second objectives. The mean difference in percentage and absolute mean difference were used to show the difference between footwear conditions and treatment groups. The mean difference in percentage was calculated for the SA even though the values were derived from equation equalled to a percentage value. Only the pre and post-intervention SH data were used to test for the significant differences between the EXP and CON group as stated in objectives three and four. The jump-landing tasks (referring to all the jumps) were statistically combined and presented for the third and fourth objectives. The fifth objective was analysed using Chi-square while independent T-test was used to analyse the seventh objective. The significance level was set at $p < 0.05$. The effect size was calculated in STATISTICA using Cohen's effect size (Cohen, 1992) and interpreted with the normative values outlined in **Table 3.4** below.

Table 3.4: Effect size interval and qualitative outcome

S/N	EFFECT SIZE	QUALITATIVE OUTCOME
1	$\geq 0 - 0.15$	Negligible (N)
2	$\geq 0.15 - 0.40$	Small (S)
3	$\geq 0.40 - 0.75$	Medium (M)
4	$\geq 0.75 - 1.10$	Large (L)
5	$\geq 1.10 \geq 1.45$	Very Large (VL)

I. ETHICAL ASPECTS

The study protocol was approved by the Ethics Committee of the Stellenbosch University (Reference number SU-HSD-003784) and aligned with the stipulations of the approval (**Appendix B**). The participants were provided with an informed consent form prior to data collection and their enrolment in the study. Those participants who agreed to take part in the study provided the researcher with a signed informed consent form. It was made clear that participation in the study is completely voluntary and they could withdraw at any time without any recourse. The study protocol was clearly explained, described and demonstrated to the participants. All the information and documents used for the study were handled with the highest level of ethical consideration. Any information related to the participants remained confidential and would only be disclosed with the explicit permission of the participants, or as required by the law. Confidentiality will be maintained by means of the anonymity of the participants. For anonymity, study-specific numerical codes were used to represent participants. All the documents for the study were handled by the study leader and the researcher.

CHAPTER FOUR

RESULTS

A. INTRODUCTION

The primary aim of this study was to determine the effects of a barefoot intervention on the landing kinetics and kinematics of netball players. The results are presented according to the formulated aims, objectives and hypotheses of the study. The differences in kinetics and kinematics between the two footwear conditions, the differences between the control (CON) and experimental (EXP) group, as well as the subjective evaluation of the landing pattern following barefoot intervention, are reported in this chapter.

B. PARTICIPANTS

Forty players from the netball club of Stellenbosch University volunteered to participate in the study. Thirty of the players met the inclusion criteria for the study and were randomly assigned to the EXP (n = 15) and CON (n = 15) groups. The two groups followed the same intervention programme (with pre-season strength and conditioning programme) at the beginning of the pre-competitive season. The EXP group underwent the barefoot intervention with a gradual increase in the duration of the time spent barefoot (BF), while the shod (SH) group underwent the intervention with their usual netball training shoes. Twenty-two participants from both groups (EXP, n = 9; CON, n = 13) underwent the post-intervention testing session. The schematic in **Figure 4.1**: shows the dropout rate of participants during the study.

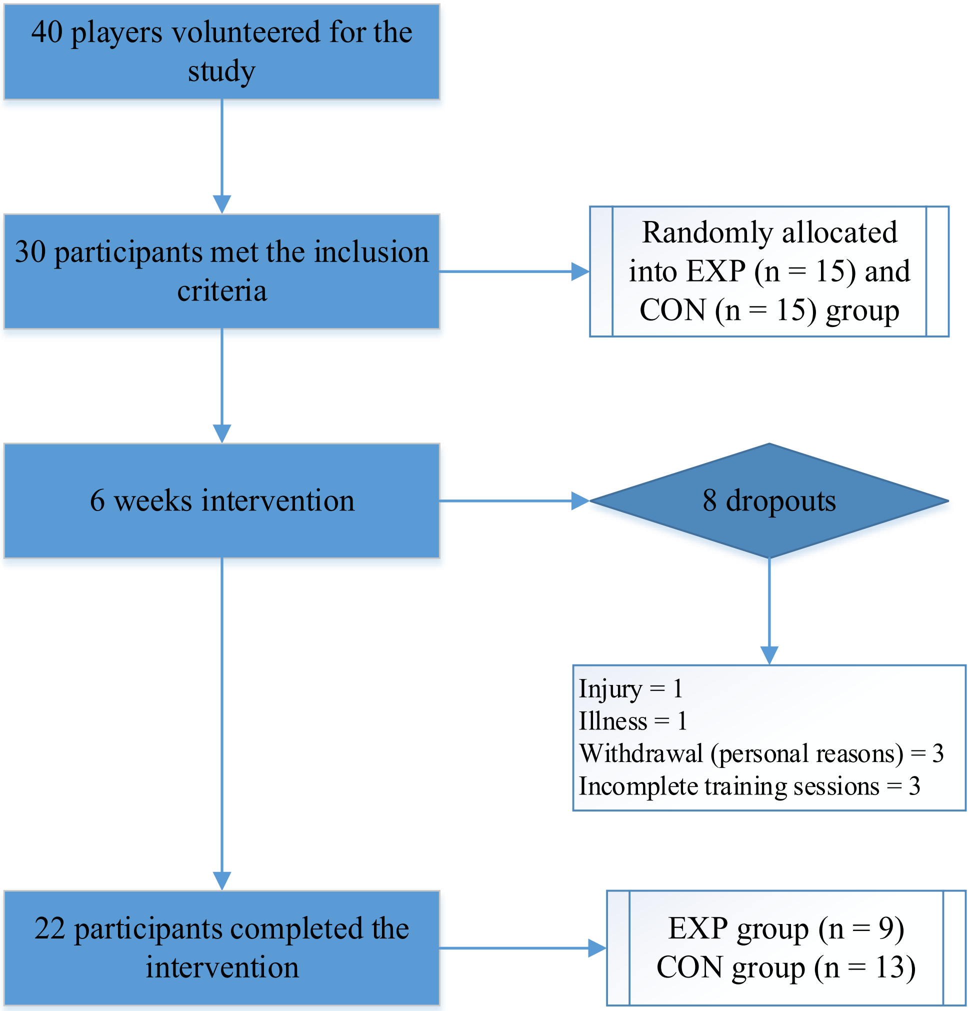


Figure 4.1: Schematic representation of the participants

There were no significant differences regarding the physical characteristics of the two groups at either of the two testing sessions ($p > 0.05$). The Cohen effect sizes were negligible and moderate as shown in **Table 4.1** and **Table 4.2** below.

Table 4.1: Physical characteristics of the EXP group

	PRE-TEST N = 15			POST-TEST N = 9				
Characteristics	Mean	SD	Range	Mean	SD	Range	P	ES
Age (years)	20	1	18 - 23	-	-	-	-	-
Height (cm)	171	4.6	162 - 178	171	4.3	162 - 178	0.67	0.13
Weight (kg)	66.6	6.7	55.8 - 79.0	65.1	5.3	58.2 - 78.4	0.20	0.41

SD = Standard deviation, P = P-value, ES = effect size

Table 4.2: Physical characteristics of the CON group

	PRE-TEST N = 15			POST-TEST N = 13				
Characteristics	Mean	SD	Range	Mean	SD	Range	P	ES
Age (years)	20	1	19 - 22	-	-	-	-	-
Height (cm)	176	5.8	162 - 189	177	2.9	172 - 181	0.45	0.23
Weight (kg)	72.2	7.5	58.4 - 87.4	73.7	7.9	59.4 - 86.7	0.63	0.14

SD = Standard deviation, P = P-value, ES = effect size

C. KINETIC VARIABLES (BAREFOOT VS SHOD CONDITION)

The following section outlines the pre-intervention differences in kinetic variables for the BF and SH conditions for all participants, during the various jump-landing tasks. The kinetic variables analysed in this section were ground reaction forces (GRFs), ground reaction forces time to peak (GRFtp) and shock attenuation (SA). The jump-landing tasks considered for the analysis were the single-leg drop landing right (SLR), the single-leg drop landing left (SLL), the drop vertical jump (DVJ) and the stop-jump performance task (SJPT).

Ground reaction forces (GRFs)

The GRFs are reported for the peak resultant force (PRF), vertical ground reaction force (VGRF), mediolateral ground reaction force (MGRF) and anteroposterior ground reaction force (AGRF) for the jump-landing tasks in BF and SH conditions. The results of the GRFs for the jump-landing tasks in BF and SH conditions are shown in **Figure 4.2, Table 4.3** and **Table 4.4.** The participants in the BF condition showed a reduction in mediolateral landing force in all jump-landing tasks, as well as a reduction in anteroposterior landing force in the single-leg tasks (**Figure 4.2**). The PRF and VGRF were lower in the SH condition when compared with BF condition. In addition, the anteroposterior force was lower in the DVJ and SJPT in SH condition.

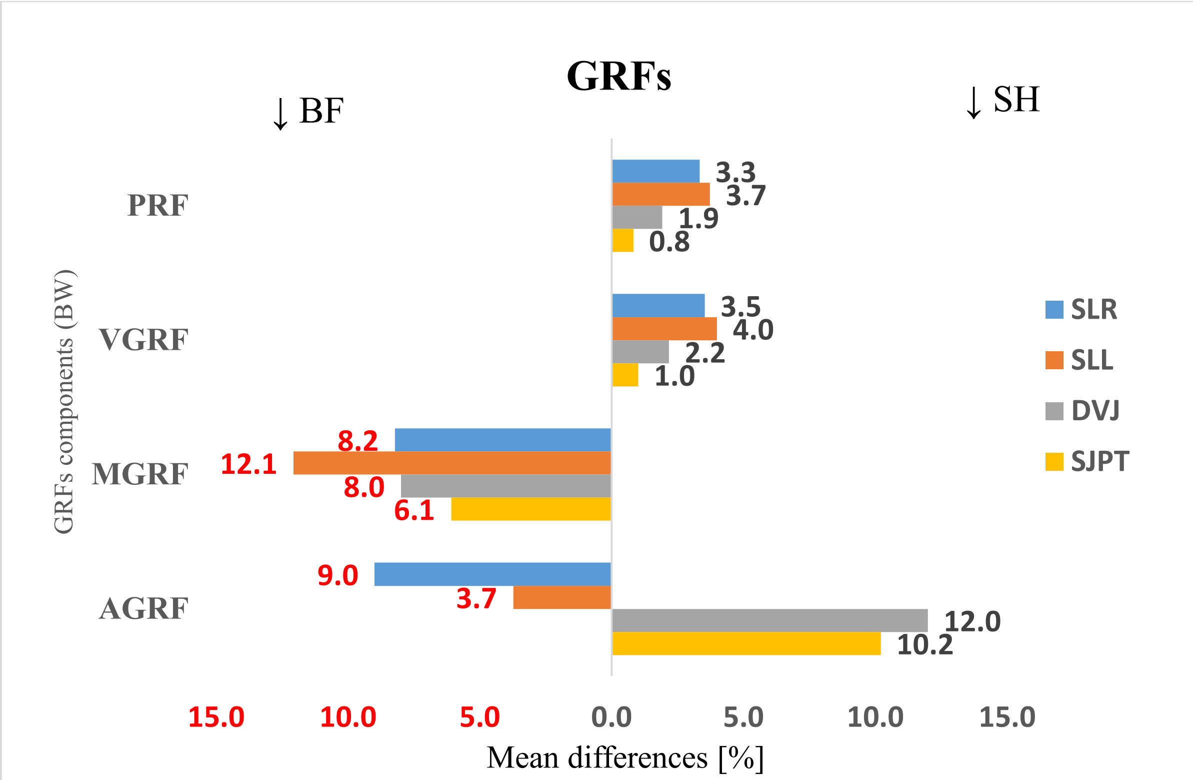


Figure 4.2: Bar chart on the PRF, VGRF, MGRF, AGRF mean value percentage differences for SLR, SLL, DVJ and SJPT in BF and SH conditions. ↓ BF on the top left represents lower values in the BF compared to SH condition. ↓ SH on the top right represents lower values in SH compared to BF conditions.

Table 4.3 shows significant differences between the BF and SH conditions in VGRF ($p = 0.05$) and MGRF ($p = 0.02$) for the SLL jump-landing task. The mean value of VGRF for SLL (3.29 ± 0.11) was lower in SH by 4 % but MGRF for SLL (0.46 ± 0.02) was reduced by 12.1 % in BF when compared with SH conditions, with small and moderate effect sizes, respectively (ES = 0.3; 0.47) (**Figure 4.2**).

Table 4.3: GRFs of SLR and SLL in BF vs SH conditions (Data represented as Mean ± SEM)

	SLR				SLL			
GRFs (BW)	BF	SH	P	ES	BF	SH	P	ES
PRF	3.59 ± 0.11	3.47 ± 0.11	0.08	0.22^	3.46 ± 0.11	3.33 ± 0.11	0.06	0.29^
VGRF	3.57 ± 0.11	3.44 ± 0.11	0.06	0.23^	3.43 ± 0.11	3.29 ± 0.11	0.05*	0.3^
MGRF	0.42 ± 0.02	0.45 ± 0.02	0.09	0.35^	0.41 ± 0.02	0.46 ± 0.02	0.02*	0.47#
AGRF	0.12 ± 0.01	0.13 ± 0.01	0.17	0.23^	0.13 ± 0.01	0.14 ± 0.01	0.55	0.07~

*@ Very large effect, ∞ Large effect, # Moderate effect, ^ Small effect, ~ Negligible effect, * Statistically significant difference*

With respect to the DVJ, there were significant differences between the BF and SH conditions in MGRF (p = 0.03) and AGRF (p = 0.05) (**Table 4.4**). The mean value of MGRF for the DVJ (0.56 ± 0.02) was 8 % lower in the BF condition, while AGRF for the DVJ (0.14 ± 0.01) was 12 % greater in the BF condition (**Figure 4.2**), with small effect sizes, respectively (ES = 0.21; 0.35).

Table 4.4: GRFs for DVJ and SJPT in BF vs SH conditions (Data represented as Mean ± SEM)

	DVJ				SJPT			
GRFs (BW)	BF	SH	P	ES	BF	SH	P	ES
PRF	3.39 ± 0.11	3.32 ± 0.11	0.33	0.15^	3.60± 0.1	3.58 ± 0.1	0.66	0.09~
VGRF	3.34 ± 0.11	3.27 ± 0.11	0.28	0.16^	3.55 ± 0.1	3.52 ± 0.1	0.59	0.1~
MGRF	0.56 ± 0.02	0.60 ± 0.02	0.03*	0.21^	0.60 ± 0.0	0.61 ± 0.0	0.07	0.2^
AGRF	0.14 ± 0.01	0.12 ± 0.01	0.05*	0.35^	0.14 ± 0.0	0.13 ± 0.0	0.08	0.21^

@ *Very large effect,* ∞ *Large effect,* # *Moderate effect,* ^ *Small effect,* ~ *Negligible effect,* * *Statistically significant difference*

Ground reaction forces time to peak (GRFtp)

The GRFtp are reported for time to peak resultant force (PRFtp), time to peak vertical ground reaction force (VGRFtp), time to peak mediolateral ground reaction force (MGRFtp) and time to peak anteroposterior ground reaction force (AGRFtp) for the jump-landing tasks in the BF and SH conditions, and outlined in **Figure** 4.3, **Table 4.5** and **Table 4.6**. The participants in the SH condition demonstrated greater PRFtp (except for SLR) and AGRFtp for the jump-landing tasks (**Figure** 4.3). However, MGRFtp (except for DVJ) and VGRFtp (except for SJPT) were greater as well for the jump-landing tasks in BF when compared with SH conditions.

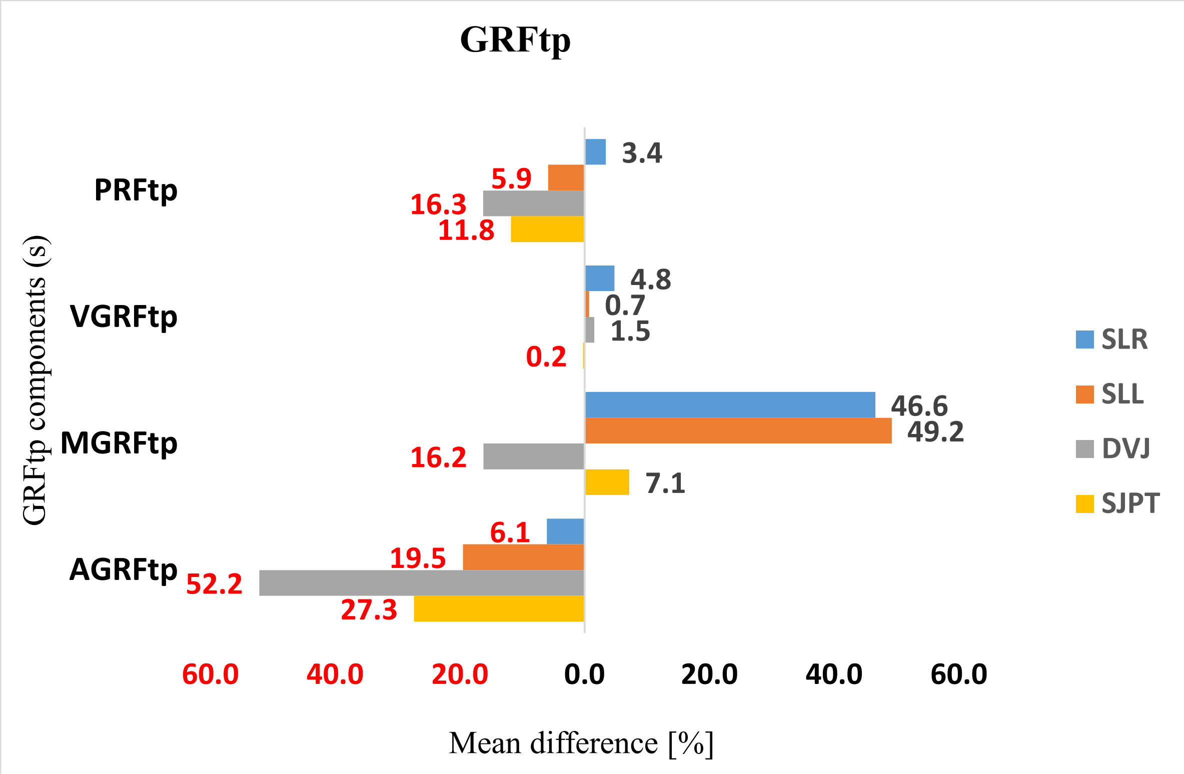


Figure 4.3: Bar chart on the PRFtp, VGRFtp, MGRFtp, AGRFtp mean value percentage differences for SLR, SLL, DVJ and SJPT in BF and SH conditions. ↑ SH on the top left represents greater values in the SH compared to BF conditions. ↑ BF on the top right represents lower in BF compared to SH condition.

Table 4.5 shows that there were significant differences between BF and SH conditions in MGRFtp for SLR (p = 0.00) and SLL (p = 0.00). The mean values of MGRFtp for SLR (0.053 ± 0.004) and SLL (0.057 ± 0.004) were significantly greater in the BF condition by 46.6 % and 49.2 % respectively (**Figure 4**.3) when compared with the SH condition, with large effect sizes (ES = 0.84; 0.93).

Table 4.5: GRFtp for SLR and SLL in BF vs SH conditions (Data represented as Mean ± SEM)

	SLR				SLL			
GRFtp (s)	BF	SH	P	ES	BF	SH	P	ES
PRFtp	0.142 ± 0.009	0.138 ± 0.009	0.67	0.02~	0.121 ± 0.009	0.128 ± 0.009	0.54	0.14~
VGRFtp	0.068 ± 0.002	0.065 ± 0.002	0.09	0.17^	0.071 ± 0.002	0.071 ± 0.002	0.80	0.11~
MGRFtp	0.053 ± 0.004	0.028 ± 0.004	0.00*	0.84∞	0.057 ± 0.004	0.029 ± 0.004	0.00*	0.93∞
AGRFtp	0.104 ± 0.008	0.109 ± 0.01	0.50	0.15~	0.061± 0.008	0.073 ± 0.01	0.22	0.58#

*@ Very large effect, ∞ Large effect, # Moderate effect, ^ Small effect, ~ Negligible effect, * Statistically significant difference*

Table 4.6 outlines the significant differences between the BF and SH conditions in AGRFtp for the DVJ (p = 0.01) and the SJPT (p = 0.04). The mean values of AGRFtp for DVJ (0.074 ± 0.007) and for SJPT (0.090 ± 0.007) were significantly greater in the SH by 52.2% and 27.3% respectively (**Figure 4**.3) with moderate and small effect sizes (ES = 0.6; 0.25).

Table 4.6: GRFtp for DJV and SJPT in BF vs SH conditions (Data represented as Mean ± SEM)

	DVJ				**SJPT**			
GRFtp (s)	BF	SH	P	ES	BF	SH	P	ES
PRFtp	0.103 ± 0.009	0.120 ± 0.009	0.14	0.42#	0.127 ± 0.009	0.142 ± 0.009	0.19	0.18^
VGRFtp	0.075 ± 0.002	0.074 ± 0.002	0.56	0.05~	0.071 ± 0.002	0.071 ± 0.002	0.93	0.03~
MGRFtp	0.026 ± 0.004	0.029 ± 0.004	0.35	0.18^	0.028 ± 0.004	0.026 ± 0.004	0.66	0.1~
AGRFtp	0.049 ± 0.007	0.074 ± 0.007	0.01*	0.6#	0.071 ± 0.008	0.090 ± 0.007	0.04*	0.25^

*@ Very large effect, ∞ Large effect, # Moderate effect, ^ Small effect, ~ Negligible effect, * Statistically significant difference*

Shock attenuation (SA)

The SA variables that are reported for the jump-landing tasks between the BF and SH conditions are hip shock attenuation (hip$_{SA}$), knee shock attenuation (knee$_{SA}$) and ankle shock attenuation (ankle$_{SA}$). The results of the SA variables are shown in **Figure 4.4, Table 4.7 and Table 4.8**. The participants in the BF condition demonstrated greater knee$_{SA}$ and hip$_{SA}$ (except for SJPT) for the jump-landing tasks **(Figure 4.4).** However, the ankle$_{SA}$ (except for SLR) for the jump-landing tasks was greater in SH when compared with BF conditions.

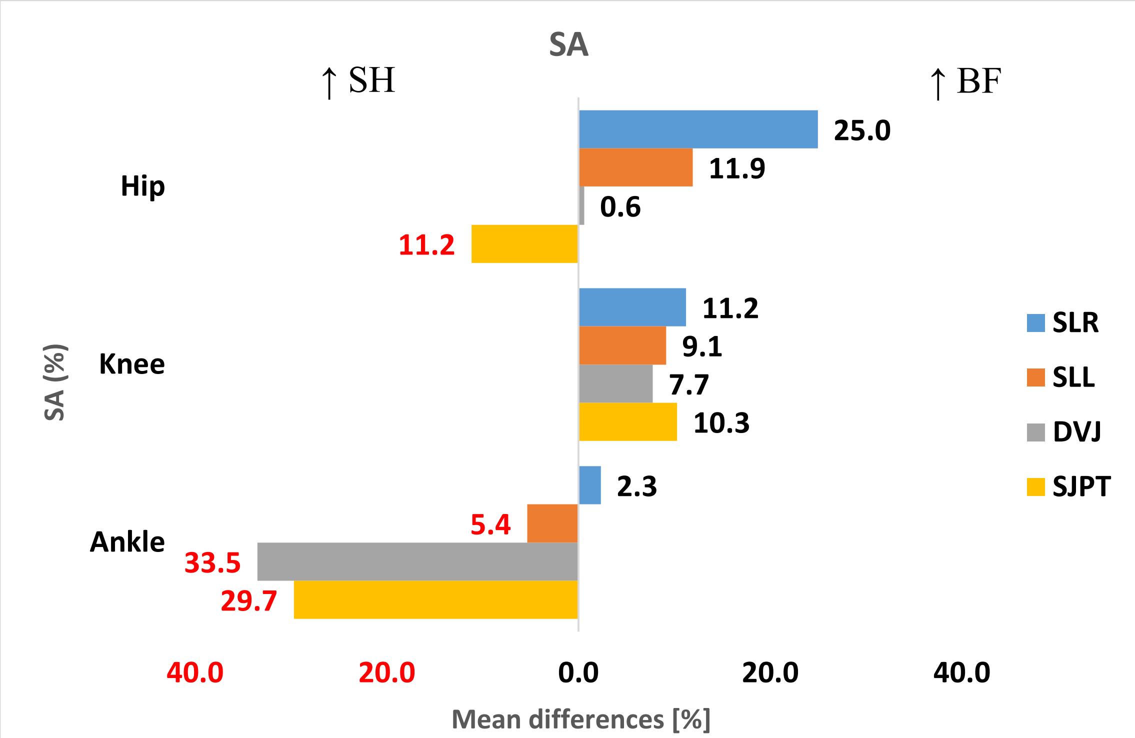


Figure 4.4: Bar chart on the hip$_{SA}$, knee$_{SA}$ and ankle$_{SA}$ mean value percentage differences for SLR, SLL, DVJ and SJPT in BF and SH conditions. ↑ SH on the top left represents greater values in SH compared to BF conditions. ↑ BF on the top right represents greater values in BF compared to SH conditions.

As outlined in **Table 4.7**, there were significant differences between the BF and SH conditions for hip$_{SA}$ (SLR; p = 0.00 and SLL; p = 0.04). The mean values (42.86 ± 2.48; 46.59 ± 2.48) of hip$_{SA}$ (SLR and SLL) were significantly greater by 25 % and 11.9 % in the BF condition when compared with the SH condition (**Figure** 4.4), with small and moderate effect sizes, respectively (ES = 0.34, 0.5).

Table 4.7: SA for SLR and SLL in BF vs SH conditions (Data represented as Mean ± SEM)

	SLR				SLL			
SA (%)	BF	SH	P	ES	BF	SH	P	ES
Hip$_{SA}$	42.86 ± 2.48	34.30 ± 2.52	0.00*	0.5$^{\#}$	46.59 ± 2.48	41.63 ± 2.52	0.04*	0.34$^{\wedge}$
Knee$_{SA}$	33.09 ± 1.91	29.75 ± 1.94	0.09	0.23$^{\wedge}$	31.54 ± 1.91	28.90 ± 1.95	0.18	0.11$^{\sim}$
Ankle$_{SA}$	20.94 ± 2.80	20.47 ± 2.95	0.90	0.02$^{\sim}$	18.61 ± 2.80	19.66 ± 2.92	0.79	0.13$^{\sim}$

$^{@}$ Very large effect, $^{\infty}$ Large effect, $^{\#}$ Moderate effect, $^{\wedge}$ Small effect, $^{\sim}$ Negligible effect, * Statistically significant difference

Table 4.8 indicates the significant differences between the BF and SH conditions in $ankle_{SA}$ for the DVJ (p = 0.01) and the SJPT (p = 0.01), respectively. The mean values of $ankle_{SA}$ for the DVJ (20.17 ± 2.80) and the SJPT (23.6 ± 2.8) were significantly lower by 33.5 % and 29.7 % in the BF condition when compared with the SH condition (**Figure 4.4)** with small and moderate effect sizes, respectively (ES = 0.38, 0.56).

Table 4.8: SA for DVJ and SJPT in BF vs SH conditions (Data represented as Mean ± SEM)

	DVJ				SJPT			
SA (%)	BF	SH	P	ES	BF	SH	P	ES
Hip_{SA}	36.16 ± 2.48	35.95 ± 2.49	0.93	0.06~	30.7 ± 2.5	34.6 ± 2.5	0.11	0.19^
$Knee_{SA}$	37.08 ± 1.91	34.42 ± 1.92	0.17	0.17^	32.9 ± 1.9	29.8 ± 1.9	0.11	0.19^
$Ankle_{SA}$	20.17 ± 2.80	30.32 ± 2.95	0.01*	0.56#	23.6 ± 2.8	33.5 ± 2.9	0.01*	0.38^

*@ Very large effect, ∞ Large effect, # Moderate effect, ^ Small effect, ~ Negligible effect, * Statistically significant difference*

Summary

The results showed that the landing impact forces in the vertical and anteroposterior axes were lower in the SH condition when compared with the BF condition. The participants had more mediolateral force reduction in the BF condition. Furthermore, the participants demonstrated greater shock attenuation at the knee joint in the jump-landing tasks, and partially at the hip during unilateral and bilateral landing in the BF condition. For the SH condition, the participants mainly absorbed shock at the ankle during bilateral landing, and partially in unilateral landing.

D. KINEMATIC VARIABLES (BAREFOOT VS SHOD CONDITION)

The following section reports on the pre-intervention differences in kinematic variables when all the participants performed the jumps in the BF and SH conditions. The kinematic variables in this section are impact peak acceleration (IPA), initial contact (IC) angles, peak angles and range of motion (ROM).

Impact Peak Acceleration (IPA)

The IPA variables, which are reported for the jump-landing tasks in the BF and SH conditions are pelvis acceleration ($pelvis_{accl}$), thigh acceleration ($thigh_{accl}$), shank acceleration ($shank_{accl}$) and foot acceleration ($foot_{accl}$), and are shown in **Figure** 4.5**, Table 4.9** and **Table 4.10.** The participants demonstrated greater $pelvis_{accl}$ in BF condition and $foot_{accl}$ in SH condition for the jump-landing tasks (**Figure** 4.5). The $thigh_{accl}$ and $shank_{accl}$ were lower in SH condition for single-leg landing, as well as in BF condition for DVJ and SJPT.

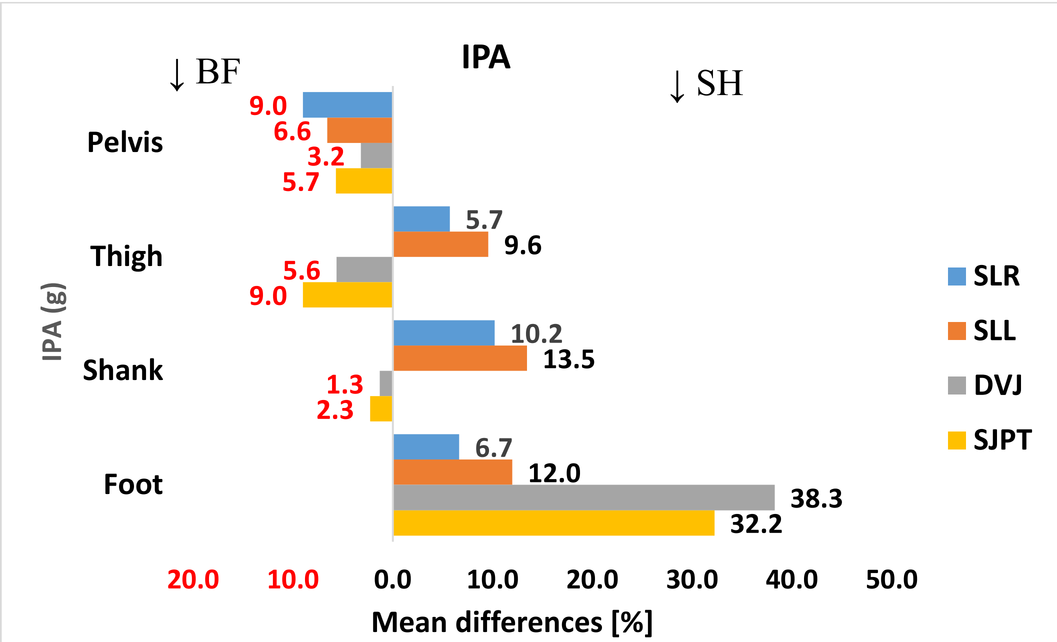


Figure 4.5: Bar chart on the $pelvis_{accl}$, $thigh_{accl}$, $shank_{accl}$, $foot_{accl}$ mean value percentage differences of SLR, SLL, DVJ and SJPT in BF and SH conditions. ↓ BF on the top left represents lower values in BF compared to SH condition. ↓ SH on the top right represents lower values in SH compared to BF conditions.

According to **Table 4.9**, there were significant differences between the BF and SH conditions in $pelvis_{accl}$ and $shank_{accl}$ (SLR; p = 0.00, 0.01), respectively. The mean value (6.23 ± 0.33) of $pelvis_{accl}$

(SLR) was significantly lower in the BF condition (9 %) (**Figure 4.5)** with the $shank_{accl}$ (SLR) mean value (16.09 ± 0.62) being significantly greater (10.2 %) **(Figure 4.5**) in the BF condition when compared with SH condition, with small and moderate effect sizes, respectively (ES = 0.22; 0.42). There were also significant differences between the BF and SH conditions (p = 0.05; 0.04; 0.00, 0.01) in $pelvis_{accl}$, $thigh_{accl}$, $shank_{accl}$ and $foot_{accl}$ (SLL), respectively. The $pelvis_{accl}$ (SLL) mean values (5.63 ± 0.33) were significantly lower in the BF condition (6.6 %), although $thigh_{accl}$, $shank_{accl}$ and $foot_{accl}$ (SLL) mean values (11.08 ± 0.51; 15.54 ± 0.61; 16.59 ± 0.48) were significantly greater in the BF condition by 9.6 %, 13.5 % and 12 %, respectively (**Figure 4.5**), with small to moderate effect sizes (ES = 0.16, 0.3, 0.59, 0.6).

Table 4.9: IPA for SLR and SLL in BF vs SH conditions (Data represented as Mean ± SEM)

	SLR				SLL			
IPA (g)	BF	SH	P	ES	BF	SH	P	ES
$Pelvis_{accl}$	6.23 ± 0.33	6.85 ± 0.33	0.00*	0.22^	5.63 ± 0.33	6.03 ± 0.33	0.05*	0.16^
$Thigh_{accl}$	10.97 ± 0.51	10.37 ± 0.52	0.20	0.15~	11.08 ± 0.51	10.11 ± 0.52	0.04*	0.3^
$Shank_{accl}$	16.09 ± 0.61	14.60 ± 0.62	0.01*	0.4^	15.54 ± 0.61	13.70 ± 0.62	0.00*	0.59#
$Foot_{accl}$	17.20 ± 0.48	16.12 ± 0.50	0.10	0.42#	16.59 ± 0.48	14.82 ± 0.49	0.01*	0.6#

*@ Very large effect, ∞ Large effect, # Moderate effect, ^ Small effect, ~ Negligible effect, * Statistically significant difference*

In **Table 4.10**, there were significant differences between the BF and SH conditions in $foot_{accl}$ (DVJ; p = 0.00 and SJPT; p = 0.00). The $foot_{accl}$ (DVJ and SJPT) mean values were significantly greater in the BF condition (15.14 ± 0.48; 14.4 ± 0.5) by 38.2 % and 32.2 %, respectively **(Figure 4.5),** with large effect sizes (ES = 1.15; 0.96) when compared with the SH conditions.

Table 4.10: IPA for DJV and SJPT in BF vs SH conditions (Data represented as Mean ± SEM)

	DVJ				SJPT			
IPA (g)	BF	SH	P	ES	BF	SH	P	ES
$Pelvis_{accl}$	5.46 ± 0.33	5.64 ± 0.33	0.36	0.08~	6.1 ± 0.3	6.4 ± 0.3	0.06	0.18^
$Thigh_{accl}$	8.22 ± 0.51	8.71 ± 0.51	0.28	0.14~	8.8 ± 0.5	9.7 ± 0.5	0.06	0.25^
$Shank_{accl}$	13.19 ± 0.61	13.36 ± 0.61	0.76	0.01~	13.2 ± 0.6	13.5 ± 0.6	0.59	0.03~
$Foot_{accl}$	15.14 ± 0.48	10.95 ± 0.48	0.00*	1.15@	14.4 ± 0.5	10.9 ± 0.5	0.00*	0.96∞

*@ Very large effect, ∞ Large effect, # Moderate effect, ^ Small effect, ~ Negligible effect, * Statistically significant difference*

Initial contact angle (IC)

The IC angle variables reported for the jump-landing tasks in the BF and SH conditions are lumbar flexion, hip flexion, hip abduction, knee flexion, knee abduction, ankle dorsiflexion, ankle inversion and ankle abduction, with the results thereof shown in **Figure 4.6, Table 4.11** and **Table 4.12.** The participants demonstrated greater lumbar flexion (except for SJPT), hip abduction (except for DVJ), ankle dorsiflexion, ankle inversion (except for SLL) and ankle abduction for the jump-landing tasks at IC angles in BF when compared to SH conditions (**Figure 4.6).** The hip flexion (except for SJPT) was greater for all the jump-landing at IC angle in SH condition. The knee flexion and knee abduction for SLL and SJPT at IC angles were greater in BF condition, as well as in SH condition for SLR and DVJ.

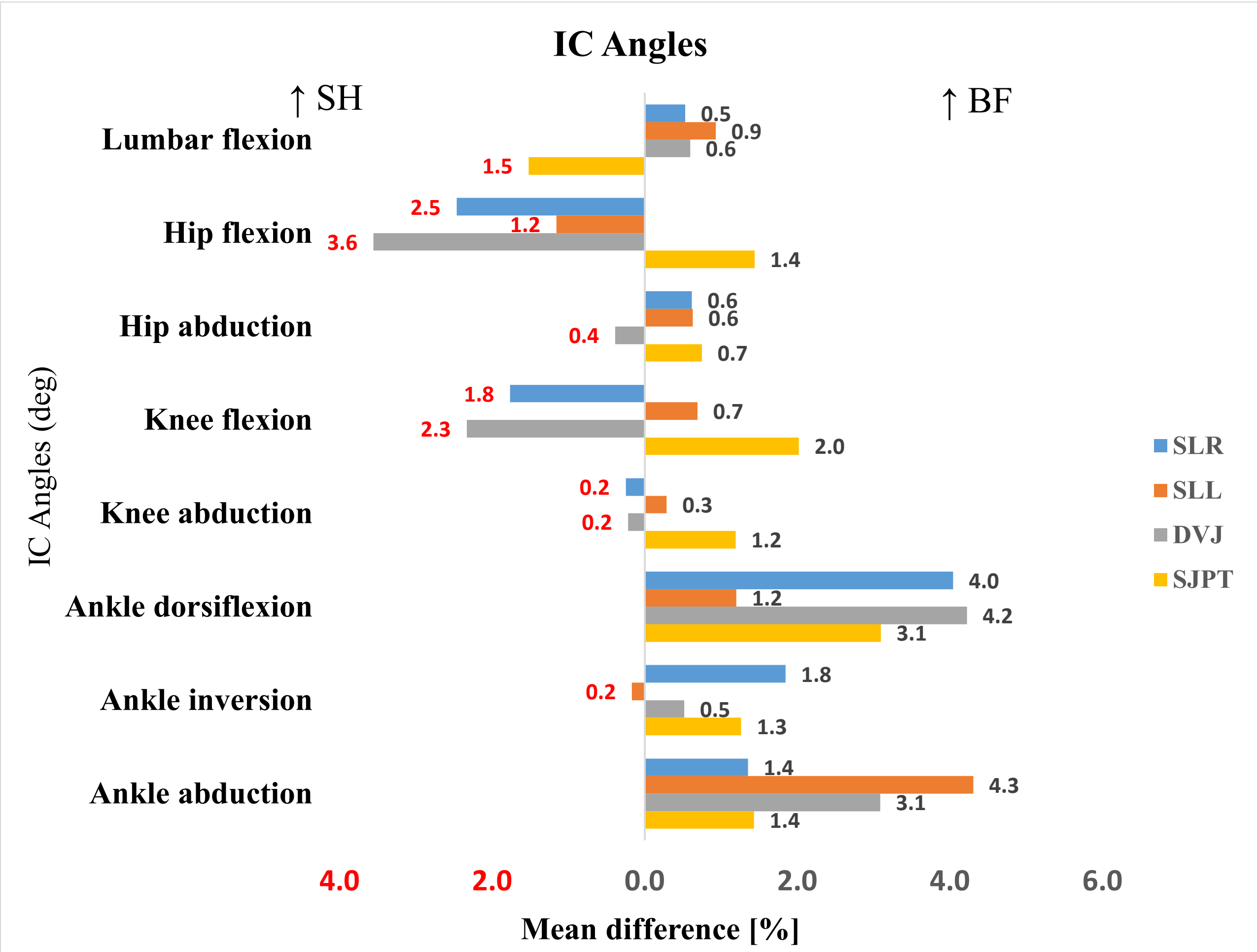


Figure 4.6: Bar chart on IC angles (lumbar flexion, hip flexion, hip abduction, knee flexion, knee abduction, ankle dorsiflexion, ankle inversion and ankle abduction) mean differences for SLR, SLL, DVJ and SJPT in BF and SH conditions. ↑ SH on the top left represents higher values in SH compared to BF conditions. ↑ BF on the top right represents higher values in BF compared to SH conditions.

Table 4.11 shows that there were significant differences between the BF and SH conditions in ankle dorsiflexion (p = 0.04) and inversion (p = 0.01) for the SLR. The mean values (35.6 ± 1.6; 7.2 ± 0.7) of ankle dorsiflexion and inversion (SLR) were significantly greater in the BF condition by 4 degrees (deg) and 1.8 deg, respectively **(Figure 4.6),** when compared with the SH condition, with small and moderate practical effect sizes (ES = 0.33; 0.58). In addition, there was a significant difference between the BF and SH conditions in ankle abduction (p = 0.00) (SLL). The mean value (7.0 ± 0.7) of ankle abduction (SLL) was significantly greater in the BF condition by 4.3 deg (**Figure 4.6**) with large effect sizes (ES = 0.97) when compared with SH condition.

Table 4.11: IC angles for SLR and SLL in BF vs SH (Data represented as Mean ± SEM)

	SLR				SLL			
IC ANGLES (deg)	BF	SH	P	ES	BF	SH	P	ES
Lumbar flexion	9.9 ± 0.9	9.3 ± 0.9	0.53	0.08~	10.4 ± 1.0	9.4 ± 1.0	0.29	0.19^
Hip flexion	21.0 ± 1.8	23.5 ± 1.8	0.23	0.3^	20.6 ± 1.7	21.8 ± 1.8	0.57	0.18^
Hip abduction	5.2 ± 0.6	4.6 ± 0.6	0.14	0.19^	7.3 ± 0.6	6.7 ± 0.6	0.15	0.1^
Knee flexion	18.7 ± 1.8	20.5 ± 1.8	0.45	0.13~	15.5 ± 1.8	14.8 ± 1.9	0.77	0.12^
Knee Abduction	2.03 ± 0.2	2.3 ± 0.3	0.43	0.09~	2.2 ± 0.3	2.0 ± 0.3	0.37	0.2^
Ankle dorsiflexion	35.6 ± 1.6	31.6 ± 1.6	0.04*	0.33^	38.5 ± 1.6	37.3 ± 1.6	0.55	0.06~
Ankle inversion	7.2 ± 0.7	5.4 ± 0.7	0.01*	0.58#	8.0 ± 0.6	8.1 ± 0.7	0.82	0.03~
Ankle abduction	7.0 ± 0.7	5.7 ± 0.7	0.10	0.22^	11.3 ± 0.7	7.0 ± 0.7	0.00*	0.97∞

*@ Very large effect, ∞ Large effect, # Moderate effect, ^ Small effect, ~ Negligible effect, * Statistically significant difference*

In **Table 4.12**, there were significant differences between the BF and SH conditions in ankle dorsiflexion (p = 0.03) and abduction (p = 0.00) for the DVJ. The mean values (28.5 ± 1.6; 10.7 ± 0.7) of ankle dorsiflexion and abduction (DVJ) were significantly greater in the BF condition by 4.2 deg and 3.1 deg, respectively **(Figure 4.6),** when compared with SH condition, with small and moderate effect sizes (ES = 0.36; 0.5). In addition, there was a significant difference between the BF and SH conditions in knee abduction (p = 0.00) for the SJPT. The mean value (4.4 ± 0.3) of knee abduction (SJPT) was significantly greater in the BF condition by 1.2 deg **(Figure 4.6)** with small practical effect size (ES = 0.39), when compared with the SH condition.

Table 4.12: IC angles for DVJ and SJPT in BF vs SH conditions (Data represented as mean ± SEM)

	DVJ				SJPT			
IC ANGLES (deg)	BF	SH	P	ES	BF	SH	P	ES
Lumbar flexion	10.4 ± 0.9	9.8 ± 0.9	0.48	0.12~	7.9 ± 0.9	9.4 ± 0.9	0.08	0.24^
Hip flexion	28.6 ± 1.98	32.2 ± 1.8	0.08	0.18^	29.3 ± 1.7	27.9 ± 1.8	0.48	0.07~
Hip abduction	8.9 ± 0.6	9.2 ± 0.6	0.36	0.1~	9.3 ± 0.6	8.5 ± 0.6	0.08	0.18^
Knee flexion	29.1 ± 1.8	31.5 ± 1.8	0.32	0.1~	33.2 ± 1.8	31.2 ± 1.8	0.39	0.07~
Knee Abduction	3.3 ± 0.3	3.5 ± 0.3	0.49	0.06~	4.4 ± 0.3	3.2 ± 0.3	0.00*	0.39^
Ankle dorsiflexion	28.5 ± 1.6	24.3 ± 1.6	0.03*	0.36^	27.6 ± 1.6	24.5 ± 1.6	0.12	0.28^
Ankle inversion	9.2 ± 0.6	8.8 ± 0.6	0.46	0.14~	10.8 ± 0.6	9.5 ± 0.6	0.07	0.28^
Ankle abduction	10.7 ± 0.7	7.6 ± 0.7	0.00*	0.5#	8.3 ± 0.7	6.9 ± 0.7	0.08	0.37^

*@ Very large effect, ∞ Large effect, # Moderate effect, ^ Small effect, ~ Negligible effect, * Statistically significant difference*

Peak angle

The peak angle variables which are reported for the jump-landing tasks in the BF and SH conditions are: lumbar flexion, hip flexion, hip abduction, knee flexion, knee abduction, ankle dorsiflexion, ankle inversion and ankle abduction, and are shown in **Figure 4.7, Table 4.13** and **Table 4.14**. The participants demonstrated greater hip flexion (except for SJPT), knee abduction, ankle dorsiflexion and ankle abduction at peak angles for the jump-landing tasks in SH condition. The knee flexion (except for DVJ) at peak angle was greater for the jump-landing tasks in BF condition. In addition, hip abduction for SLL and SJPT at peak angle was greater in BF and in SH conditions for SLR. In addition, the ankle inversion for DVJ and SJPT at peak angle was greater in BF and in SH conditions for the single-leg landings **(Figure 4.7).**

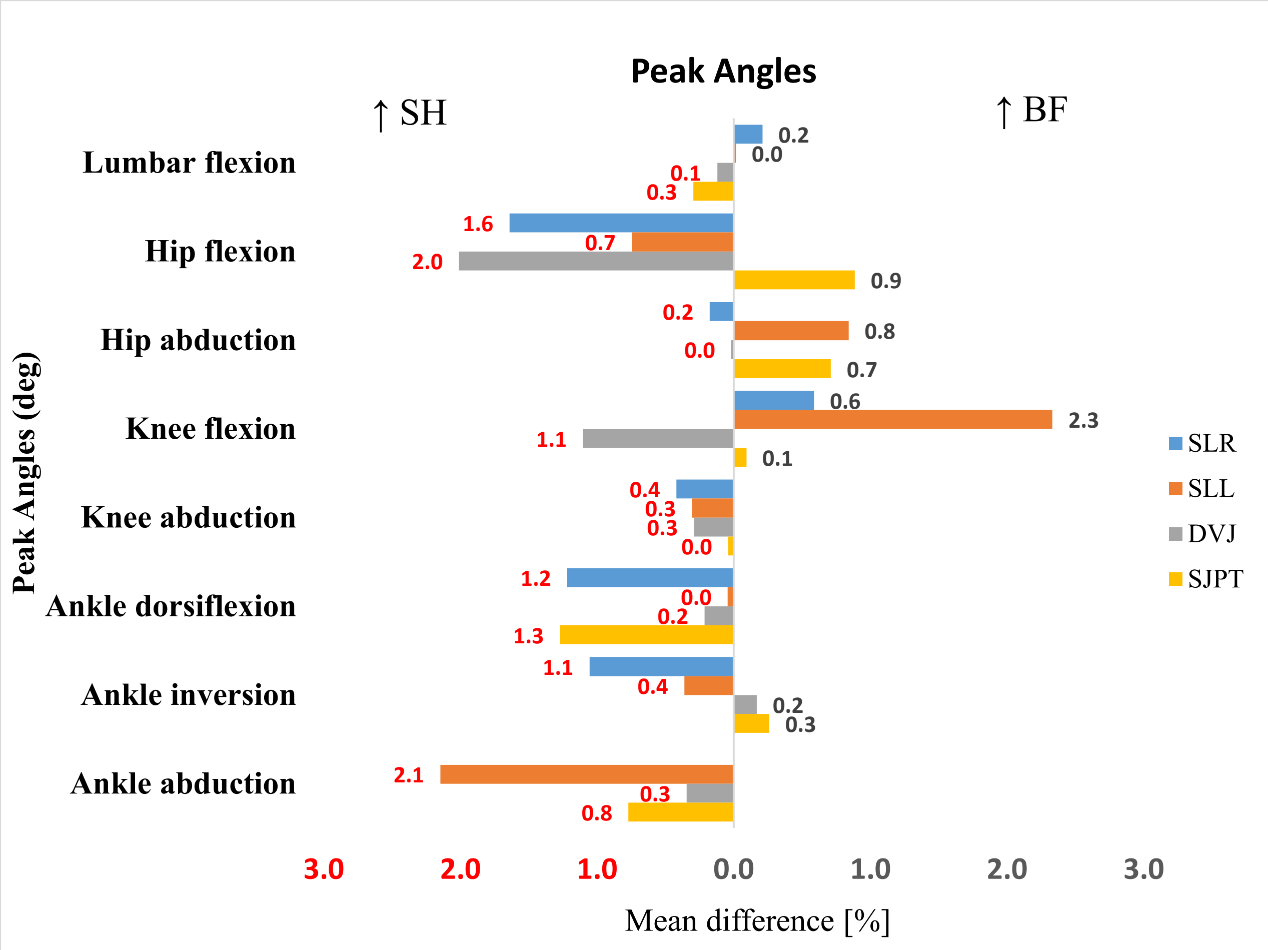


Figure 4.7: Bar chart on peak angles (lumbar flexion, hip flexion, hip abduction, knee flexion, knee abduction, ankle dorsiflexion, ankle inversion and ankle abduction) mean difference for SLR, SLL, DVJ and SJPT in BF and SH conditions. ↑ SH on the top left represents higher values in SH compared to BF conditions. ↑ BF on the top right represents higher values in BF compared to SH conditions.

Table 4.13 indicates that there were significant differences between the BF and SH conditions in ankle abduction (SLL). The mean value of ankle abduction (SLL) was significantly lower in the BF condition (3.6 ± 0.5) by 2.1 deg **(Figure 4.7),** with moderate effect sizes (ES = 0.65), when compared with the SH condition.

Table 4.13: Peak angles for SLR and SLL in BF vs SH conditions (Data represented as Mean ± SEM)

	SLR				**SLL**			
PEAK ANGLES (deg)	BF	SH	P	ES	BF	SH	P	ES
Lumbar flexion	7.8 ± 0.9	7.6 ± 0.9	0.80	0.01~	7.5 ± 0.9	7.5 ± 0.9	0.99	0.02~
Hip flexion	30.1 ± 1.8	31.7 ± 1.8	0.35	0.21^	30.8 ± 1.8	31.5 ± 1.8	0.68	0.14~
Hip abduction	3.9 ± 0.6	4.1 ± 0.6	0.71	0.08~	6.3 ± 0.7	5.4 ± 0.7	0.09	0.18^
Knee flexion	36.3 ± 1.8	35.7 ± 1.8	0.75	0.05~	36.0 ± 1.8	33.7 ± 1.8	0.22	0.18^
Knee Abduction	3.9 ± 0.4	4.3 ± 0.4	0.32	0.23^	4.0 ± 0.4	4.3 ± 0.4	0.47	0.11~
Ankle dorsiflexion	12.2 ± 1.0	13.4 ± 1.0	0.24	0.22^	10.1 ± 1.0	10.1 ± 1.0	0.97	0.1~
Ankle inversion	6.7 ± 0.6	7.7 ± 0.6	0.10	0.28^	8.1 ± 0.6	8.4 ± 0.6	0.57	0.03~
Ankle abduction	7.7 ± 0.5	7.1 ± 0.5	0.30	0.12~	3.6 ± 0.5	5.7 ± 0.6	0.00*	0.69#

@ *Very large effect,* ∞ *Large effect,* # *Moderate effect,* ^ *Small effect,* ~ *Negligible effect,* * *Statistically significant difference*

Table 4.14 shows that there were no significant differences between the BF and SH conditions in peak angles for bilateral landing ($p > 0.05$), with the effect sizes being negligible to small.

Table 4.14: Peak angle for DVJ and SJPT in BF vs SH conditions (Data represented as Mean ± SEM)

	DVJ				**SJPT**			
PEAK ANGLES (deg)	BF	SH	P	ES	BF	SH	P	ES
Lumbar flexion	10.6 ± 0.9	10.7 ± 0.9	0.88	0.02~	9.7 ±0.9	10.0± 0.9	0.72	0.03~
Hip flexion	53.1 ± 1.8	55.1 ± 1.8	0.25	0.09~	51.1 ±1.8	50.2 ±1.8	0.61	0.02~
Hip abduction	10.1 ± 0.6	10.1 ± 0.6	0.97	0.03~	9.9 ±0.6	9.1 ±0.6	0.14	0.13~
Knee flexion	59.8 ± 1.8	61.0 ± 1.8	0.55	0.07~	58.9± 1.8	58.8± 1.8	0.96	0.03~
Knee Abduction	6.0 ± 0.4	6.3 ± 0.4	0.49	0.13~	6.3 ±0.4	6.4± 0.4	0.92	0.08~
Ankle dorsiflexion	20.7 ± 1.0	20.9 ± 1.0	0.84	0.04~	18.5± 1.0	19.7± 1.0	0.22	0.25^
Ankle inversion	6.7 ± 0.6	6.6 ± 0.6	0.79	0.07~	6.1± 0.6	5.9 ±0.6	0.68	0.04~
Ankle abduction	5.7 ± 0.5	6.0 ± 0.5	0.59	0.14~	6.1 ±0.5	6.9± 0.5	0.23	0.24^

@ *Very large effect,* ∞ *Large effect,* # *Moderate effect,* ^ *Small effect,* ~ *Negligible effect,* * *Statistically significant difference*

Range of motion (ROM)

The ROM variables which are reported for the jump-landing tasks in the BF and SH conditions are: hip flexion, hip abduction, knee flexion, knee abduction, ankle dorsiflexion, ankle inversion and ankle abduction, and are shown in **Figure 4**.8, **Table 4.15** and **Table 4.16.** The participants demonstrated greater hip flexion ROM, hip abduction ROM (except for SJPT), ankle inversion ROM (except for SLL), and ankle abduction ROM for the jump-landing tasks in SH condition (**Figure 4.8).** The knee abduction ROM was greater for the jump-landing tasks in BF condition. In addition, the knee flexion and ankle dorsiflexion ROM for single-leg landings were greater in BF condition and in SH condition for DVJ and SJPT.

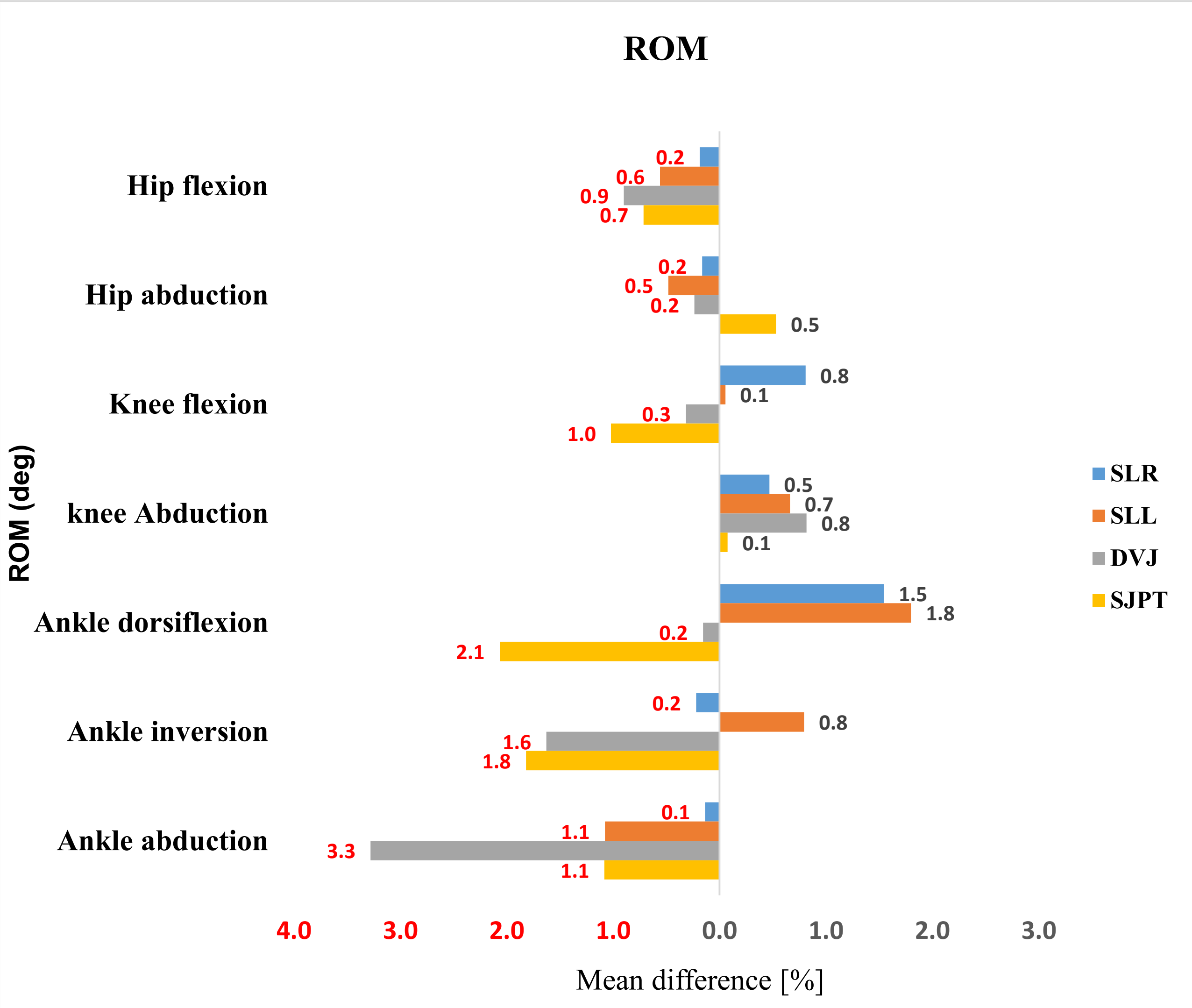


Figure 4.8: Bar chart on ROM (lumbar flexion, hip flexion, hip abduction, knee flexion, knee abduction, ankle dorsiflexion, ankle inversion and ankle abduction) mean differences for SLR, SLL, DVJ and SJPT in BF and SH conditions. ↑ SH on the top left represents higher values in SH compared to BF condition. ↑ BF on the top right represents higher values in BF compared to SH condition.

Table 4.15 indicates that there were significant differences between the BF and SH conditions in ankle dorsiflexion ROM for SLR ($p = 0.03$) and SLL ($p = 0.02$). The mean values of ankle dorsiflexion ROM for SLR (11.8 ± 1.3) and SLL (11.1 ± 1.3) were significantly greater in the BF condition by 1.5 deg and 1.8 deg, respectively (**Figure 4.8),** when compared with SH conditions, with negligible effect sizes (ES = 0.03; 0.02).

Table 4.15: ROM for SLR and SLL in BF vs SH conditions (Data represented as Mean ± SEM)

	SLR				SLL			
ROM (deg)	BF	SH	P	ES	BF	SH	P	ES
Hip flexion	22.0 ± 4.2	22.2 ± 4.3	0.86	0.04~	23.2 ± 4.3	23.8 ± 4.3	0.60	0.06~
Hip abduction	-2.9 ± 0.6	-2.7 ± 0.6	0.62	0.03~	-0.7 ± 0.6	-0.3 ± 0.6	0.16	0.12~
Knee flexion	29.0 ± 4.1	28.2 ± 4.2	0.48	0.04~	29.4 ± 4.2	29.3 ± 4.2	0.96	0.01~
Knee Abduction	3.0 ± 0.7	2.5 ± 0.7	0.30	0.11~	-1.0 ± 0.7	-1.7 ± 0.7	0.15	0.24^
Ankle dorsiflexion	11.8 ± 1.2	10.3 ± 1.3	0.03*	0.17^	11.1 ± 1.3	9.3 ± 1.3	0.02*	0.24^
Ankle inversion	-1.3 ± 0.6	-1.1 ± 0.6	0.74	0.05~	-5.5 ± 0.6	-6.3 ± 0.6	0.24	0.1~
Ankle abduction	-1.5 ± 0.6	-1.3 ± 0.6	0.86	0.05~	1.5 ± 0.6	2.6 ± 0.6	0.16	0.26^

*@ Very large effect, ∞ Large effect, # Moderate effect, ^ Small effect, ~ Negligible effect, * Statistically significant difference*

Table 4.16 shows the ROM results for the DVJ and the SJPT when comparing the BF and SH conditions. There were significant differences in ankle inversion (p = 0.02) and abduction (p = 0.00) for the DVJ as well as ankle dorsiflexion (p = 0.00) and inversion (p = 0.01) for the SJPT. The mean values of ankle inversion and abduction (DVJ) were lower in the BF condition (0.7 ± 0.6; -1.0 ± 0.6) by 1.6 deg and 3.3 deg, respectively (**Figure 4.8**) when compared with the SH condition, with moderate effect sizes (ES = 0.42; 0.73). The mean values of ankle dorsiflexion and inversion (SJPT) significantly decreased also in the BF condition (4.5 ± 1.3; 0.2 ± 0.6) when compared with SH conditions, with moderate practical effect sizes (ES = 0.4; 0.55).

Table 4.16: ROM for DVJ and SJPT in BF vs SH conditions (Data represented as Mean ± SEM)

	DVJ				SJPT			
ROM (deg)	BF	SH	P	ES	BF	SH	P	ES
Hip flexion	54.2 ± 4.3	55.1 ± 4.3	0.39	0.01~	41.6 ±4.3	42.3± 4.3	0.49	0.01~
Hip abduction	5.7 ± 0.6	5.9 ± 0.6	0.48	0.03~	4.9 ±0.6	4.4 ±0.6	0.12	0.16^
Knee flexion	50.1 ± 4.2	50.4 ± 4.2	0.78	0.01~	41.7 ±4.2	42.8 ±4.2	0.37	0.02~
Knee Abduction	2.0 ± 0.7	1.2 ± 0.7	0.07	0.18^	1.1 ±0.7	1.1 ±0.7	0.87	0.03~
Ankle dorsiflexion	11.4 ± 1.3	11.6 ± 1.3	0.83	0.02~	4.5 ±1.3	6.6 ±1.3	0.00*	0.4^
Ankle inversion	0.7 ± 0.6	2.3 ± 0.6	0.02*	0.42#	0.2 ±0.6	2.0 ±0.6	0.01*	0.55#
Ankle abduction	-1.0 ± 0.6	2.2 ± 0.6	0.00*	0.73#	1.5 ±0.6	2.5 ±0.6	0.16	0.26^

*@ Very large effect, ∞ Large effect, # Moderate effect, ^ Small effect, ~ Negligible effect, * Statistically significant difference*

Summary

The results reveal that the mean values of pelvis acceleration were lower in the BF condition, while foot acceleration was lower in the SH condition for the jump-landing tasks. Furthermore, the mean values of shank and thigh acceleration in the BF condition were greater for single-leg landing, while being greater for bilateral landing in the SH condition. The participants demonstrated increased sagittal plane kinematics such as lumbar flexion, hip flexion and knee flexion in the BF condition at initial contact, but decreased at peak angle. The mean values of frontal plane kinematics such as hip abduction, knee abduction, ankle dorsiflexion, ankle inversion and ankle abduction were greater in the BF than the SH condition at IC but were lower at peak angle.

E. KINETIC VARIABLES (EXPERIMENTAL VS CONTROL)

The following section reports on the differences between the experimental (EXP) and control (CON) groups after the intervention. The kinetic variables in this section are ground reaction forces (GRFs), ground reaction forces time to peak (GRFtp), impact peak acceleration (IPA) and shock attenuation (SA). The jump-landing tasks which formed part of this analyses included the; single-leg drop landing right (SLR), single-leg drop landing left (SLL), drop vertical jump (DVJ) and stop-jump performance task (SJPT).

Ground reaction forces

The GRFs are reported for peak resultant force (PRF), vertical ground reaction force (VGRF), mediolateral ground reaction force (MGRF) and anteroposterior ground reaction force (AGRF) for the jump-landing tasks in the EXP and CON group. **Figure 4.9** shows that the EXP group had a greater reduction in all the GRFs than the CON group after the intervention.

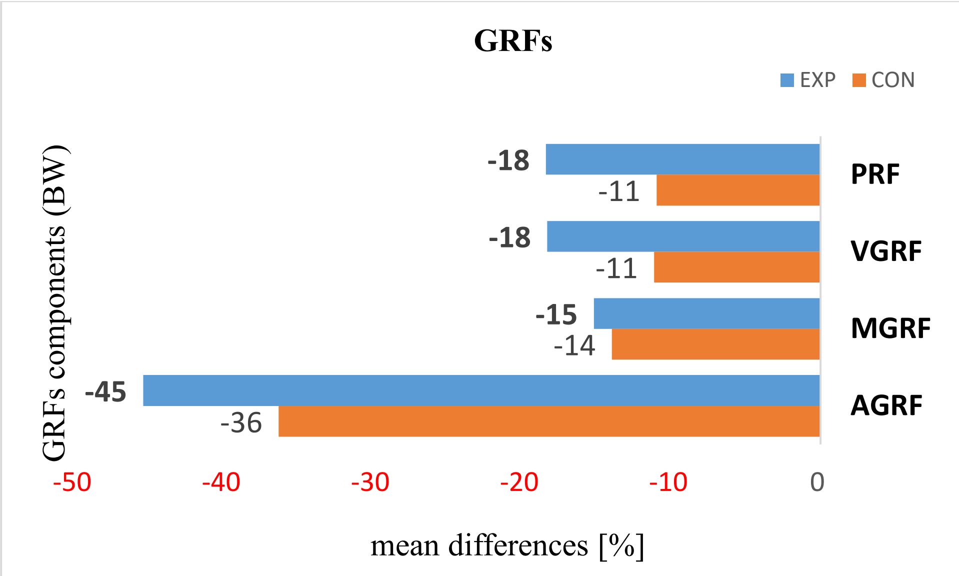


Figure 4.9: Bar chart on the GRFs mean value percentage differences for the EXP and CON groups

Table 4.17 presents the GRFs summary of the jump-landing tasks for the GRF components. There were significant differences ($p < 0.05$) in PRF, VGRF, MGRF and AGRF for the EXP and CON group in the jump-landing tasks. The effect sizes were higher in the EXP when compared with the CON group.

Table 4.17: GRFs summary of the jump-landing tasks (Data represented as Mean ± SEM)

	EXP				CON				EXP-CON	
GRF (BW)	Pre	Post	P	ES	Pre	Post	P	ES	P	ES
PRF	3.65 ± 0.13	3.26 ± 0.16	0.00*	1.01$^{\infty}$	3.53 ± 0.13	3.27 ± 0.14	0.01*	0.51$^{\#}$	0.79	0.15$^{\sim}$
VGRF	3.74 ± 0.13	3.16 ± 0.15	0.00*	1.01$^{\infty}$	3.58 ± 0.13	3.22 ± 0.13	0.01*	0.5$^{\#}$	0.75	0.16$^{\wedge}$
MGRF	0.53 ± 0.02	0.46 ± 0.03	0.02*	0.4$^{\wedge}$	0.57 ± 0.02	0.50 ± 0.02	0.01*	0.41$^{\#}$	0.20	0.16$^{\wedge}$
AGRF	0.16 ± 0.01	0.11 ± 0.01	0.00*	0.88$^{\infty}$	0.15 ± 0.01	0.11 ± 0.01	0.00*	0.66$^{\#}$	0.82	0.13$^{\sim}$

$^{@}$ *Very large effect,* $^{\infty}$ *Large effect,* $^{\#}$ *Moderate effect,* $^{\wedge}$ *Small effect,* $^{\sim}$ *Negligible effect,* * *Statistically significant difference*

Table 4.18 indicates that there were significant differences in PRF, VGRF and AGRF (SLR) for the EXP and CON group ($p < 0.05$). However, the EXP group showed a significant difference in PRF, VGRF and AGRF for the SLL ($p < 0.05$).

Table 4.18: GRFs of SLR and SLL (Data represented as mean ± SEM)

	SLR				SLL			
	EXP		CON		EXP		CON	
GRF (BW)	Pre	Post	Pre	Post	Pre	Post	Pre	Post
PRF	3.81 ± 0.17*	3.34 ± 0.20*	3.55 ± 0.17*	3.20 ± 0.18*	3.62 ± 0.17*	3.10 ± 0.20*	3.42 ± 0.17	3.18 ± 0.18
VGRF	3.77 ± 0.17*	3.31 ± 0.20*	3.51 ± 0.17*	3.17 ± 0.17*	3.59 ± 0.17*	3.07 ± 0.20*	3.38 ± 0.17	3.14 ± 0.18
MGRF	0.49 ± 0.03	0.46 ± 0.04	0.45 ± 0.03	0.42 ± 0.04	0.49 ± 0.03	0.45 ± 0.04	0.46 ± 0.03	0.45 ± 0.04
AGRF	0.15 ± 0.01*	0.12 ± 0.02*	0.16 ± 0.01*	0.10 ± 0.01*	0.18 ± 0.01*	0.11 ± 0.02*	0.14 ± 0.01	0.11 ±0.02

* *Statistically significant difference*

Table 4.19 shows that the EXP group demonstrated significant differences in PRF and VGRF for the DVJ ($p < 0.05$). However, the CON group demonstrated significant differences in MGRF and AGRF for DVJ ($p < 0.05$). In addition, both groups showed significant differences in GRFs for the SJPT.

Table 4.19: GRFs of DVJ and SJPT (Data represented as Mean ± SEM)

	DVJ				SJPT			
	EXP		CON		EXP		CON	
GRF (BW)	Pre	Post	Pre	Post	Pre	Post	Pre	Post
PRF	3.38 ± 0.17*	3.13 ± 0.20*	3.50 ± 0.17	3.29 ± 0.18	3.81 ± 0.17*	3.45 ± 0.20*	3.65 ± 0.17*	3.41 ± 0.18*
VGRF	3.33 ± 0.17*	3.08 ± 0.20*	3.43 ± 0.17	3.22 ± 0.17	3.75 ± 0.17*	3.40 ± 0.20*	3.56 ± 0.17*	3.35 ± 0.17*
MGRF	0.54 ± 0.03	0.54 ± 0.04	0.69 ± 0.03*	0.64 ± 0.04*	0.62 ± 0.03*	0.55 ± 0.04*	0.76 ± 0.03*	0.62 ± 0.04*
AGRF	0.13 ± 0.01	0.12 ± 0.02	0.13 ± 0.01*	0.10 ± 0.01*	0.16 ± 0.01*	0.09 ± 0.02*	0.17 ± 0.01*	0.10 ± 0.01*

* *Statistically significant difference*

Ground reaction forces time to peak

The GRFtp variables reported for the jump-landing tasks when comparing the EXP and CON groups are PRFtp (time to peak resultant force), VGRFtp (time to peak vertical ground reaction force), MGRFtp (time to peak mediolateral ground reaction force) and AGRFtp (time to peak anteroposterior ground reaction force). The EXP group decreased by 3 % and 7 % while the CON group increased by 25 % and 33 % in PRFtp and AGRFtp, respectively. In addition, the EXP group increased by 6 % while the CON group remained unchanged in VGRFtp after the intervention (**Figure 4.10**)

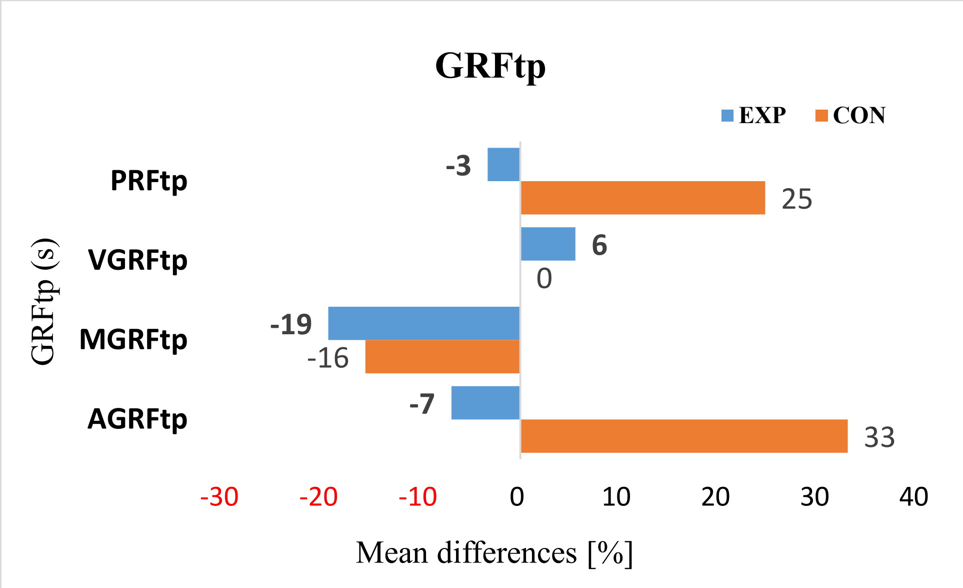


Figure 4.10: Bar chart on the GRFtp mean value percentage differences for the EXP and CON groups

Table 4.20 outlines the GRFtp summary of the the jump-landing tasks. The CON group demonstrated significant differences in PRFtp and AGRFtp ($p < 0.05$) with moderate effect sizes.

Table 4.20: GRFtp summary of the jump-landing tasks (Data represented as Mean ± SEM)

	EXP				CON				EXP-CON	
GRFtp (s)	Pre	Post	P	ES	Pre	Post	P	ES	P	ES
PRFtp	0.126 ± 0.008	0.122 ± 0.01	0.77	0.16^	0.113 ± 0.008	0.15 ± 0.009	0.00*	0.49#	0.46	0.11~
VGRFtp	0.068 ± 0.002	0.072 ± 0.003	0.19	0.38^	0.072 ± 0.003	0.072 ± 0.003	0.87	0.04~	0.60	0.14~
MGRFtp	0.037 ± 0.004	0.031 ± 0.005	0.14	0.31^	0.037 ± 0.004	0.032 ± 0.004	0.1	0.2^	0.89	0.09~
AGRFtp	0.077 ± 0.006	0.072 ± 0.007	0.49	0.13~	0.067 ± 0.006	0.1 ± 0.006	0.00*	0.57#	0.18	0.13~

*@ Very large practical effect, ∞ Large practical effect, # Moderate practical effect, ^ Small practical effect, ~ Negligible practical effect, * Statistically significant difference*

Table 4.21 shows that the CON group demonstrated significant differences in PRFtp and AGRFtp for the SLR ($p < 0.05$), while the EXP group showed significant differences in VGRF for the SLL ($p < 0.05$).

Table 4.21: GRFtp of SLR and SLL (Data represented as Mean ± SEM)

	SLR				SLL			
	EXP		CON		EXP		CON	
GRFtp (s)	Pre	Post	Pre	Post	Pre	Post	Pre	Post
PRFtp	0.144± 0.017	0.134 ± 0.021	0.120± 0.017*	0.154 ± 0.018*	0.106 ±0.017	0.126 ± 0.021	0.114 ±0.018	0.169 ± 0.019
VGRFtp	0.062± 0.004	0.068 ± 0.005	0.063± 0.004	0.068 ± 0.004	0.065 ±0.004*	0.070 ± 0.005*	0.073 ±0.004	0.075 ± 0.004
MGRFtp	0.027± 0.007	0.018 ± 0.008	0.034± 0.007	0.036 ± 0.007	0.030 ±0.007	0.022 ± 0.008	0.032 ±0.007	0.031 ± 0.008
AGRFtp	0.119± 0.013	0.105 ± 0.017	0.088± 0.014*	0.127 ± 0.014*	0.075 ±0.013	0.068 ± 0.018	0.075 ±0.014	0.076 ± 0.016

* *Statistically significant difference*

When assessing the data of the DVJ and SJPT, **Table 4.22** indicates that the EXP and CON groups demonstrated a significant difference in MGRFtp for the DVJ while the CON group showed significant differences in PRFtp and AGRFtp for the SJPT.

Table 4.22: GRFtp of DVJ and SJPT (Data represented as mean ± SEM)

	DVJ				SJPT			
	EXP		CON		EXP		CON	
GRFtp (s)	Pre	Post	Pre	Post	Pre	Post	Pre	Post
PRFtp	0.131 ± 0.017	0.108 ± 0.021	0.113 ± 0.017	0.130 ± 0.018	0.128 ± 0.017	0.120 ± 0.021	0.119 ± 0.017*	0.200 ± 0.018*
VGRFtp	0.073 ± 0.004	0.076 ± 0.005	0.078 ± 0.004	0.072 ± 0.004	0.071 ± 0.004	0.070 ± 0.005	0.074 ± 0.004	0.071 ± 0.004
MGRFtp	0.043 ± 0.007*	0.027 ± 0.008*	0.034 ± 0.007*	0.015 ± 0.007*	0.031 ± 0.007	0.022 ± 0.008	0.033 ± 0.007	0.017 ± 0.007
AGRFtp	0.072 ± 0.014	0.062 ± 0.017	0.072 ± 0.014	0.091 ± 0.014	0.078 ± 0.014	0.083 ± 0.017	0.049 ± 0.014*	0.151 ± 0.015*

* *Statistically significant difference*

Shock attenuation

The differences between the two groups with respect to SA are illustrated in **Figure 4.11**. The hip$_{SA}$ in the CON group decreased by 12 % with a decrease of 10 % seen in the EXP group. However, when assessing knee$_{SA}$ and ankle$_{SA}$, the CON group increased by 45 % and 30 %, while the EXP group increased by 42 % and 0 %, respectively.

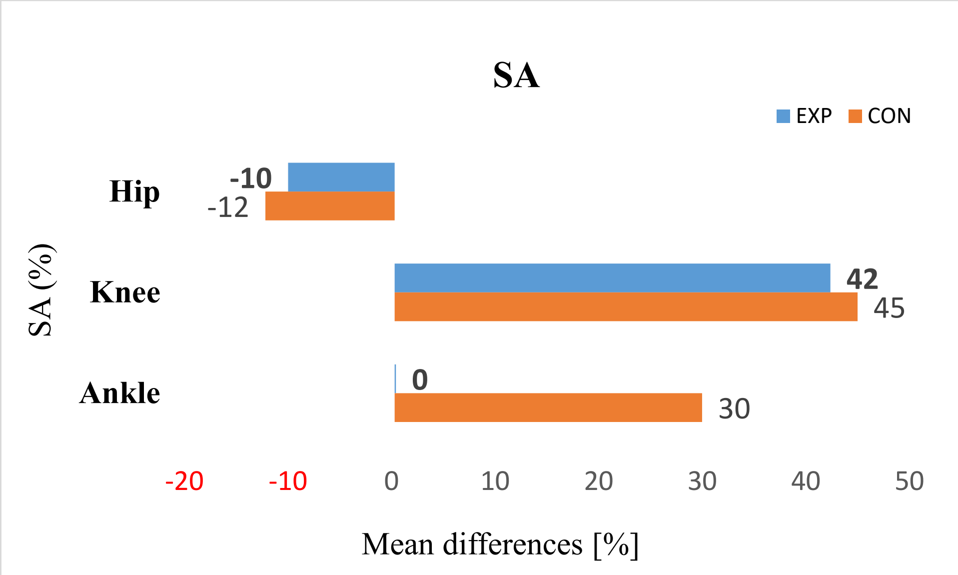


Figure 4.11: Bar chart on the SA mean value percentage differences for the EXP and CON groups

Table 4.23 outlines the SA summary of the the jump-landing tasks. The EXP and CON groups demonstrated significant differences in knee$_{SA}$ ($p < 0.05$). However, only the CON group showed significant differences in ankle$_{SA}$ ($p < 0.05$).

Table 4.23: SA summary of the jump-landing tasks (Data represented as Mean ± SEM)

	EXP				CON				EXP-CON	
SA (%)	Pre	Post	P	ES	Pre	Post	P	ES	P	ES
Hip$_{SA}$	41.88 ± 2.79	37.97 ± 3.48	0.30	0.19^	37.86 ± 2.80	33.66 ± 2.97	0.21	0.3^	0.25	0.3^
Knee$_{SA}$	22.51 ± 2.19	38.85 ± 2.83	0.00*	1.19@	24.01 ± 2.2	43.39 ± 2.36	0.00*	1.46@	0.23	0.28^
Ankle$_{SA}$	24.24 ± 2.25	24.21 ± 2.84	0.99	0.04~	18.66 ± 2.27	26.53 ± 2.43	0.01*	0.39^	0.56	0.09~

*@ Very large effect, ∞ Large effect, # Moderate effect, ^ Small effect, ~ Negligible effect, * Statistically significant difference*

When assessing SA during the SLR and SLL (**Table 4.24**), it was found that the EXP and CON groups had significant differences for SLR ($p < 0.05$) and CON group for SLL ($p < 0.05$), in knee$_{SA}$.

Table 4.24: SA of SLR and SLL (Data represented as Mean ± SEM)

	SLR				SLL			
	EXP		CON		EXP		CON	
SA (%)	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Hip$_{SA}$	36.89 ± 4.27	40.98 ± 5.30	26.43 ± 4.28	32.88 ± 4.58	39.38 ± 4.17	44.48 ± 5.30	44.04 ± 4.28	38.63 ± 4.72
Knee$_{SA}$	18.00 ± 3.52*	38.49 ± 4.43*	19.56 ± 3.52*	42.96 ± 3.79*	19.05 ± 3.43	37.49 ± 4.43	21.05 ± 3.52*	38.01 ± 3.91*
Ankle$_{SA}$	21.60 ± 5.35	20.83 ± 6.19	23.65 ± 5.16	15.79 ± 5.37	25.66 ± 4.98	18.81 ± 6.18	17.02 ± 5.16	17.16 ± 5.59

** Statistically significant difference*

Table 4.25 shows that both the EXP and CON groups demonstrated significant differences for the DVJ ($p < 0.05$), with the CON group having a significant difference for the SJPT ($p < 0.05$) in knee$_{SA}$. In addition, the CON group showed significant differences in ankle$_{SA}$ for both the DVJ and SJPT.

Table 4.25: SA of DVJ and SJPT (Data represented as Mean ± SEM)

	DVJ				SJPT			
	EXP		CON		EXP		CON	
SA (%)	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Hip$_{SA}$	43.04 ± 4.17	38.58 ± 5.30	31.19 ± 4.28	30.99 ± 4.46	38.22 ± 4.17	35.00 ± 5.30	33.10 ± 4.28	31.88 ± 4.46
Knee$_{SA}$	26.65 ± 3.43*	38.82 ± 4.43*	27.22 ± 3.52*	44.99 ± 3.69*	24.75 ± 3.43	32.81 ± 4.43	20.12 ± 3.52*	41.62 ± 3.69*
Ankle$_{SA}$	34.90 ± 4.82	16.32 ± 6.53	22.49 ± 4.98*	47.57 ± 5.84*	34.20 ± 4.82	42.72 ± 6.53	16.71 ± 4.98*	40.55 ± 5.36*

* *Statistically significant difference*

Summary

The changes in the landing impact forces were significant for both groups after the intervention. However, GRFs components (except MGRF) showed significant differences in both groups for unilateral landing. The EXP group experienced more landing forces during the SLL. Both groups had significant landing impact changes in the SJPT. However, in the DVJ, the EXP group had significant changes in vertical ground reaction force, while the CON group had significant mediolateral and anteroposterior changes. Time to peak changed significantly mediolaterally in both groups during the DVJ, however, the CON group peak resultant and anteroposterior force-time to peak increased more for the SJPT. The EXP and CON groups experienced significant changes in knee and ankle shock attenuation. The CON group increased more in knee and ankle shock attenuation during unilateral and bilateral landing.

F. KINEMATIC VARIABLES (EXPERIMENTAL VS CONTROL)

The following section reports on the differences between the EXP and CON groups in kinematic variables, both pre- and post-intervention. The kinematic variables that were analysed were impact peak acceleration (IPA) initial contact angles (IC angles), peak angles and range of motion (ROM).

Impact Peak Acceleration (IPA)

The IPA is reported for $pelvis_{accl}$, $thigh_{accl}$, $shank_{accl}$, and $foot_{accl}$, for the jump-landing tasks in the EXP and CON groups. The results of the IPA are presented in **Figure 4.12, Table 4.26, Table 4.27** and **Table 4.28**. The EXP group demonstrated a greater reduction post-intervention in $pelvis_{accl}$ (37 %), $thigh_{accl}$ (44 %) and $shank_{accl}$ (9 %) compared to the CON group (19 %, 38 % and 1 %, respectively). However, the CON group reduced $foot_{accl}$ by 13 % while there was no change in the EXP group (**Figure 4.12**).

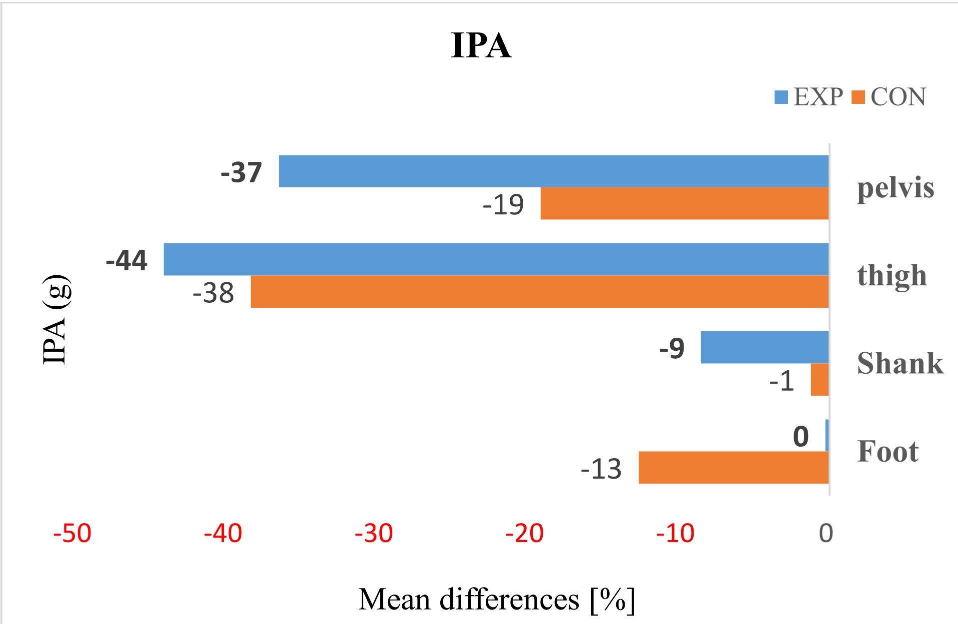


Figure 4.12: Bar chart on the IPA mean value percentage differences in the EXP and CON groups

Table 4.26 presents the IPA summary of the jump-landing tasks. There were significant differences for the EXP and CON groups in $pelvis_{accl}$ and $thigh_{accl}$, however, the effect sizes were higher in the EXP group when compared with CON group. The CON group demonstrated significant differences in $foot_{accl}$ ($p = 0.01$).

Table 4.26: IPA summary of the jump-landing tasks (Data represented as Mean ± SEM)

	EXP				CON				EXP-CON	
IPA (g)	Pre	Post	P	ES	Pre	Post	P	ES	P	ES
Pelvis$_{accl}$	6.88 ± 0.4	5.04 ± 0.49	0.00*	0.99∞	6.66 ± 0.4	5.59 ± 0.42	0.02*	0.44#	0.75	0.04~
Thigh$_{accl}$	11.92 ± 0.55	8.27 ± 0.68	0.00*	1.11@	10.89 ± 0.56	7.87 ± 0.59	0.00*	0.89∞	0.33	0.26^
Shank$_{accl}$	14.79 ± 0.67	13.63 ± 0.81	0.17	0.32^	14.16 ± 0.67	13.99 ± 0.59	0.71	0.06∞	0.88	0.07~
Foot$_{accl}$	14.68 ± 0.41	14.64 ± 0.52	0.94	0.01~	15.24 ± 0.41	13.53 ± 0.44	0.01*	0.45#	0.57	0.07~

*@ Very large effect, ∞ Large effect, # Moderate effect, ^ Small effect, ~ Negligible effect, * Statistically significant difference*

When examining the results of the unilateral jump-landing tasks (**Table 4.27**), it was found that both the EXP and CON groups had significant differences in pelvis$_{accl}$ and thigh$_{accl}$ for the SLR ($p < 0.05$). However, only the EXP group demonstrated significant differences in pelvis$_{accl}$ and foot$_{accl}$ for the SLL ($p < 0.05$). When assessing thigh$_{accl}$ for the SLL, it was found that both the EXP and CON group had significant differences ($p < 0.05$).

Table 4.27: IPA of SLR and SLL (Data represented as mean ± SEM)

	SLR				SLL			
	EXP		CON		EXP		CON	
IPA (g)	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Pelvis$_{accl}$	8.13 ± 0.55*	5.21 ± 0.68*	8.10 ± 0.55*	5.95 ± 0.58*	7.58 ± 0.54*	4.80 ± 0.68*	6.24 ± 0.55	5.49 ± 0.59
Thigh$_{accl}$	13.33 ± 0.86*	8.59 ± 1.05*	11.44 ± 0.86*	8.13 ± 0.92*	11.93 ± 0.84*	8.88 ± 1.05*	10.75 ± 0.86*	8.88 ± 0.94*
Shank$_{accl}$	15.67 ± 1.03	14.33 ± 1.27	14.00 ± 1.03	14.40 ± 1.10	13.20 ± 1.01	14.23 ± 1.27	12.98 ± 1.03	14.39 ± 1.13
Foot$_{accl}$	15.77 ± 0.93	16.16 ± 1.08	16.98 ± 0.90	15.58 ± 0.93	13.85 ± 0.86*	16.40 ± 1.08*	14.15 ± 0.90	14.89 ± 0.97

** Statistically significant difference*

Table 4.28 indicates the results pertaining to the bilateral jump-landing tasks. In this case, it was found that both the EXP and CON groups had significant differences in thigh$_{accl}$ for the DVJ and the SJPT ($p < 0.05$). However, only the CON group demonstrated a significant difference in foot$_{accl}$ for the DVJ. When assessing foot$_{accl}$, it was found that both groups had significant differences for the SJPT.

Table 4.28: IPA of DVJ and SJPT (Data represented as Mean ± SEM)

	DVJ				SJPT			
	EXP		CON		EXP		CON	
IPA (g)	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Pelvis$_{accl}$	5.67 ± 0.54	4.87 ± 0.68	6.38 ± 0.55	5.63 ± 0.57	6.87 ± 0.54	5.94 ± 0.68	6.76 ± 0.55	6.20 ± 0.57
Thigh$_{accl}$	9.95 ± 0.84*	8.03 ± 1.05*	9.57 ± 0.86*	7.29 ± 0.89*	11.24 ± 0.84*	9.26 ± 1.05*	10.25 ± 0.86*	7.89 ± 0.89*
Shank$_{accl}$	13.13 ± 1.01	13.53 ± 1.27	13.27 ± 1.03	13.53 ± 1.07	14.20 ± 1.01	14.00 ± 1.27	12.94 ± 1.03	12.83 ± 1.07
Foot$_{accl}$	11.73 ± 0.84	11.22 ± 1.08	11.63 ± 0.87*	9.21 ± 0.90*	11.69 ± 0.84*	10.14 ± 1.08*	12.24 ± 0.87*	9.60 ± 0.90*

** Statistically significant difference*

Initial contact angles

The IC angles are reported for lumbar flexion, hip flexion, hip abduction, knee flexion, knee abduction, ankle dorsiflexion, ankle inversion and ankle abduction for the jump-landing tasks in the EXP and CON groups. **Figure 4.13** shows that the EXP group had greater mean differences in hip and knee flexion (11.2 deg and 15.0 deg, respectively) compared to the CON group (9.5 deg and 9.5 deg, respectively). However, the CON group had greater knee abduction mean differences (3.3 deg) than the EXP group (1.1 deg). The CON group showed a larger reduction in ankle dorsiflexion and inversion (7.3 deg and 3.6 deg, respectively) in comparison to the EXP group (5.5 deg and 3.3 deg, respectively). Furthermore, there was an increase in ankle abduction (1.3 deg) in the CON group, with no change seen in the EXP group.

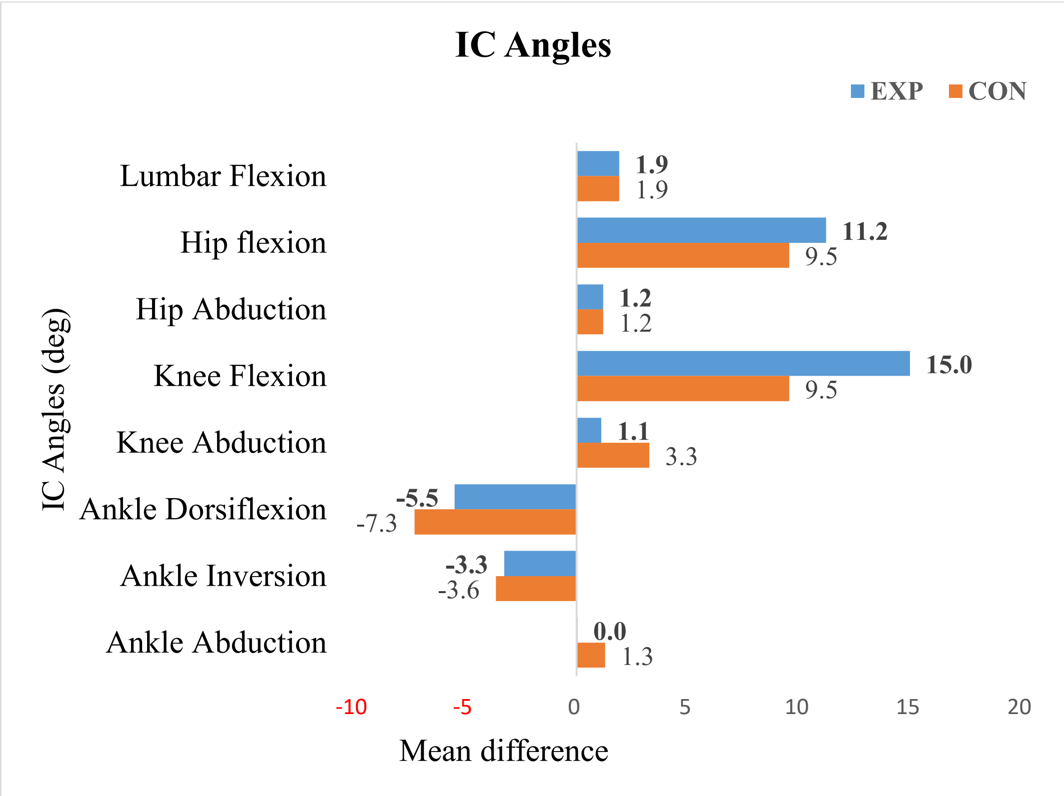


Figure 4.13: Bar chart on the IC angles mean value percentage differences in the EXP and CON groups

Table 4.29 presents the IC angles summary of the jump-landing tasks. The EXP and CON groups showed significant differences in hip flexion, hip abduction, knee flexion, knee abduction and ankle inversion ($p < 0.05$). However, only the EXP group demonstrated a significant difference in ankle dorsiflexion ($p < 0.05$).

Table 4.29: IC angles summary of the jump-landing tasks (Data represented as Mean ± SEM)

	EXP				CON				EXP-CON	
IC ANGLES (deg)	Pre	Post	P	ES	Pre	Post	P	ES	P	ES
Lumbar Flexion	8.6 ± 1.1	10.5 ± 1.3	0.16	0.21^	8.7 ± 1.1	10.6 ± 1.2	0.11	0.28^	0.96	0.05~
Hip flexion	19.6 ± 1.6	30.8 ± 2.0	0.00*	1.04∞	21.2 ± 1.6	30.8 ± 1.7	0.00*	0.71#	0.71	0.14~
Hip Abduction	7.2 ± 0.7	8.4 ± 0.8	0.05*	0.09~	6.5 ± 0.7	7.7 ± 0.7	0.03*	0.31^	0.49	0.03~
Knee Flexion	17.2 ± 1.6	32.2 ± 2.0	0.00*	1.1∞	21.2 ± 1.6	30.8 ± 1.7	0.00*	0.82∞	0.70	0.05~
Knee Abduction	2.4 ± 0.3	3.5 ± 0.3	0.01*	0.5#	4.4 ± 0.5	7.7 ± 0.6	0.00*	0.17^	0.66	0.01~
Ankle Dorsiflexion	33.2 ± 1.6	27.8 ± 2.0	0.04*	0.44#	35.1 ± 1.6	27.9 ± 1.7	0.00*	0.66#	0.56	0.05~
Ankle Inversion	10.2 ± 0.5	7.0 ± 0.7	0.00*	0.67#	10.0 ± 0.51	6.3 ± 0.5	0.00*	0.88∞	0.46	0.16^
Ankle Abduction	8.7 ± 0.6	8.7 ± 0.8	0.97	0.04~	6.8 ± 0.6	8.1 ± 0.7	0.06	0.27^	0.13	0.29^

*@ Very large practical effect, ∞ Large practical effect, # Moderate practical effect, ^ Small practical effect, ~ Negligible practical effect, * Statistically significant difference*

When assessing the IC angle changes for the unilateral jump-landing tasks (**Table 4.30**), it was found that the EXP and CON groups had significant differences in knee flexion and ankle dorsiflexion for the SLR ($p < 0.05$). However, only the EXP group demonstrated significant differences in hip flexion and ankle inversion for the SLR ($p < 0.05$). Furthermore, both groups experienced significant differences in ankle inversion for the SLL ($p < 0.05$), while the CON group demonstrated a significant difference in ankle abduction for the SLR ($p < 0.05$).

Table 4.30: IC angles of SLR and SLL (Data represented as Mean ± SEM)

	SLR				SLL			
	EXP		CON		EXP		CON	
IC ANGLES (deg)	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Lumbar Flexion	9.7 ± 1.5	9.5 ± 1.9	9.3 ± 1.6	8.8 ± 1.6	8.3 ± 1.6	10.3 ± 1.9	9.5 ± 1.6	9.6 ± 1.7
Hip flexion	18.4 ± 3.0*	29.1 ± 3.9*	20.9 ± 3.1	25.5 ± 3.2	18.5 ± 3.1	24.6 ± 3.9	21.8 ± 3.1	22.2 ± 3.5
Hip Abduction	4.4 ± 0.9	5.4 ± 1.1	3.8 ± 0.9	4.7 ± 1.0	6.8 ± 0.9	7.3 ± 1.1	6.5 ± 0.9	6.0 ± 1.0
Knee Flexion	12.0 ± 3.2*	29.9 ± 4.2*	14.6 ± 3.3*	25.5 ± 3.5*	11.8 ± 3.3	20.0 ± 4.2	13.7 ± 3.3	13.7 ± 3.8
Knee Abduction	1.4 ± 0.5	2.9 ± 0.6	2.3 ± 0.5	2.5 ± 0.5	2.2 ± 0.5	2.6 ± 0.6	1.4 ± 0.5	1.6 ± 0.6
Ankle Dorsiflexion	40.3 ± 2.8*	27.9 ± 3.5*	36.1 ± 2.8*	22.0 ± 3.0*	39.8 ± 2.8	33.6 ± 3.5	40.1 ± 2.8	35.8 ± 3.2
Ankle Inversion	5.5 ± 1.1*	6.3 ± 1.4*	4.2 ± 1.1	5.5 ± 1.1	9.7 ± 1.1*	5.6 ± 1.4*	11.1 ± 1.1*	6.1 ± 1.2*
Ankle Abduction	7.2 ± 1.1	6.3 ± 1.4	4.1 ± 1.2*	5.1 ± 1.2*	8.3 ± 1.2	8.6 ± 1.4	4.7 ± 1.2	6.2 ± 1.3

** Statistically significant difference*

The results of the changes in IC angle for the bilateral jump-landing tasks are outlined in **Table 4.31**. It was found that the EXP and CON groups had significant differences in knee flexion for the DVJ ($p < 0.05$). However, when looking at ankle dorsiflexion and inversion for the DVJ, only the CON group demonstrated significant differences ($p < 0.05$). Conversely, only the EXP group showed significant differences in lumbar flexion for the DVJ ($p < 0.05$). With respect to the SJPT, both groups had significant differences in hip flexion, knee flexion and ankle inversion ($p < 0.05$), while only the

CON group showed significant differences in lumbar flexion, hip abduction and ankle dorsiflexion ($p < 0.05$).

Table 4.31: IC angles of DVJ and SJPT (Data represented as Mean ± SEM)

	DVJ				SJPT			
	EXP		CON		EXP		CON	
IC ANGLES (deg)	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Lumbar Flexion	8.3 ± 1.5*	12.5 ± 1.9*	9.0 ± 1.6	9.4 ± 1.6	8.0 ± 1.5	7.6 ± 1.9	8.3 ± 1.6*	13.9 ± 1.6*
Hip flexion	26.5 ± 3.0	36.8 ± 3.9	23.1 ± 3.1*	42.4 ± 3.2*	17.5 ± 3.0*	42.1 ± 3.9*	17.8 ± 3.1*	34.2 ± 3.2*
Hip Abduction	8.5 ± 0.9	10.3 ± 1.1	8.0 ± 0.9	10.2 ± 1.0	8.1 ± 0.9	9.1 ± 1.1	7.1 ± 0.9*	9.8 ± 1.0*
Knee Flexion	22.4 ± 3.2*	39.1 ± 4.2*	21.3 ± 3.3*	43.2 ± 3.5*	21.1 ± 3.2*	46.3 ± 4.2*	21.2 ± 3.3*	36.1 ± 3.5*
Knee Abduction	3.0 ± 0.5	4.5 ± 0.6	2.7 ± 0.5	4.0 ± 0.5	2.5 ± 0.5*	3.6 ± 0.6*	2.9 ± 0.5	3.6 ± 0.5
Ankle Dorsiflexion	26.3 ± 2.8	20.9 ± 3.5	29.5 ± 2.8*	20.7 ± 3.0*	26.5 ± 2.8	18.7 ± 3.5	31.0 ± 2.8*	21.9 ± 3.0*
Ankle Inversion	11.0 ± 1.1	8.2 ± 1.4	9.3 ± 1.1*	6.4 ± 1.1*	11.3 ± 1.1*	6.7 ± 1.4*	11.2 ± 1.1*	8.9 ± 1.1*
Ankle Abduction	8.9 ± 1.1	5.4 ± 1.4	8.4 ± 1.2	7.8 ± 1.2	8.5 ± 1.1	6.1 ± 1.4	7.1 ± 1.2	5.9 ± 1.2

* *Statistically significant difference*

Peak angles

The peak angles are reported for lumbar flexion, hip flexion, hip abduction, knee flexion, knee abduction, ankle dorsiflexion, ankle inversion and ankle abduction for the jump-landing tasks in the EXP and CON group. **Figure 4.14** illustrates that the CON group increased more than the EXP group in lumbar flexion (4.4 deg vs 2.4 deg) and hip abduction (1.5 deg vs 1.2 deg), respectively after the intervention. However, the EXP group increased hip flexion (13.0 deg vs 10.7 deg), knee flexion (14.8 deg vs 9.2 deg), knee abduction (0.1 deg vs -0.3 deg), ankle dorsiflexion (2.5 deg vs 2.3 deg) and ankle inversion (0.7 deg vs 0.5 deg) to a greater extent than the CON group. In addition, ankle abduction in the EXP group (0.7 deg) was reduced more than in the CON group (0.6 deg).

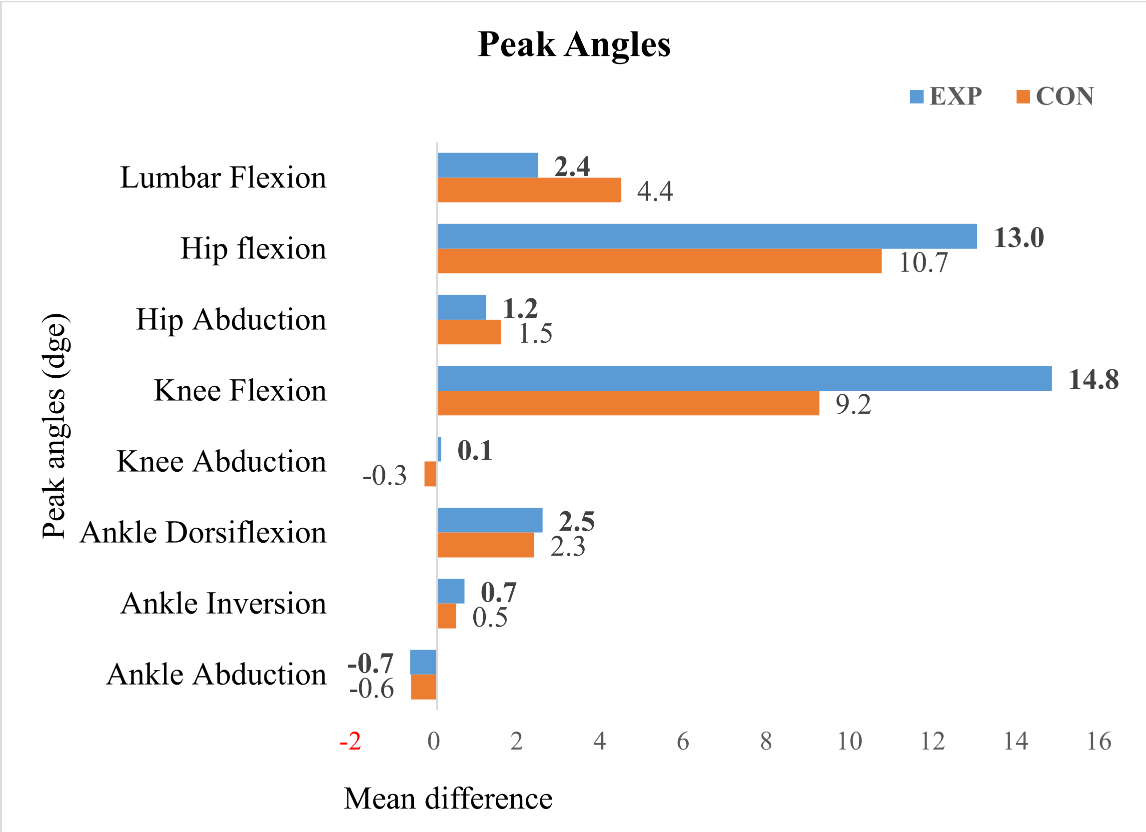


Figure 4.14: Bar chart on the peak angles mean value percentage differences in the EXP and CON groups

Table 4.32 shows the peak angles summary of the jump-landing tasks. Both the EXP and CON groups had significant differences in hip flexion, knee flexion, knee abduction and ankle dorsiflexion ($p < 0.05$). However, only the CON group demonstrated significant differences in lumbar flexion and hip abduction ($p < 0.05$).

Table 4.32: Peak angles summary of the jump-landing tasks (Data represented as Mean ± SEM)

	EXP				CON				EXP-CON	
PEAK ANGLES (deg)	Pre	Post	P	ES	Pre	Post	P	ES	P	ES
Lumbar Flexion	7.6 ± 1.1	10.0 ± 1.4	0.16	0.44#	6.8 ± 1.1	11.3 ± 1.2	0.01*	0.72#	0.85	0.07~
Hip flexion	36.1 ± 2.2	49.1 ± 2.7	0.00*	0.86∞	36.3 ± 2.2	47.0 ± 2.3	0.00*	0.55#	0.94	0.09~
Hip Abduction	7.2 ± 0.7	8.4 ± 0.8	0.10	0.03~	6.1 ± 0.7	7.7 ± 0.7	0.02*	0.34^	0.37	0.06~
Knee Flexion	40.1 ± 2.1	54.9 ± 2.6	0.00*	0.86∞	42.5 ± 2.2	51.7 ± 2.3	0.00*	0.55#	0.79	0.11~
Knee Abduction	5.3 ± 0.4	5.4 ± 0.6	0.02*	0.45#	5.4 ± 0.5	5.1 ± 0.5	0.02*	0.27^	0.97	0.03~
Ankle Dorsiflexion	14.1 ± 1.1	16.6 ± 1.3	0.02*	0.45#	14.9 ± 1.1	17.2 ± 1.2	0.02*	0.27^	0.64	0.03~
Ankle Inversion	6.7 ± 0.4	7.8 ± 0.5	0.21	0.18^	6.8 ± 0.4	7.2 ± 0.4	0.33	0.11~	0.93	0.01~
Ankle Abduction	6.1 ± 0.4	5.5 ± 0.6	0.30	0.21^	6.7 ± 0.4	6.1 ± 0.5	0.25	0.18^	0.27	0.14~

@ *Very large effect,* ∞ *Large effect,* # *Moderate effect,* ^ *Small effect,* ~ *Negligible effect,* * *Statistically significant difference*

When assessing the peak angle changes for the unilateral jump-landing tasks (**Table 4.33**), it was found that the EXP and CON groups had significant differences in knee flexion and ankle inversion for the SLR ($p < 0.05$). However, only the EXP group demonstrated a significant difference in ankle abduction for the SLR ($p < 0.05$), while the CON group demonstrated a significant difference in ankle dorsiflexion for the SLR ($p < 0.05$). Furthermore, the EXP group experienced significant differences in knee flexion and ankle dorsiflexion for the SLL ($p < 0.05$).

Table 4.33: Peak angles of SLR and SLL (Data represented as Mean ± SEM)

	SLR				SLL			
	EXP		CON		EXP		CON	
PEAK ANGLES (deg)	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Lumbar Flexion	7.5 ± 1.5	7.8 ± 1.9	6.7 ± 1.5	8.4 ± 1.6	7.2 ± 1.5	7.5 ± 1.9	6.4 ± 1.6	8.8 ± 1.7
Hip flexion	28.4 ± 3.0	35.0 ± 3.8	28.7 ± 3.1	34.8 ± 3.2	27.9 ± 3.1	33.7 ± 3.8	31.6 ± 3.1	32.9 ± 3.4
Hip Abduction	2.8 ± 1.0	4.4 ± 1.2	3.9 ± 1.0	5.1 ± 1.1	6.5 ± 1.0	6.8 ± 1.2	4.4 ± 1.0	3.9 ± 1.1
Knee Flexion	29.4 ± 2.9*	41.3 ± 3.7*	30.9 ± 3.0*	41.4 ± 3.1*	27.6 ± 3.0*	38.3 ± 3.7*	33.0 ± 3.0	35.6 ± 3.3
Knee Abduction	4.0 ± 0.7	3.4 ± 0.9	4.9 ± 0.7	5.0 ± 0.8	4.9 ± 0.7	5.7 ± 0.9	2.5 ± 0.7	4.0 ± 0.8
Ankle Dorsiflexion	14.2 ± 1.6	12.4 ± 2.0	12.7 ± 1.7*	14.4 ± 1.7*	7.8 ± 1.7*	11.5 ± 2.0*	10.1 ± 1.7	11.2 ± 1.8
Ankle Inversion	6.0 ± 0.9*	9.4 ± 1.2*	7.3 ± 1.0*	8.3 ± 1.0*	8.3 ± 1.0	7.9 ± 1.2	8.3 ± 1.0	9.2 ± 1.1
Ankle Abduction	7.8 ± 0.9*	4.9 ± 1.2*	8.6 ± 0.9	6.9 ± 1.0	5.7 ± 0.9	3.9 ± 1.2	7.6 ± 0.9	5.6 ± 1.0

* *Statistically significant difference*

The results of the changes in IC angle for the bilateral jump-landing tasks are outlined in **Table 4.34**. It was found that the EXP and CON groups had significant differences in lumbar and knee flexion for the DVJ ($p < 0.05$), while only the CON group demonstrated a significant difference in ankle dorsiflexion for DVJ ($p < 0.05$). For the SJPT, both groups had significant differences in knee flexion ($p < 0.05$), while only the CON group experienced significant differences in lumbar flexion and hip abduction ($p < 0.05$).

Table 4.34: Peak angles of DVJ and SJPT (Data represented as Mean ± SEM)

	DVJ				SJPT			
	EXP		CON		EXP		CON	
PEAK ANGLES (deg)	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Lumbar Flexion	9.0 ± 1.5*	13.5 ± 1.9*	9.4 ± 1.5*	11.1 ± 1.6*	8.8 ± 1.5	10.6 ± 1.9	6.6 ± 1.5*	13.8 ± 1.6*
Hip flexion	46.9 ± 3.0	63.7 ± 3.8	45.0 ± 3.1	64.7 ± 3.2	41.0 ± 3.0	64.0 ± 3.8	40.0 ± 3.1	55.9 ± 3.2
Hip Abduction	9.6 ± 1.0	11.1 ± 1.2	8.9 ± 1.0	10.7 ± 1.1	9.5 ± 1.0	9.7 ± 1.2	6.9 ± 1.0*	10.5 ± 1.1*
Knee Flexion	53.1 ± 2.9*	69.2 ± 3.7*	53.7 ± 3.0*	67.7 ± 3.1*	50.4 ± 2.9*	70.6 ± 3.7*	52.3 ± 3.0*	61.9 ± 3.1*
Knee Abduction	6.1 ± 0.7	6.6 ± 0.9	7.1 ± 0.7	5.5 ± 0.8	6.3 ± 0.7	5.9 ± 0.9	7.1 ± 0.7	6.1 ± 0.8
Ankle Dorsiflexion	18.9 ± 1.6	21.3 ± 2.0	20.3 ± 1.7*	23.0 ± 1.7*	19.9 ± 1.6	20.2 ± 2.0	18.5 ± 1.7	20.3 ± 1.7
Ankle Inversion	7.6 ± 0.9	7.0 ± 1.2	6.3 ± 1.0	5.4 ± 1.0	6.6 ± 0.9	5.8 ± 1.2	6.0 ± 1.0	5.1 ± 1.0
Ankle Abduction	6.0 ± 0.9	5.7 ± 1.2	6.0 ± 0.9	6.2 ± 1.0	6.4 ± 0.9	7.3 ± 1.2	7.4 ± 0.9	6.5 ± 1.0

* *Statistically significant difference*

Range of motion

The ROM findings are reported for hip flexion, hip abduction, knee flexion, knee abduction, ankle dorsiflexion, ankle inversion and ankle abduction for the jump-landing tasks in the EXP and CON groups. The results of the ROM are presented in **Figure 4.15, Table 4.35, Table 4.36** and **Table 4.37**. Figure 4.15 shows that the EXP group had greater increases in hip flexion (9.0 deg vs 4.8 deg), hip abduction (2.2 deg vs 1.8 deg), knee flexion (7.3 deg vs 4.0 deg), ankle dorsiflexion (1.7 deg vs 1.5 deg) and ankle abduction (2.0 deg vs 0.5 deg) when compared to the CON group. Conversely, the CON showed decreases in ankle inversion (2.1 deg vs 1.1 deg) and knee abduction (2.7 deg vs 1.0 deg) to a greater extent than found in the EXP group.

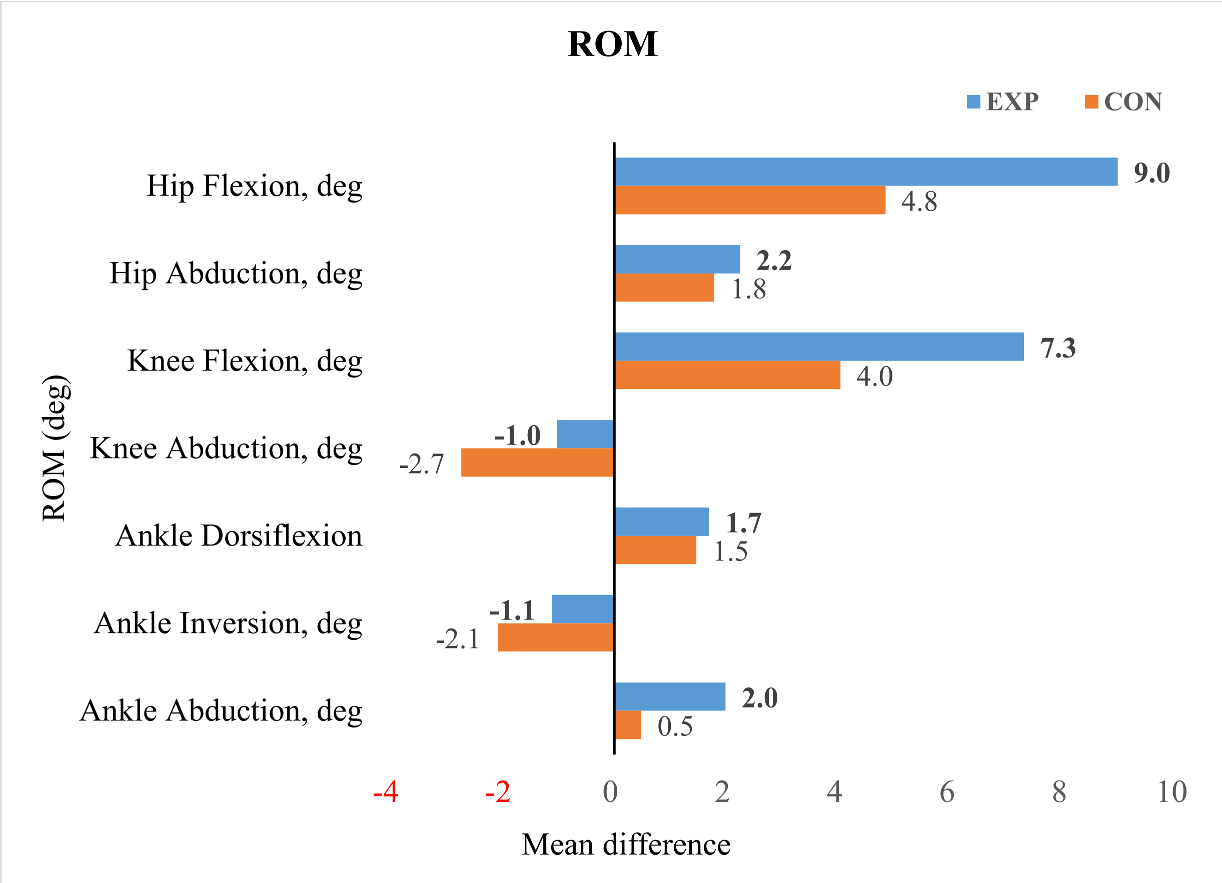


Figure 4.15: Bar chart on the ROM mean value percentage differences for the EXP and CON groups

Table 4.35 indicates the ROM summary of the jump-landing tasks. The EXP and CON groups had significant differences in hip abduction ($p < 0.05$). With respect to the remaining variables, the EXP group demonstrated significant differences in hip flexion, knee flexion and ankle abduction, while the CON group showed significant differences in knee abduction and ankle inversion ($p < 0.05$).

Table 4.35: ROM summary of the jump-landing tasks (Data represented as Mean ± SEM)

	EXP				CON				EXP-CON	
ROM (deg)	Pre	Post	P	ES	Pre	Post	P	ES	P	ES
Hip flexion	28.8 ± 4.6	37.8 ± 5.2	0.03*	0.66#	35.4 ± 4.6	40.2 ± 4.7	0.15	0.33^	0.48	0.13~
Hip Abduction	0.5 ± 0.5	2.7 ± 0.6	0.00*	0.59#	1.1 ± 0.5	2.9 ± 0.6	0.00*	0.39^	0.62	0.12~
Knee Flexion	31.1 ± 4.3	38.4 ± 4.7	0.03*	0.69#	38.4 ± 4.3	42.5 ± 4.4	0.13	0.34^	0.32	0.21^
Knee Abduction	1.1 ± 0.7	0.1 ± 0.8	0.22	0.1~	2.8 ± 0.7	0.1 ± 0.7	0.00*	0.58#	0.35	0.17^
Ankle Dorsiflexion	8.3 ± 1.4	9.9 ± 1.6	0.22	0.48#	9.4 ± 1.4	10.8 ± 1.4	0.21	0.26^	0.51	0.08~
Ankle Inversion	-0.5 ± 0.6	-1.6 ± 0.7	0.15	0.19^	-0.2 ± 0.6	-2.3 ± 0.6	0.00*	0.36^	0.34	0.16^
Ankle Abduction	-0.3 ± 0.5	1.7 ± 0.6	0.02*	0.43#	0.7 ± 0.5	1.2 ± 0.5	0.5	0.1~	0.60	0.08~

@ *Very large effect,* ∞ *Large effect,* # *Moderate effect,* ^ *Small effect,* ~ *Negligible effect,* * *Statistically significant difference*

When assessing the results with respect to ROM during the unilateral jump-landing tasks (**Table 4.36**), it was found that the EXP and CON groups had significant differences in ankle inversion for the SLR ($p < 0.05$). However, only the CON group demonstrated significant differences in hip abduction, knee flexion, and ankle dorsiflexion for the SLR ($p < 0.05$). The EXP group exhibited a significant difference in ankle abduction for the SLR ($p < 0.05$). When assessing the SLL, it was found that the EXP group had significant differences in hip flexion, hip abduction, and knee flexion ($p < 0.05$), while the CON group had a significant difference in ankle abduction ($p < 0.05$).

Table 4.36: ROM of SLR and SLL (Data represented as Mean ± SEM)

	SLR				SLL			
	EXP		CON		EXP		CON	
ROM (deg)	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Hip flexion	18.4 ± 6.2	25.4 ± 6.9	19.0 ± 6.3	25.9 ± 6.4	17.4 ± 6.2*	30.0 ± 6.9*	21.8 ± 6.2	25.9 ± 6.4
Hip Abduction	-3.3 ± 0.9	-2.0 ± 1.1	-4.2 ± 0.9*	-1.3 ± 1.0	-1.1 ± 0.9*	1.2 ± 1.1*	-0.6 ± 0.9	-0.5 ± 1.0
Knee Flexion	22.9 ± 6.0	29.8 ± 6.5	26.3 ± 6.1*	33.9 ± 6.2*	22.5 ± 6.0*	38.4 ± 6.5*	25.3 ± 6.1	31.0 ± 6.2
Knee Abduction	2.4 ± 1.0	2.3 ± 1.3	3.1 ± 1.1	2.2 ± 1.1	-2.7 ± 1.0	-1.2 ± 1.3	-0.8 ± 1.1	-1.9 ± 1.1
Ankle Dorsiflexion	8.4 ± 1.9	9.3 ± 2.2	9.4 ± 2.0*	14.1 ± 2.0*	6.6 ± 2.0	9.6 ± 2.2	9.3 ± 2.0	11.8 ± 2.1
Ankle Inversion	3.8 ± 1.0*	-5.8 ± 1.3*	3.7 ± 1.1*	-6.0 ± 1.1*	-6.3 ± 1.1	-5.3 ± 1.3	-6.2 ± 1.1	-7.4 ± 1.2
Ankle Abduction	-5.9 ± 1.1*	2.0 ± 1.4*	-5.1 ± 1.1*	3.7 ± 1.2*	2.6 ± 1.1	0.7 ± 1.4	5.2 ± 1.1*	1.9 ± 1.3*

* *Statistically significant difference*

With respect to the bilateral jump-landing tasks (**Table 4.37**), it was found that the EXP and CON groups had significant differences in knee abduction for the DVJ and hip abduction for the SJPT ($p < 0.05$). The EXP group demonstrated significant differences in hip flexion, hip abduction and knee flexion for the DVJ while the CON group showed significant differences in knee abduction for the SJPT ($p < 0.05$).

Table 4.37: ROM of DVJ and SJPT (Data represented as mean ± SEM)

	DVJ				SJPT			
	EXP		CON		EXP		CON	
ROM (deg)	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Hip flexion	44.8 ± 6.2*	58.5 ± 6.9*	53.9 ± 6.2	63.2 ± 6.4	33.9 ± 6.2	43.5 ± 6.9	42.8 ± 6.2	48.9 ± 6.4
Hip Abduction	3.7 ± 0.9*	7.0 ± 1.1*	5.7 ± 0.9	7.3 ± 1.0	1.7 ± 0.9*	5.4 ± 1.1*	4.0 ± 0.9*	6.3 ± 1.0*
Knee Flexion	42.0 ± 6.0*	51.3 ± 6.5*	51.6 ± 6.1	56.9 ± 6.2	35.5 ± 6.0	40.0 ± 6.5	46.4 ± 6.1	49.1 ± 6.2
Knee Abduction	1.6 ± 1.0*	-1.2 ± 1.3*	3.6 ± 1.1*	0.7 ± 1.1*	1.0 ± 1.0	-0.6 ± 1.3	3.8 ± 1.1*	0.0 ± 1.1*
Ankle Dorsiflexion	9.8 ± 1.9	12.9 ± 2.2	11.8 ± 1.9	11.9 ± 2.0	8.1 ± 1.9	5.9 ± 2.2	6.5 ± 1.9	6.0 ± 2.0
Ankle Inversion	0.1 ± 1.0	2.3 ± 1.3	3.5 ± 1.1	3.3 ± 1.1	1.6 ± 1.0	1.7 ± 1.3	2.4 ± 1.1	2.3 ± 1.1
Ankle Abduction	0.6 ± 1.1	3.8 ± 1.4	1.4 ± 1.1	3.2 ± 1.2	1.2 ± 1.1	3.3 ± 1.4	3.1 ± 1.1	2.6 ± 1.2

** Statistically significant difference*

Summary

With respect to IPA, the EXP group showed a greater reduction at the pelvis, thigh and shank while the CON group showed a greater reduction in the foot. For the initial contact angles, both groups had a significant increase in knee flexion and knee abduction and reduction in ankle inversion. At peak angles, both groups also had significant increases in hip flexion, knee flexion, knee abduction and ankle dorsiflexion. Furthermore, the CON group significantly increased in lumbar flexion and hip abduction peak angles. Both groups significantly increased in hip abduction ROM, while the EXP group significantly increased ROM for ankle abduction, hip and knee flexion.

G. SUBJECTIVE EVALUATION

The following section reports on the descriptive and inferential analysis of the subjective evaluation between the EXP and CON groups. The subjective evaluations in this section are the Landing Error Scoring System (LESS), subjective experience of barefoot activities, and modified Lower Limb Comfort Index (mLLCI).

Landing Error Scoring System

The results of the LESS for the EXP and CON groups are presented in **Figure 4.16, Table 4.38,** Error! Reference source not found.**, Table 4.40, Table 4.41** and **Table 4.42**, respectively. **Table 4.38** shows that the EXP group had a higher frequency of excellent ratings (50 %) than the CON group (40 %), although the EXP group had a lower frequency of good ratings (26.7 %) than the CON group (33.3 %) at pre-testing. Both groups had the same moderate LESS rating, and only the CON group had two participants with a poor LESS rating.

Table 4.38: Descriptive summary of the pre-testing LESS score rating

	EXP (Pre-test, n=15)			**CON (Pre-test, n=15)**		
	Rating	Frequency	Percent	Rating	Frequency	Percent
1	Excellent	9	50	Excellent	6	40
2	Good	4	26.7	Good	5	33.3
3	Moderate	2	13.3	Moderate	2	13.3
4	Poor	-	-	Poor	2	13.3

When assessing the LESS ratings between the groups after the intervention (**Table 4.39**), it was found that the EXP group had the highest rating possible for all participants (Excellent = 100 %), while the CON group only had an excellent rating for 69.2 % of the participants, with the remaining 30.8 % falling in the good category.

Table 4.39: Descriptive summary of the post-testing LESS score rating

	EXP (Post-test, n=9)			**CON (Post-test, n=12)**		
	Rating	Frequency	Percent	Rating	Frequency	Percent
1	Excellent	9	100	Excellent	9	69.2
2	Good	-	-	Good	4	30.8
3	Moderate	-	-	Moderate	-	-
4	Poor	-	-	Poor	-	-

Table 4.40 presents pre-test Chi-square analysis of the LESS items between the EXP and CON groups. Knee flexion (item 1), hip flexion (item 2) and knee flexion displacement (item 5) were not analysed due to no injury risk score. Ankle plantar flexion (item 4), trunk flexion (item 6), and hip flexion (item 7) had negligible effect sizes. There were small effect sizes for sagittal plane overall impression (item 8), lateral trunk flexion (item 9), symmetric initial foot contact (item 11), foot position (item 12,), knee valgus displacement (item 16) and the overall impression (item 17). The sagittal plane overall impression shows that the EXP group had a higher frequency correct landing score than the CON group [7 (50 %) vs 4 (28.6 %)]; a lower frequency with respect to average landing [7 (50 %) vs 8 (57.1 %)]; and had no stiff landings in comparison to the CON group [2 (14.3 %)]. According to the overall impression (item 17), the EXP group had more excellent landings [4 (28.6 %) vs 2 (14.3 %)] and a lower frequency of average landings [10 (71.4 %) vs 12 (85.7 %)] than the CON group. There were no significant differences reported in any of the other items for the EXP and CON groups.

Table 4.40: LESS items pre-test Chi-square result

PRE-TEST						
	LESS ITEMS	**EXP**	**CON**	χ^2	**P**	**V**
1	Knee flexion: greater than 30 deg (Sagittal View evaluated at IC)	Y^C=14(100%) N^E=0 (0%)	Y^C=14(100%) N^E=0 (0%)	NA	NA	NA
2	Hip flexion: Hips are flexed (Sagittal View evaluated at IC)	Y^C=14(100%) N^E=0 (0%)	Y^C=14(100%) N^E=0 (0%)	NA	NA	NA
3	Trunk flexion: Trunk is flexed on hips (Sagittal View evaluated at IC)	Y^C=10(71.4%) N^E=4 (28.6%)	Y^C=10(71.4%) N^E=4 (28.6%)	0.00	1.00	0.00~
4	Ankle Plantar Flexion: Toes to heel (Sagittal View evaluated at IC)	Y^C=10(71.4%) N^E=4 (28.6%)	Y^C=11(78.6%) N^E=3 (21.4%)	0.19	0.66	0.08~
5	Knee Flexion Displacement: greater than 45 deg (Sagittal View evaluated between IC and MKF)	Y^C=14(100%) N^E=0 (0%)	Y^C=14(100%) N^E=0 (0%)	NA	NA	NA
6	Trunk Flexion: greater than at contact (Sagittal View evaluated between IC and MKF)	Y^C=11(78.6%) N^E=3 (21.4%)	Y^C=8(57.1.6%) N^E=6 (42.9%)	0.19	0.66	0.08~
7	Hip Flexion: greater than at contact (Sagittal View evaluated between IC and MKF)	Y^C=10(71.4%) N^E=4 (28.6%)	Y^C=11(78.6%) N^E=3 (21.4%)	0.19	0.66	0.08~
8	Sagittal plane joint displacement (Overall)	Y^C=7(50%) AV^E=7 (50%)	Y^C=4(28.6%) AV^E=8(57.1%) ST^E=2(14.3%)	2.8	0.24	0.32^
9	Lateral trunk flexion: trunk flexed to left or right (Frontal View evaluated at IC)	N^C=3(21.4%) Y^E=11(78.6%)	N^C=5(35.7%) Y^E=9(64.3%)	0.70	0.40	0.16^
10	Knee valgus: knees over the midfoot (Frontal View evaluated at IC)	Y^C=4(28.6%) N^E=10(71.4%)	Y^C=4(28.6%) N^E=10(71.4%)	0.00	1.00	0.00~
11	Initial Foot Contact: Symmetric (Frontal View evaluated at IC)	Y^C=11(78.6%) N^E=3(21.4%)	Y^C=13(92.9%) N^E=1(7.1%)	1.16	0.28	0.20^
12	Foot position: Toes pointing out greater than 30 degrees (Frontal View evaluated at entire foot contact with Ground)	N^C=14(100%) Y^E=0(0%)	N^C=13(92.9%) Y^E=1(7.1%)	1.03	0.31	0.19^
13	Foot position: Toes pointing out less than 30 deg (Frontal View evaluated at entire foot contact with Ground)	N^C=1(7.1%) Y^E=13(92.9%)	N^C=2(14.3%) Y^E=12(85.7%)	0.37	0.54	0.12~
14	Stance width: less than shoulder width (Frontal View evaluated at entire foot contact with Ground)	N^C=11(78.6%) Y^E=3(21.4%)	N^C=12(85.7%) Y^E=2(14.3%)	0.24	0.62	0.09~
15	Stance width: greater than shoulder width (Frontal View evaluated at entire foot contact with Ground)	N^C=9(64.3%) Y^E=5(35.7%)	N^C=10(71.4%) Y^E=4(28.6%)	0.16	0.69	0.08~
16	Knee valgus displacement: inside of large toe (Frontal View evaluated at IC and MKF)	N^C=3(21.4%) Y^E=11(78.6%)	N^C=1(7.1%) Y^E=13(92.9%)	1.17	0.28	0.20^
17	Overall impression	EX^C=4(28.6%) AV^E=10(71.4%)	EX^C=2(14.3%) AV^E=12(85.7%)	0.85	0.36	0.17^

χ^2 = Chi-square, P = P-value, V = Cramer V, Y^C = Yes Correct, N^C = No Correct, N^E = No Error, Y^E = Yes Error, EX^C = Excellent Correct, AV^E = Average Error, ST^E = Stiff Error, PO^E = Poor Error, NA = Not Available, ^ Small effect, ~ Negligible effect.

Table 4.41 presents the post-test Chi-square analysis of LESS items between the EXP and CON groups. Knee flexion (item 1), hip flexion (item 2), trunk flexion (item 3), knee flexion displacement (item 5), trunk flexion (item 6), hip flexion (item 7), foot position toe in (item 12), foot position toe out (item 13), and stance width (item 14) had no error score and were therefore not analysed. Ankle plantarflexion (item 4), sagittal plane overall impression (item 8), knee valgus (item 10), symmetric initial foot contact (item 11), stance width (item 15) and overall impression (item 17) had small effect sizes. In the overall sagittal joint displacement (item 8), the EXP had a lower number of correct scores [4 (50 %) vs 7 (58.3 %)], higher average error score [5 (50 %) vs 3 (25 %)] and no stiff error score when compared with the CON group [2 (16.7 %)]. The overall impression also shows that the EXP group had lower frequency of excellent scores [3 (33.3 %) vs 6 (50 %)], more average error scores [6 (66.7 %) vs 5 (41.7 %)] and no poor error scores when compared with the CON group [1 (8.3 %)]. There were no significant differences reported in any of the items for the EXP and CON groups.

Table 4.41: LESS items post-test Chi-square result

POST-TEST						
	LESS ITEMS	**EXP**	**CON**	χ^2	**P**	**V**
1	Knee flexion: greater than 30 degrees (Sagittal View evaluated at IC)	Y^C=9(100%) N^E=0(0%)	Y^C=12(100%) N^E=0(0%)	NA	NA	NA
2	Hip flexion: Hips are flexed (Sagittal View evaluated at IC)	Y^C=9(100%) N^E=0(0%)	Y^C=12(100%) N^E=0(0%)	NA	NA	NA
3	Trunk flexion: Trunk is flexed on hips (Sagittal View evaluated at IC)	Y^C=9(100%) N^E=0(0%)	Y^C=12(100%) N^E=0(0%)	NA	NA	NA
4	Ankle Plantar Flexion: Toes to heel (Sagittal View evaluated at IC)	Y^C=8(71.4%) N^E=1 (28.6%)	Y^C=12(100%) N^E=0(0%)	1.40	0.24	0.26^
5	Knee Flexion Displacement: greater than 45 degrees (Sagittal View evaluated between IC and MKF)	Y^C=9(100%) N^E=0(0%)	Y^C=12(100%) N^E=0(0%)	NA	NA	NA
6	Trunk Flexion: greater than at contact (Sagittal View evaluated between IC and MKF)	Y^C=9(100%) N^E=0(0%)	Y^C=12(100%) N^E=0(0%)	NA	NA	NA
7	Hip Flexion: greater than at contact (Sagittal View evaluated between IC and MKF)	Y^C=9(100%) N^E=0(0%)	Y^C=12(100%) N^E=0(0%)	NA	NA	NA
8	Sagittal plane joint displacement (Overall)	Y^C=4(50%) AV^E=5 (50%) ST^E=0(0%)	Y^C=7(58.3%) AV^E=3(25%) ST^E=2(16.7%)	2.95	0.23	0.38^
9	Lateral trunk flexion: trunk flexed to left or right (Frontal View evaluated at IC)	N^C=5(55.6%) Y^E=4(44.4%)	N^C=7(58.3%) Y^E=5(41.7%)	0.02	0.89	0.03~
10	Knee valgus: knees over the midfoot (Frontal View evaluated at IC)	Y^C=5(55.6%) N^E=4(44.4%)	Y^C=3(25%) N^E=9(75%)	2.03	0.15	0.31^
11	Initial Foot Contact: Symmetric (Frontal View evaluated at IC)	Y^C=6(66.7%) N^E=3(33.3%)	Y^C=11(91.7%) N^E=1(8.3%)	2.08	0.15	0.32^
12	Foot position: Toes pointing out greater than 30 degrees (Frontal View evaluated at entire foot contact with Ground)	Y^C=9(100%) N^E=0(0%)	Y^C=12(100%) N^E=0(0%)	NA	NA	NA
13	Foot position: Toes pointing out less than 30 degrees (Frontal View evaluated at entire foot contact with Ground)	Y^C=9(100%) N^E=0(0%)	Y^C=12(100%) N^E=0(0%)	NA	NA	NA
14	Stance width: less than shoulder width (Frontal View evaluated at entire foot contact with Ground)	Y^C=9(100%) N^E=0(0%)	Y^C=12(100%) N^E=0(0%)	NA	NA	NA
15	Stance width: greater than shoulder width (Frontal View evaluated at entire foot contact with Ground)	N^C=5(55.6%) Y^E=4(44.4%)	N^C=10(83.3%) Y^E=2(16.7%)	1.94	0.16	0.30^
16	Knee valgus displacement: inside of large toe (Frontal View evaluated at IC and MKF)	Y^C=9(100%) N^E=0(0%)	Y^C=12(100%) N^E=0(0%)	NA	NA	NA
17	Overall impression	EX^C=3(33.3%) AV^E=6(66.7%)	EX^C=6(50%) AV^E=5(41.7%) PO^E=1(8.3%)	1.69	0.43	0.28^

χ^2 = Chi-square, P = P-value, V = Cramer V, Y^C = Yes Correct, N^C = No Correct, N^E = No Error, Y^E = Yes Error, EX^C = Excellent Correct, AV^E = Average Error, ST^E = Stiff Error, PO^E = Poor Error, NA = Not Available, ^Small effect, ~ Negligible effect.

Figure 4.16 illustrates that the LESS score was reduced more in the EXP group (30 %) compared to the CON group (28 %).

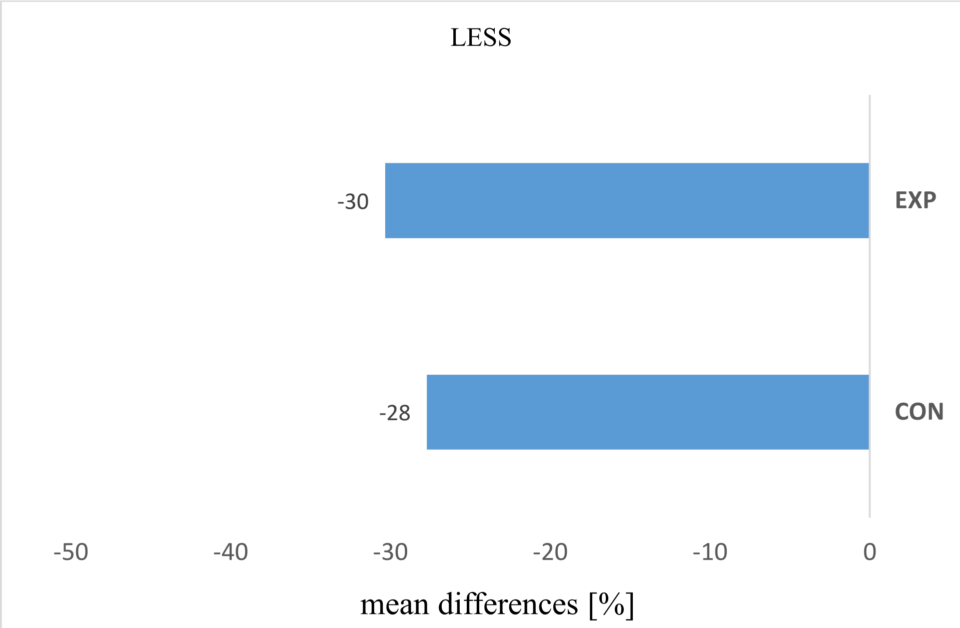


Figure 4.16: Bar chart on the LESS mean value percentage differences in EXP and CON group

Table 4.42 shows that the EXP and CON groups both demonstrated significant differences in LESS scores after the intervention.

Table 4.42: LESS result of EXP and CON (Data represented as mean ± SEM)

	EXP				CON				EXP-CON	
	Pre	Post	P	ES	Pre	Post	P	ES	P	ES
LESS	4.10±0.30	3.15±0.38	0.04*	0.75#	3.99±0.31	3.12±0.33	0.04*	0.67	0.85	0.11~

@ *Very large practical effect,* ∞ *Large practical effect,* # *Moderate practical effect,* ^ *Small practical effect,* ~ *Negligible practical effect,* * *Statistically significant difference*

Previous barefoot experience

Before the intervention, the participants completed a questionnaire, specifically designed for the study to assess their previous barefoot experience (**Appendix E**). On the primary school barefoot experience, 65 % of the participants answered YES, while 35 % answered NO. On the seasonal barefoot experience, 45 % went barefoot during summer holidays, 27 % went barefoot during summer at the university, 18 % went barefoot during winter holidays and 10 % went barefoot during winter at the university.

Subjective experience of barefoot activities

The results of the additional questionnaire on the subjective experiences of the barefoot intervention as described in Chapter Three are shown in **Table 4.43**. It was found that 33 % of the participants had perceived injury risk experiences (E.g. sensitive shins, sore feet and blisters), while 22 % experienced neuromuscular benefits of barefoot training. The choice of training surfaces formed part of the negative experience (E.g. barefoot on the court, grass training and hard surface) for 33 % of the participants, while another 33 % preferred the choice of training surface. Drills for the intervention which formed the components of the barefoot intervention were not comfortable for 22 % of the participants (E.g. running barefoot), while another 22 % preferred the components of the drills. Most of the participants (77.8 %) were positive about participating in a potential future barefoot intervention programme. According to the survey result, participants believed that the programme may prevent injuries and enhance sports performance.

Table 4.43: Response of the EXP group to the barefoot intervention programme

	Categories	**Responses to the barefoot training experience**	
		Negative	Positive
1	Injury risk	33 % (n = 3)	-
2	Training surface	33 % (n = 3)	33 % (n = 3)
3	Training drills	22 % (n = 2)	22 % (n = 2)
4	Neuromuscular benefits	-	22 % (n = 2)
5	No comments	11 % (n = 1)	22 % (n = 2)
6.	Another barefoot intervention	NO (n = 2, 22.2 %)	YES (n=7, 77.8 %)

Modified lower limb comfort index (mLLCI)

The mLLCI form was given to the participants in both groups on three occasions during the course of the study (before, during and after intervention), to monitor the adaptation to the barefoot intervention programme. **Figure 4.17** shows that there were significant differences in discomfort in the various anatomical segments (feet, ankle, calves and shins) between the EXP and CON groups.

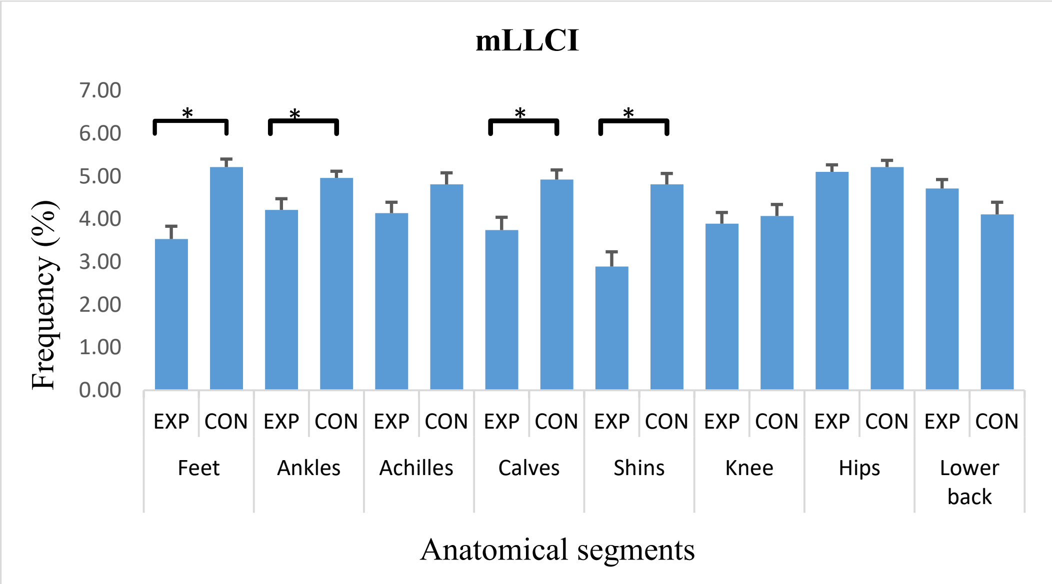


Figure 4.17: Bar chart on mLLCI between BF and SH group. The asterisks (*) show significant differences

Table 4.44 indicates that there were significant differences between EXP and CON group at the feet, calves, ankles and shins ($p = 0.00$, $p = 0.00$, $p = 0.02$ and $p = 0.00$, respectively). The effect sizes were very large for the feet, calves and shins (1.92, 1.35 and 1.87, respectively) with large effect sizes seen in the Achilles and ankles (0.77 and 1.01, respectively). No statistically significant differences ($p > 0.05$) were found between the EXP and CON groups for the Achilles, knees, hips and lower back.

Table 4.44: Average value of the mLLCI item at six weeks (Data represented as Mean ± SEM)

Comfort Items	Group	Mean and SEM	P	ES
Feet	EXP	3.54 ± 0.30	0.00*	1.92$^{@}$
	CON	5.22 ± 0.18		
Ankles	EXP	4.21 ± 0.26	0.02*	1.01$^{\infty}$
	CON	4.96 ± 0.16		
Achilles	EXP	4.14 ± 0.26	0.08	0.77$^{\infty}$
	CON	4.81 ± 0.27		
Calves	EXP	3.75 ± 0.29	0.00*	1.35$^{@}$
	CON	4.93 ± 0.23		
Shins	EXP	2.89 ± 0.34	0.00*	1.87$^{@}$
	CON	4.81 ± 0.26		
Knee	EXP	3.89 ± 0.26	0.63	0.20$^{\wedge}$
	CON	4.07 ± 0.27		
Hips	EXP	5.11 ± 0.17	0.61	0.20$^{\wedge}$
	CON	5.22 ± 0.15		
Lower back	EXP	4.71 ± 0.21	0.09	0.72$^{\#}$
	CON	4.11 ± 0.28		

$^{@}$ *Very large effect,* $^{\infty}$ *Large effect,* $^{\#}$ *Moderate effect,* $^{\wedge}$ *Small effect,* $^{\sim}$ *Negligible effect,* * *Statistically significant difference*

Summary

According to the LESS, the EXP group had more excellent ratings and larger effect sizes than the CON group, even though both groups had significant changes after the intervention. The feedback of subjective experience of BF activities after the intervention showed that the negative experience of injury risks did not outweigh the positive experience of neuromuscular benefits and other related factors. Moreover, the participants were still positively eager to participate in another barefoot intervention programme in the future. The modified lower comfort index shows that feet, ankles, calves and shins were significantly different between the EXP and CON groups while Achilles, knees, hips and lower back remained the same after the intervention.

CHAPTER FIVE

DISCUSSION

A. INTRODUCTION

This chapter presents a discussion of the study findings related to the effect of a six-week barefoot training intervention on landing biomechanics, as well as acute kinetics and kinematics differences of netball players between barefoot (BF) and shod (SH) conditions. The participants performed four different jump-landing tasks in BF and SH conditions. The kinetic and kinematic variables were measured during the tasks performance. The two different footwear conditions were adopted for the study to understand the lower limb biomechanics of natural and footwear-aided landing. Studies have tested different footwear conditions to investigate the biomechanical changes in the lower limbs during landing (Zifchock et al., 2011; Sinclair, 2016; Bowser et al., 2017; Buhagiar et al., 2018; Lesinski et al., 2018). However, the current study explored the influence of jump-landing tasks on the dynamics of footwear conditions, and role of a barefoot intervention in relation to landing biomechanics. The objectives and hypothesis will be discussed in this chapter. Furthermore, the previously used abbreviations will be limited to enhance the readability. GRFs will be used interchangeably with force-magnitude as well as GRFtp for force-time. Vertical GRF will be used for vertical ground reaction force, mediolateral GRF will be used for mediolateral ground reaction force, while anteroposterior GRF will be used for anteroposterior ground reaction force.

B. RESEARCH OBJECTIVE ONE

To determine the acute differences in lower body landing kinetics (ground reaction forces, time to peak ground reaction forces and shock attenuation) for single-leg drop landing (right and left), drop vertical jump and stop-jump performance task between BF and SH conditions.

Ground reaction forces

For the first objective, it was hypothesized that peak resultant force, vertical ground reaction force, mediolateral ground reaction force and anteroposterior ground reaction force for single-leg drop landing (right and left), drop vertical jump and stop-jump performance task would not be significantly different in the BF and SH conditions. The hypothesis was rejected. The mediolateral GRF of single-leg drop landing left and drop vertical jump was significantly lower in BF when compared with the SH condition. However, the vertical GRF of single-leg drop landing left and the anteroposterior GRF of the drop vertical jump were significantly higher in the BF condition.

Significant differences were observed in some of the GRFs for the jump-landing tasks between the BF and SH conditions. The current study elicited similar results to Steele and Milburn (1987), who compared four different footwear conditions among 15 centre court netball players. The study reported 4.26 BW (VGRF) for BF, which was greater than 4.02 BW (VGRF) for SH landing in netball shoes. The vertical GRFs reported in the current study for BF (3.39 – 3.60 BW) were greater than SH conditions (3.32 – 3.58 BW) across the jump-landing tasks, with the magnitude of the differences between the two footwear conditions being similar to what was found by Steele and Milburn (1987).

Despite the similarity between Steele and Milburn and the current study, the protocol for their study involved an approach run and halt to receive a pass from a given direction (5.6 m away), while the current study utilised four different jump-landing tasks with passive and active components. Moreover, the Steele and Milburn study adopted a standard pass while the current study simulated a high pass with the stop-jump performance task. The mean differences between both studies could be as a result of variations in experimental protocol and biomechanical modification of netball footwear over the years. Even though Steele and Milburn did not report on surface interaction with force mechanism, the shock-absorbing properties of footwear and ground surface condition may have influenced the magnitude of impact forces (Brizuela et al., 1997; Hart & Smith, 2008). Shultz, Schmitz, Tritsch and Montgomery (2012) described this influence for the drop jump and drop landing as stiffness modulation. This occurs when the body absorbs more shock proximally in the extended position by increasing ankle joint work.

In contrast to the current study, Yeow, Lee and Goh, (2011) found no significant differences in peak vertical GRFs between BF and SH landing (bilateral drop landing) for two different landing heights, although the peak vertical GRFs were greater in SH landing. Yeow, Lee and Goh's sample differed in size (n = 20), sex (male) and age (23.1 ± 0.8 years) from the size (n = 30), sex (female) and age (20 ± 1 years) reported in the current study.

There was a difference in one of the landing heights utilised in the study, when compared to the current study. While the current study used a landing height of 30 cm, the study by Yeow, Lee and Goh used both 30 cm and 60 cm, which may explain the contradictory results.

A further reason for the contrast seen could be due to the differences in sample gender, which may impact on GRFs at landing due to the anatomical differences between men and women, regardless of footwear conditions. This reasoning wouldn't apply to other studies that did explore impact forces between footwear conditions. For instance, some running studies have reported greater impact forces in SH conditions (Wit, Clercq & Aerts, 2000; Divert et al., 2005; Braunstein, Arampatzis, Eysel & Brüggemann, 2010). In a study which compared the running mechanics between BF and SH conditions, Divert et al. (2005) reported significantly greater passive and active vertical peak force in SH conditions. However, Perkins, Hanney and Rothschild (2014) in a systematic review on the injury risk of barefoot running, observed moderate evidence for lower peak vertical GRF in barefoot running, when compared to other footwear conditions.

Furthermore, the current study observed that the anteroposterior GRFs were lower for single leg landing but greater for bilateral landing (drop vertical jump and stop jump performance task) in BF conditions. This force variation implies possible risk of injury in barefoot condition, if the intensity of movement task overloads the lower limbs. Steele and Milburn (1987), in a study on kinematic analysis of netball, reported a lower anteroposterior GRF in BF compared to other SH conditions adopted for the study. It is possible that the variations between the current study and Steele and Milburn, were influenced by lower limb joint coordination and velocity of the movement. Steele (1986) earlier speculated that high anteroposterior GRF generated at landing by a player, could serve as a major contributing factor to potential injuries. The ligaments of the lower limb, especially the knee, could be subjected to undue stress due to the high impact force at landing (Steele, 1986; 1993).

It is for this reason that Stuelcken, Greene, Smith and Vanwanseele (2013) emphasized the need for absorption of GRFs by the distal segments of the lower limbs. Nigg (2001) agreed with other studies that increases in GRFs at landing could result in ligament damage, articular cartilage degeneration, osteoarthritis or musculoskeletal disorders. There were some instances with the jump-landing tasks in the current study, where barefoot conditions contributed to a safe landing by lowering the magnitude of the GRFs. However, it is important to note that a gradual progression of low- to moderate intensity activity in barefoot conditions, would be optimal for avoiding injury. Depending on the individual, caution should be exercised when considering barefoot training for high impact activities or high velocity sports.

When considering the differences in mediolateral GRFS between the two footwear conditions, the GRFs for all the jump-landing tasks were lower in the BF condition. It is possible that during the landing tasks in the BF condition, the various stabilizing muscles of the ankle joint contributed to the reduction in mediolateral GRF along the kinetic chain, more than the SH condition. However, this is a speculation and would only be confirmed by measuring the strength of the intrinsic and extrinsic foot muscles, which were not assessed as part of this study. In addition, an inverse relationship was observed between the mediolateral GRF and time to peak component (increased in force vs decrease in time) in BF and SH conditions. The time component of force is discussed later under this objective. As much as stability is desired during movement, a sudden rise in the time to peak mediolateral GRF could possibly increase the risk of injury to the lower limb.

This assumption is subject to the magnitude of the shock transmission during ground contact. Shultz et al. (2012) suggested that low-intensity BF training could act as a gradual conditioning program for the lower limbs, to mitigate against excessive anteroposterior GRFs in dynamic movement. This would result in less joint loading, and could ultimately transition into the introduction of high intensity movement pattern in SH conditions. Yeow, Lee and Goh (2011) were of the opinion that footwear is essential for landing tasks on hard surfaces to improve shock attenuation, and possibly to replicate greater knee flexion, as is traditionally observed in BF conditions. Perhaps, the result of the current study could have been different with the inclusion of landing height variation to test for the force-magnitude against the time component and verify changes in mediolateral GRF in footwear conditions.

Time to peak ground reaction forces

It was hypothesized that time to peak resultant force, time to peak vertical GRF, time to peak mediolateral GRF and time to peak anteroposterior GRF for single-leg drop landing (right and left), drop vertical jump and stop-jump performance task would not be significantly different in the BF and SH conditions. The hypothesis was rejected. The time to peak mediolateral GRFs for single-leg drop landing (left and right) were significantly greater in BF conditions, while the time to peak anteroposterior GRFs for the drop vertical jump and the stop-jump performance task were significantly lower in the BF condition.

The inverse relationship between force-time and force-magnitude was observed for some of the unilateral and bilateral landings between BF and SH conditions. In the SH condition for the drop vertical jump and stop jump performance task, it was found that anteroposterior GRFs were lower, with time to peak being longer. There were slightly different findings for the BF condition, where mediolateral GRFs were lower, with time to peak being longer for the jump tasks involving single leg landings. Within the context of the current study, the mechanism of interaction between the force-magnitude and time component in BF and SH conditions, might further explain the dynamics of movement patterns in relation to shock absorption.

There were also cases where a direct relationship was found between force-time and force-magnitude. In SH conditions, anteroposterior GRF and time to peak were greater for the single leg landing tasks. It is possible that by maintaining an equidistant relationship between force-magnitude and force-time, it could enhance performance and reduce the risk of injury when landing (**Appendix O).** Steele (1988) noted that a shortened time period to the peak resultant force, may serve as a contributory factor to higher levels of stress placed on lower extremity, which would therefore increase the likelihood of injury. Following this observation, it is widely recommended not to engage in barefoot activity, without a gradual transition period (Altman & Davis, 2012; Bonacci et al., 2013; Fredericks et al., 2015). The current study therefore suggested that the force-time delay should be accounted for in the injury prevention programme.

On the other hand, time to peak resultant force was lower for almost all the jump-landing tasks in the BF condition, as well as time to peak VGRFs in SH condition. The current study had similar findings to those of Steele and Milburn (1987), who compared time to peak VGRF between BF and SH conditions. They reported that time to peak vertical force in BF conditions (BF = 18.0 ms; SH = 28.3

- 32.3 ms), was significantly shorter than the time reported for the three other footwear conditions used for the study. Steele (1986) earlier identified that shoes did not alter the magnitude of the VGRF, however, the increase in time to peak led to greater shock attenuation. It could be deduced that the interdependence of force-time and force-magnitude could determine, to an extent, the incidence of lower limb injury. In another study, Steele (1988) reported that average time to maximum vertical force at landing when receiving a high pass, was longer than when receiving a standard pass in usual netball shoes. The current study also observed greater time to peak resultant force and time to peak anteroposterior GRF for the stop jump performance task in SH condition, however, the force-magnitudes were lower.

The inverse relationship identified between force-time and force-magnitude could be attributed to increasing sagittal kinematic adjustments which take place to accommodate joint loading in the deceleration phase of landing. Shultz et al. (2012) observed that drop landing and drop jump performance is centred on the reduction of body momentum to gain stability and increase shock absorption, to reduce the likelihood of injury. McClay et al. (1994) noted that time to peak force, is proportionate to the magnitude of the shock transmission experienced by the body. One of the possible mechanisms of attenuating shock transmission, is to adjust musculoskeletal motion to the movement demand. Caster (1996) found that increased knee flexion is a commonly utilized strategy to absorb landing momentum over a longer period of time. These findings had indirectly been earlier reported by Steele (1988), who identified that time to peak was associated with an increase in the degree of flexion at the knee and hip joints. However, Steele also noted that players who demonstrated increase in time to peak VGRF, also showed an increase in the degree of ankle and hip inversion. In the current study, the sagittal kinematic parameters in BF conditions were lower at initial contact but greater at peak angles, and vice versa for the frontal kinematics in the same condition.

In addition, Bates et al. (2013a) examined timing differences between the first and second landing of the drop vertical jump, and reported that time to peak GRFs increased during the second landing. They noted that a sudden increase in time to peak GRF might heighten the likelihood of an individual sustaining an injury to the ligaments of the lower limb, especially the ACL, due to the increase in joint loading. There were no significant differences found in the left leg time to peak VGRF between landings, although there was an increase noted in the right leg. This finding, while interesting, did not hold any clinical relevance as the reduction in the duration of time to peak between landings (0.008s) was too brief to be of any significance. In addition, Dai et al. (2015) noted that decreases in GRFs were possible due to the range of motion of the lower extremities, which allowed subjects to dissipate landing force over a longer period of time. Apparently, safe landing requires appropriate interactions, involving force-time, force-magnitude and kinematic adjustment to reduce the incidence of lower limb injury. In terms of safe landing, the players demonstrated more mediolateral control in BF condition.

Shock attenuation

It was hypothesized that hip, knee and ankle shock attenuation of the single-leg drop landing (right and left), the drop vertical jump and the stop-jump performance task would not be significantly different in the BF and SH conditions. The hypothesis was rejected. The hip shock attenuation of single-leg drop landing was significantly greater in BF condition. Furthermore, the knee shock attenuation of the jump-landing tasks as well as the hip shock attenuation of the stop-jump performance task was greater in the BF when compared with the SH conditions.

The hip could be regarded as the most significant anatomical region for lower limb shock absorption due to the number of muscles supporting the joint, and the diathrodial articulation permissible in the region (Nordin & Frankel, 2001). According to the current study, the significant shock absorption seen in the hip confirms the speculation that the body would lower the centre of mass during BF landing. This is further confirmed by greater knee shock attenuation in the BF condition. Shultz et al. (2012) found that the relative absorption of energy at the hip was greater in the drop jump task (41.6 %) compared to the drop landing task (35.4 %), while the rate of energy absorption at the knee was relatively similar for the two landing tasks. However, the relative absorption of energy at the ankle was greater in the drop landing task (46.9 %) compared to the drop jump task (42.1 %). In contrast, the current study reported that hip shock attenuation for single leg landing (BF = 43 – 47 %; SH = 34 – 42 %) was greater than the drop vertical jump task (BF = 36 %, SH = 36 %) and stop jump performance task (BF = 31 %, SH = 35 %). The study by Shultz et al. (2012) involved males and females while the current study involved only females, which may account for the differences seen between the two studies. Differences in landing strategies between males and females have been mentioned previously.

The current study reported greater shock attenuation at the knee for all the jump-landing tasks in the BF when compared with the SH conditions. Shultz et al. (2012) noted that generation of shock attenuation with the drop landing and drop jump flows in the opposite direction. The attenuation strategy tends to be more proximal in the drop jump and distal in the drop landing. It is not yet clear whether the stance phase, slow progression of movement, absence of muscle pre-activation, mass of the body, or force of gravity determines perturbation during single leg landing, which in turn influences shock attenuation. The results of the current study were in agreement with Brizuela et al. (1997), who compared the effects of head acceleration and tibial acceleration on shock attenuation in three different footwear conditions. The study reported that BF conditions have the lowest values of tibial and head shock transmission, when compared with other conditions. Clinically, it translates to a reduction in the rate on perturbation in barefoot conditions. Therefore, it is possible that absence of artificial inhibitions, such as ankle brace and footwear, increase the mobility of the lower limbs, provide the ground surface maintains adequate friction.

Yeow et al. (2011) pointed out in their study that increased landing height could possibly alter shock absorption, regardless of footwear condition (BF or SH). In addition, Yeow et al. (2011) added that the SH condition might contribute more to the lower limb shock absorption through knee range of motion. It is assumed that lower limb range of motion would influence shock attenuation, based on the theoretical framework of the kinetic chain of the human body (interconnectivity of the musculoskeletal framework). Moreover, Sinclair et al. (2012) in their study on the influence of barefoot and barefoot-inspired footwear in comparison to conventional running shoes, reported that the shock absorbing materials of conventional running shoes were superior to barefoot or barefoot-inspired shoes. Gross and Nelson (1988) also reported that a more controlled lowering of the heel, irrespective of footwear condition, compared to uncontrolled heel contact landing, significantly reduced maximum force by 22 % and decreased peak loads in the lower extremity.

In the current study, shock attenuation at the ankle for all the jump-landing tasks, except with the SLR, was significantly greater in SH condition. These findings were in agreement with Yeow, Lee and Goh (2011), who noted that the absorbent materials of footwear could directly influence the extent to which the ankle joint attenuates shock. The cushioning properties of traditional sport shoes are diverse, although they are all designed with the purpose of attenuating impact forces when landing (Edwards, 2000). Hamill (1999) noted that the properties of footwear intricately influenced shock attenuation. The current study assumed that the long-term effect of ankle shock attenuation in SH conditions, could increase lower limb injury due to the wear and tear of footwear over time. Players should therefore be trained to attenuate shock distally along the kinetic chain.

Gross and Nelson (1988) also noted that an ankle joint with an average range of motion of 50 degrees contributed largely to shock attenuation. The question of whether the shock-absorbing properties and mobility control mechanisms of footwear have been able to prevent foot related injuries, is yet to be fully answered, either biomechanically or pathologically (Mcgrath & Ozanne-Smith, 1998; Richards et al., 2009). According to the current study, the pattern of shock attenuation revealed that most of the load was placed through the ankle for the SH condition, whereas most of the load was placed through the hips and knees in the BF condition. As much as the magnitude of landing impact is essential to understand the pattern of shock transmission along the kinetic chain, the segmental proportion of shock absorption in the lower body could provide a clearer indication of joint loading and injury risk.

C. RESEARCH OBJECTIVE TWO

To determine the acute differences in lower body kinematics (impact peak acceleration, initial contact angle, peak angle and range of motion) for single-leg drop landing (right and left), drop jump and stop-jump performance task between BF and SH conditions.

Impact peak acceleration

It was hypothesized that pelvis, thigh, shank and foot acceleration of single-leg drop landing (right and left), the drop vertical jump and the stop-jump performance task would not be significantly different in the BF and SH conditions. The hypothesis was rejected. The $pelvis_{accl}$ of single-leg drop landing (left and right) were significantly lower in BF condition. Furthermore, the $pelvis_{accl}$ (5.46 ± 0.33 g; 6.1 ± 0.3 g), $thigh_{accl}$ (8.22 ± 0.51g; 8.8 ± 0.5 g) and $shank_{accl}$ (13.19 ± 0.61 g; 13.2 ± 0.6 g) of the drop vertical jump and the stop-jump performance task were lower in the BF when compared with the SH conditions.

According to the current study, the lower extremities were more stable during dynamic movement around the pelvic, thigh and shank region in BF conditions. Wade et al. (2012) noted that uncontrolled movement in the pelvic region could increase the risk of developing lower back pain, while Weltin et al. (2016) observed that uncontrolled lateral movement of the trunk, could be associated with knee injury risk. In the current study, it was observed that pelvic, thigh and shank acceleration were greater for bilateral landing in SH conditions. The acceleration in the above-mentioned regions, resulted in lower shock attenuation at the knee join, which could increase the risk of injury. Generally, pelvic acceleration contributes to the stability of the lower extremities during dynamic movements. Pelvic stability is mechanically associated with the centre of mass, and the established neuromuscular link could reduce non-contact injury risk of the lower limbs (Baker, 2001). The movement of the pelvis is conventionally reported in anteroposterior, mediolateral and proximal-distal axes (Baker, 2001). Ferreira and Spamer (2010) reported pelvic asymmetry in a study among netball players, and the associated strain on pelvic girdle. Female athletes were found to present with greater displacement of the trunk, hip flexion, adduction and internal rotation during movement tasks, in comparison to their male counterparts (Mendiguchia et al., 2011). The risk of lower limb injuries were reported to be generally higher in female athletes (Salci et al., 2004; Mendiguchia et al., 2011). In the current study, the landing pattern in BF conditions, may have reduced the tendency towards excessive pelvic movement for all the jump-landing tasks.

The shank acceleration (also known as tibial acceleration) reported in the current study in BF conditions was greater for the single leg landing (11.08 g), but lower in the drop vertical jump (8.22 g) and the stop jump performance task (8.8 g) when compared with SH conditions. Brizuela et al. (1997), in a study which compared three different footwear conditions (barefoot, shoe with ankle low support and shoe with high support) in running and jumping, had contrasting findings. Their study reported tibial acceleration was highest in BF conditions (6.4 g) compared to the other conditions (5.9 g and 6.0 g). It is postulated that the increased sagittal kinematics, reported later in the second objective, may have influenced the reduction in shank acceleration. Furthermore, there appears to be a relationship between shank acceleration during knee motion, and the magnitude of the risk of injury to the knee complex. Sell et al. (2014) found no correlation between proximal anterior tibia shear force and acceleration, even though there was significant correlation between acceleration data and peak posterior GRF. The same authors also found that tibial shear force is different from tibial acceleration, even though both provide biomechanical metrics on tibial motion. It was reported by Brizuela et al. (1997), that forehead acceleration was significantly lower in the BF condition (3.2 g) when compared with other conditions (3.5 g, 3.8 g), which means that shock transmission along the kinetic chain might be mostly absorbed in BF conditions.

Bishop et al. (2006) had previously indicated that shock absorption and acceleration at the shank and head could not provide sufficiently detailed information on the transmission of impact acceleration in the body. In the current study, accelerometers were attached to the pelvis, thigh (femur), shank (tibia) and foot, to measure segmental acceleration and to provide specific metrics to be used in the interpretation of lower body activities in order to substantiate for the gap in previous studies (Shorten & Winslow, 1992; Bishop et al., 2006). Shorten and Winslow (1992), in a study of impact shock, reported that segmental acceleration tends to increase based on running speed, although shock transmission to the head was minimal. With the attachment of an accelerometer to the shank and gripped by the teeth, it was noted that there was increased synchronization between the impact phase and peak acceleration, than the propulsive phase during running (Shorten & Winslow, 1992).

The changes in acceleration reported in the current study could be associated with the GRFs reported under the first objective. It is possible that the magnitude of force absorbed by the plantar surface, influenced the acceleration of the foot during ground contact in the BF condition. It was observed that the foot acceleration of all the jump landing tasks, was less in SH conditions. Therefore, the results of the current study confirmed the biomechanical role of footwear in minimising perturbation around foot region during ground contact, even though SH conditions resulted in greater pelvis, thigh and shank acceleration. Thompson, Seegmiller and McGowan (2016) in their study on impact accelerations in BF and SH running, reported that increases in GRF and decreases in impact acceleration were associated with the midsole absorption of force in the running shoes. However, a shorter stride length which is commonly associated with forefoot ground contact in BF conditions, decreased peak force and acceleration. The study reported the lowest impact peak values for BF running with a forefoot strike, compared to BF running with a heel strike and SH running. In addition, the study observed a decrease in impact acceleration and peak magnitude due to a shorter stride length and plantar flexed movement at ground contact, which was found in BF running with a forefoot strike.

Warburton (2001) indicated that poor sensory perception of foot orientation in SH conditions could expose an athlete to the risk of an ankle sprain. Within the context of the current study, this proposition is related to the landing tasks in SH conditions due to inhibition of the plantar mechanoreceptor, which aids neuromuscular facilitation. This could provide further explanation to the observed differences between the BF and SH conditions. Foot-strike patterns during the landing tasks in the current study were not analysed. It might be that players changed their foot-strike patterns (midfoot versus forefoot landing) based on the footwear condition. Foot-strike patterns during landing tasks in different footwear conditions could be further investigated in future studies.

Initial contact and peak angle

It was hypothesized that sagittal plane excursion (lumbar flexion, hip flexion, knee flexion and ankle dorsiflexion) at initial contact (IC) and peak angles for single-leg drop landing (right and left), the drop vertical jump and the stop-jump performance task would not be significantly different in the BF and SH conditions. The hypothesis was rejected. The ankle dorsiflexion at the IC angle for single-leg drop landing left and the drop vertical jump were significantly greater in the BF condition. However, ankle dorsiflexion for both jump-landing tasks was minimally reduced in the BF condition.

It is important to note that greater ankle dorsiflexion at IC in BF conditions may have contributed to the greater foot acceleration, peak resultant force, and time to peak observed in the current study. Further evidence is provided when assessing lumbar and hip flexion at peak angles in BF conditions, even though knee flexion at peak angles was greater in the BF conditions for all the jump-landing tasks, except for the drop vertical jump. While there are some common findings between the current study and the study by Shultz et al. (2012), the latter reported greater hip and ankle flexion at IC in BF conditions during the drop jump, while knee flexion was greater in SH conditions. In addition, the study found that knee flexion and ankle plantarflexion at IC were greater in BF conditions during drop landing, while hip flexion at IC was greater in SH conditions. Safe landing requires adequate flexion of the lumbar spine, hip, knee and ankle. In the current study, these sagittal angles were greater for almost all the jump-landing tasks at IC, but were lower at peak in BF conditions.

Leppänen et al., (2016) noted that ACL risk increases in young female athletes with a reduction in knee flexion, and elevation in the VGRF during the drop vertical jump. The study reported knee flexion at IC (30.2 deg), knee valgus at initial contact (0.9 deg) and peak knee flexion (81.5 deg) for ACL-injured knees; while the uninjured knees had less knee valgus (-1.8 deg), less knee flexion at IC (27.6 deg) and a higher peak knee flexion (84.6 deg). For the current study, the knee flexion angles at IC for the drop vertical jump were 29.2 deg (BF) and 31.5 deg (SH), while the peak knee flexion angles were 59.8 deg (BF) and 60.9 deg (SH). The knee flexion at IC as well as peak force reported in their study were greater than the current study in all the jump-landing tasks. Moreover, in the current study, greater knee flexion was observed at IC in SH conditions, but at peak angle in BF conditions. Furthermore, the peak resultant and VGRFs reported in the current study were lower in SH conditions, and could be associated with knee flexion angles. In a controlled laboratory study which involved women who had undergone ACL reconstruction, as well as healthy controls, Ortiz et al. (2008) reported differences between the two groups for hip flexion (59.5 deg – healthy; 45.9 deg – ACL), hip abduction (4.4 deg – healthy; 4.1 deg – ACL) and knee flexion (57.9 deg – healthy; 57.7 deg – ACL) when performing the drop jump task. The hip and knee flexion angles reported in their study for healthy controls were greater than what was found in the current study, with lower levels of hip abduction. In the current study, knee flexion at peak angles was greater for almost all the jump-landing tasks in the BF condition.

Cowling and Steele (2001), in a study on gender influence and muscle synchronization during landing, reported the knee flexion angle at IC (18.6 deg – male; 18.3 deg – female) and knee flexion angle at peak (31.5 deg – male; 27.0 deg – female) when receiving a chest pass and then gradually decelerating. The knee flexion at IC and peak reported for all the jump-landing tasks (BF and SH conditions) in the current study were greater than those reported by Cowling and Steele (2001). Derrick (2004) agreed with the associated risks of knee extension at ground contact, but identified the likelihood of performance deficits when knee flexion is increased to accommodate landing impact. The highlighted concern gave rise to the critical question of which side of the continuum (adjusting for landing impact at the expense of performance, or prioritising performance at the expense of high landing impact) should the priority of athlete lie (**Appendix O**). Powell et al. (2012) therefore proposed the possibility of increasing knee flexion as well as ankle joint mobility in the landing phase of the drop landing task. Steele (1988) also recommended that to reduce the VGRF, players should be encouraged to land with flexed knees. Steele further suggested that players should be encouraged to eliminate excessive eversion of the ankle. In the current study, the players demonstrated greater knee flexion in BF than SH condition across the jump-landing tasks.

Steele (1988) reported greater average hip flexion at foot-strike when receiving a standard pass (33.7 deg) compared to when receiving a high pass (25.1 deg). At maximum resultant force, the hip flexion increased to 45.2 deg for the standard pass and 32.1 deg for the high pass. In the current study, hip flexion at IC for the stop jump performance task was 29.3 deg and 27.9 deg, for BF and SH conditions, respectively. The peak angles for the two footwear conditions were 51.1 degrees and 50.2 degrees, respectively. The results from Steele's study demonstrated that landing phase knee motion from an overhead target attempt during performance, would differ from a cutting movement task and non-target flight. It is assumed that movement kinematics that are relevant to the absorption of shock transmission, would contribute to improved performance. Steele (1988) recommended that hip flexion at IC (33 deg) and at the peak resultant force (45 deg), should be maintained to reduce the size and rate of loading of VGRFs at landing. When comparing these results to that of the current study, the hip and knee flexion at IC and peak angles for all the jump-landing tasks in BF and SH conditions were greater than the values reported by Steele (1988), which would place the players within the low risk margin of athletic performance. Steele further stated that increased hip flexion when receiving a standard or high pass, would enhance stability at landing and minimize the effect of GRFs. In addition, Shultz et al. (2012), noted that increased energy utilization in the drop landing and drop jump is characterized by increased knee and hip flexion at IC as well as greater muscle activation. Blackburn, Norcross and Mcgrath (2011) found that the degree of knee displacement during landing determines impact forces and influences ankle (dorsiflexion) and knee (valgus) mobility.

It was further hypothesized that frontal plane excursion (hip abduction, knee abduction, ankle abduction and ankle inversion at IC and peak angles) for single-leg drop landing (right and left), drop vertical jump and stop-jump performance task would not be significantly different in BF when compared with SH conditions. The hypothesis was rejected. The ankle abduction for single-leg drop landing left at peak angle was significantly lower in BF condition. Even though the ankle abduction was lower in BF condition, ankle inversion was present in BF and SH landings.

The incidence of ankle inversion and abduction would indicate the uneven orientation of the feet at landing. Increases in these movements in the frontal plane, could strain the ligaments and tendons within the foot region, increasing the risk of injury. When these conditions are combined with other lower limb frontal plane excursions, the probability of injury is further increased. For instance, greater levels of hip abduction, knee abduction and ankle inversion found for some of the jump-landing tasks in the SH condition, could constitute an injury risk. Yeow, Lee and Goh (2009) in a study on frontal plane kinematics, reported that hip abductors were associated with shock absorption at landing. Considering the outcome of shock attenuation and frontal plane excursion, the current study agreed with this finding.

In the current study, the magnitude of ankle inversion was less in the SH conditions at IC for almost all the jump-landing tasks. However, at peak angles the levels were similar between the two conditions. In a running study, which compared BF with three different types of footwear, it was reported that knee extension and abductions moment in the BF group were significantly lower than the other conditions, while ankle inversion moments were significantly greater in the BF condition (Bonacci et al., 2013). Furthermore, the negative work at the knee was significantly greater, and positive work at the ankle was significantly lower in the BF condition (Bonacci et al., 2013). Schutte (2012), in a study which involved recreation runners, reported significantly greater knee abduction and ankle inversion in BF conditions compared to minimalist and regular footwear. Despite the differences in experimental procedures, these studies provide further evidence on the influence that BF conditions have on sagittal kinematics, which could possibly translate into improvements in jump-landing performance.

Range of motion

It was hypothesized that sagittal plane angle excursion (hip flexion, knee flexion and ankle dorsiflexion ROM) for single-leg drop landing (right and left), the drop vertical jump and the stop-jump performance task would not be significantly different in the BF and SH conditions. The hypothesis was rejected. The ankle dorsiflexion ROM for single leg landing (right and left) was significantly greater in the BF condition. Conversely, ankle dorsiflexion ROM for the bilateral landing tasks was greater in the SH condition. A similar pattern was seen for knee flexion ROM, which indicates a degree of movement coordination in both conditions. Whilst the difference in ankle dorsiflexion between the two conditions was minimal (approximately 0.2 deg), there was a more significant difference in knee flexion ROM (approximately 3.3 deg).

Fong, Blackburn, Norcross, McGrath and Padua (2011), in a descriptive study on the biomechanics of landing, reported that greater ankle dorsiflexion ROM (18.9 ± 5.9 deg) contributed to the reduction of ACL loading, and was able to identify individuals at risk of ACL injury. The study further identified the association between greater ankle dorsiflexion, knee flexion, lower GRFs and ACL injury risk reduction. The study involved 25 healthy participants (male, n = 17; female, n = 18), who performed drop landing from a 40 cm box. In the current study, the ankle dorsiflexion ROM, reported for both groups across all the jumps, was lower than reported by Fong et al. (2011), although the vertical and posterior forces were greater in the current study. Even though both studies measured ankle dorsiflexion ROM and force components, the variations of landing protocol may have influenced the differences in outcome measures. Greene et al. (2014) identified that a reduction in sagittal plane ankle ROM was associated with the use of ankle support during a side-cutting task, although this made no different to lower limb joint loading.

The sagittal plane angle excursion results could be related to the outcome of impact peak acceleration and shock attenuation in both conditions. There were similar increases in pelvis acceleration and hip flexion ROM in SH conditions across all the jump-landing tasks, although hip shock attenuation was greater in BF conditions. In addition, the mean differences showed that hip flexion ROM in BF conditions was lower in all the jump-landing tasks. Gomes, de Castro and Becker (2008) proposed in their study that decreased hip ROM is associated with an increased risk of ACL injury. Similarly, knee flexion ROM, thigh and shank acceleration showed common pattern of magnitude in both conditions. Knee flexion ROM was greater in BF conditions for unilateral landing, and in SH conditions for bilateral landing. The same pattern was seen for thigh and shank acceleration. The knee shock attenuation however, was greater in BF conditions for all the jump-landing tasks.

The current study is in agreement with Zhang, Derrick, Evans and Yu (2008) who reported that knee ROM was not significantly different across the landing heights. The landing height variations used in their study were 30 cm, 45 cm, 60 cm, 75 cm and 90 cm. Despite the landing knee flexion ROM not being significantly different between the conditions, greater values were reported with single leg landing in BF conditions, and bilateral landing in SH conditions. Yeow et al. (2011) reported that SH landing demonstrated greater knee ROM and peak knee flexion angular velocity, when compared with BF landing from 30 cm and 60 cm. Levangie and Norkin (2011) therefore suggested that movement efficiency requires greater ROM, and responsive muscle contraction.

It was also hypothesized that frontal plane angle excursion (hip abduction, knee abduction, ankle abduction and ankle inversion ROM) for single-leg drop landing (right and left), drop vertical jump and stop-jump performance task would not be significantly different in BF when compared with SH conditions. The hypothesis was rejected. The ankle inversion ROM for the drop vertical jump and the stop-jump performance task and ankle abduction ROM for drop vertical jump were significantly lower in BF condition.

Even though foot acceleration and ankle shock attenuation were greater in SH conditions for all the jump-landing tasks, ankle inversion and eversion ROM were lower in BF conditions. The kinematics results further confirmed the outcome of mediolateral GRFs discussed in the first objective. With this is mind, it is assumed that greater stability is experienced in BF conditions. Zhang, Paquette and Zhang (2013) observed that ankle eversion ROM was lower in BF conditions when compared with SH conditions. However, knee flexion ROM in SH conditions was significantly greater than BF conditions. In contrast, the current study observed that ankle inversion ROM for all the jump-landing tasks was lower in BF, while knee flexion ROM for the drop vertical jump and the stop jump performance task were lower in BF conditions.

D. RESEARCH OBJECTIVE THREE

To determine the effect of a six-week barefoot intervention on landing kinetics (ground reaction force, impact distribution and shock attenuation) for single-leg drop landing (right and left), the drop jump and the stop-jump performance task between EXP and CON groups.

Ground reaction forces

It was hypothesized that peak resultant force, vertical GRF, mediolateral GRF and anteroposterior GRF for the jump-landing tasks would not be significantly different after the barefoot intervention; (a) between the EXP and CON groups; (b) within the EXP and CON groups. The hypothesis was accepted in (a) and rejected in (b). There were no significant differences found between the EXP and CON group in GRFs. Both groups experienced significant changes in GRFs after the intervention, however, the EXP group had larger effect sizes than CON group. The effect of the barefoot intervention on the EXP group compared to the CON group was evident when reviewing the magnitude of the percent mean differences between the two groups. The EXP group demonstrated a significantly greater reduction in all the components of GRFs compared to the CON group, according to the effect sizes.

According to the current study, the EXP group exhibited a greater reduction in peak resultant force (-18 % vs -11 %), vertical GRF (-18 % vs -11 %), mediolateral GRF (-15 % vs -14 %) and anteroposterior GRF (-45 % vs -36 %) compared to the CON group. Somewhat different results were seen in an 8-week study by Tam, Tucker and Wilson (2016), who observed a 1 % reduction in anteroposterior GRF for the SH group, while the BF group remained unchanged. Furthermore, the peak mediolateral GRF increased in the BF group and decreased by 3 % in the SH group. The peak vertical GRF remained unchanged in both groups after the intervention. The study concluded that barefoot interventions may not precipitate significant changes in habitual shod runners transitioning into barefoot running, without structured instructions.

The findings of the current study were corroborated by Azevedo, Mezencio, Amadio and Serrao (2016) in a study which involved a 16-week barefoot intervention for habitually shod runners. The study reported a reduction in vertical GRF of 20.1 % following the completion of the intervention, while the post-test comparison of BF vs SH showed a 22.6 % reduction in the BF group. It was proposed that the duration of the intervention was sufficient to reduce vertical GRF and increase shock absorption, for both shod and unshod populations. Furthermore, the magnitude of the reduction was greater in the EXP group. The study was completed with six participants (3 males and 3 female). The study reported significant changes in BF group but the drop out was 70 %, compared to 40 % drop out in the current study. Even though the study involved runners only, it was concluded that biomechanical factors contributing to lower limb injury risk, could be altered through a well-designed barefoot intervention programme. Drop-out rate is a concern in barefoot interventions, but could possibly be mitigated by integrating barefoot as a micro unit of an injury prevention program, to build up familiarisation to barefoot conditions as a form of transition. For instance, the barefoot intervention designed for the current study progressed intensity and duration based on the compliance and feedback of the EXP group.

In the current study, it was observed that the various components related to ground reaction forces for the stop jump performance task, were significantly different after the intervention in both groups. In the single leg landing task, the EXP group had significant changes in all the force components, with the exception of mediolateral GRF. The CON group experienced similar changes on the right leg, but no changes on the left leg. When looking at the drop vertical jump, the EXP group experienced significant changes in the peak resultant force and vertical GRF. The CON group experienced significant changes in mediolateral GRF and anteroposterior GRF.

The results of the current study suggest that a barefoot intervention seems to have a significantly greater contribution to the reduction of landing forces. This is founded on the fact that the EXP group demonstrated comparatively greater ground reaction forces at baseline, except for mediolateral GRF. At post-testing, GRFs were lower in the EXP group, with the exception of the anteroposterior GRF, which remained unchanged. Hewett, Lindenfeld, Riccobene and Noyes (1999) reported a reduction in the incidence of knee injury after six-weeks of participation in a plyometric injury prevention training programme for 366 female athletes. The study showed that untrained female athletes were more likely to experience knee injury than trained female athletes. This study is included in our discussion to validate evidence of training in injury prevention. Ter Stege, Dallinga, Benjaminse and Lemmink (2014) suggested that the integration of feedback in a neuromuscular intervention programme would facilitate the injury reduction objectives of the programme. Even though feedback was not directly measured in the current study, the use of the mLLCI to evaluate barefoot training adaptation could be considered as a form of feedback. There are only a handful of studies examining the effects of a barefoot intervention on landing biomechanics of netball players or team athletes, with most studies examining runners. This is the first study that would investigate the effects of landing kinetics and kinematics of netball players, which made finding studies to compare the results of the current study to, extremely difficult.

Time to peak ground reaction forces

It was hypothesized that time to peak resultant force, time to peak vertical GRF, time to peak mediolateral GRF and time to peak anteroposterior ground reaction force for the jump-landing tasks would not be significantly different after the BF intervention; (a) between the EXP and CON group; (b) within the EXP and CON group. The hypothesis was accepted in (a) and rejected in (b). There were no significant differences between the EXP and CON group after the intervention.

It is believed that the reduction in force-magnitude and increase in force-time is relevant to injury prevention; both groups differed in these components in this study. The CON group demonstrated significant increases in time to peak vertical GRF and time to peak anteroposterior ground reaction force after the intervention. The EXP group however, exhibited a greater increase in time to peak vertical GRF and a greater reduction in time to peak mediolateral GRF compared to the CON group. Comparing time to peak and ground reaction forces between both groups, the EXP group demonstrated a reduction in both outcome measures, while the opposite was found with the CON group, who showed an increase following the completion of the intervention.

McClay et al. (1994) noted that the decrease in time to peak force, is proportional to the magnitude of shock transmission experienced by the body. Carcia, Kivlan and Scibek (2012) observed that a delay in time to peak force, may increase the likelihood of knee valgus during landing task among female athletes, which may predispose them to injury. This finding contradicted Steele (1988) who identified that time to peak VGRF was associated with an increase in hip and knee flexion. The study reported that players who demonstrated increases in time to peak VGRF, also increased the degree of ankle inversion and hip (knee valgus). Carcia, Kivlan and Scibek (2012) also reported a strong inverse correlation between time to peak force and frontal plane kinematics at IC, and at 100 ms post-contact during a unilateral squat. It was suggested that a longer peak force would lead to poor landing kinematics. In contrast, the CON group in the current study had a greater increase in time to peak but demonstrated lower knee abduction at IC angle and peak angles. The results of both studies highligh the importance of paying attention to both frontal and sagittal plane kinematics in landing manuevres during training and competition.

As a point of reference within the context of the current study, there were significant increases in ankle dorsiflexion ROM, as well as hip and knee flexion ROM, which may provide some insight to the force-time changes seen in the EXP group. In the single leg landing task, the CON group experienced significant increases in time to peak resultant force, and a significant reduction in time to peak anteroposterior ground reaction force on the right leg after the intervention. The EXP group on the other hand, experienced a significant increase in time to peak vertical GRF on the left leg. In the drop vertical jump task, both the EXP and CON groups experienced a significant reduction in time to peak mediolateral ground reaction force. In the stop jump performance task, the EXP group experienced a significant reduction in time to peak resultant force, while the CON group experienced a significant increase in time to peak resultant force and time to peak anteroposterior ground reaction force. The time component of force-magnitude depicts the rate at which landing impact is dampened by the joint complex of the kinetic chain. The extrinsic factors such as foot positioning within the footwear, surface friction and kinematics parameters could have possibly influenced the time delay of ground reaction forces in the current study.

Shock attenuation

It was hypothesized that hip, knee and ankle shock attenuation for the jump-landing tasks would not be significantly different after the BF intervention; (a) between the EXP and CON groups; (b) within the EXP and CON groups. The hypothesis was accepted in (a) and rejected in (b). There were no significant differences between the EXP and CON group. The changes in knee shock attenuation was significant within the EXP and CON groups, however, ankle shock attenuation was only significant within the CON group. The magnitude of the percent mean differences showed that the increase in knee and ankle shock attenuation, and decrease in hip shock attenuation, was greater in the CON group.

In order to reduce the risk of injury at landing, the current study proposed that the proportionate distribution of shock attenuation should follow a high-medium-low pattern down the kinetic chain, into the lower extremities (**Appendix P**). This would equate to: hip-high, knee-medium and ankle-low. Both the EXP and CON groups followed this pattern of shock absorption by attenuating more shock in the hip followed by the knee and ankle in the single leg landing tasks at baseline, although the magnitude was higher in the EXP group. The drop vertical jump and stop jump performance task showed the same pattern (high, medium and low) along the kinetic chain at the pre-test in both groups.

This same pattern didn't hold true following the intervention, where both the EXP and CON groups absorbed the most shock at the knee followed by the ankle.

Based on the results of the current study, it is assumed that the decrease in the impact peak acceleration and shock attenuation after the intervention, could be associated with increased sagittal plane excursion in both groups. Yeow, Lee and Goh (2009) in their study on the effect of landing height on frontal plane kinematics, kinetics and energy dissipation at lower extremity joints, noted that hip and knee joints kinematics play significant role in shock absorption and the attenuation of impact force at landing. The study further identified that the hip joint has the greatest capacity to absorb energy transmission, especially in the frontal plane, with the increasing heights. Aizawa et al. (2016) noted that absorption of landing impact force during a single leg landing from lateral movement, is possibly aided by an appropriate degree of knee flexion and pelvic tilt. Yeow et al. (2011) described greater lower limb kinematics during bilateral landing from increased height, as an attempt to absorb shock propagation and minimize the risk of injury to the lower limbs. Inadequate shock attenuation at the ankle and knee joint complex during single leg landing could indirectly strain the abductor muscles of the thigh where there is simultaneous over-pronation and rotation of the ankle joint (Dare, 2014).

E. RESEARCH OBJECTIVE FOUR

To determine the effect of a six-week barefoot intervention on landing kinematics (impact peak acceleration, initial contact angle, peak angle and range of motion) for single-leg drop landing (right and left), the drop vertical jump and the stop-jump performance task between the EXP and CON groups.

Impact peak acceleration

It was hypothesized that pelvis, thigh, shank and foot acceleration for the jump-landing tasks would not be significantly different after the BF intervention; (a) between the EXP and CON groups; (b) within the EXP and CON group. The hypothesis was accepted in (a) and rejected in (b). There were no significant differences between the EXP and CON group. However, the EXP and CON group had significant within-group differences in the pelvis and thigh acceleration with larger effect sizes in the EXP group. In addition, the CON group had significant differences in foot acceleration.

When looking at the magnitude of the percent mean differences prior to and after the intervention, it was found that the EXP group decreased pelvis, thigh and shank acceleration to a greater extent than was what was seen in the CON group, while foot acceleration was decreased to a greater extent in the CON group. The same anatomical segments (pelvis and shank) were also found to have lower acceleration values when comparing the acute differences between BF and SH. The findings of the current study are in agreement with Weltin, Gollhofer and Mornieux (2017), who reported increases in trunk control and a reduction in knee joint motion after four-weeks of perturbation and plyometric training in female athletes. It is postulated that the increased activation of the lumbopelvic muscles and greater ROM in sagittal plane kinematics, accounted for the changes in the EXP group in the study. Mendiguchia et al. (2011) noted that dynamics of lumbopelvic control might increase the risk of injury more than knee complex interactions, even though several findings have established the evidence of knee joint loading and ACL injury in female athletes (Hewett et al., 2005). The muscles in the lumbo-pelvic region, which stabilizes the trunk and the hip distally, contributes to control of the knee joint and enables neuromuscular coordination and balance of the lower extremity (Mendiguchia et al., 2011).

In the current study, the pattern of acceleration after the intervention between both groups (post-test comparison), showed that pelvis and shank acceleration was reduced to a greater extent in the EXP group, while thigh and foot acceleration was reduced to a greater extent in the CON group. Nagano, Sasaki, Higashihara and Ichikawa (2016), in their study on the relationships between trunk and knee acceleration and the GRFs during single leg landing, found a strong positive correlation between peak VGRF and trunk peak acceleration, even though there was no correlation between the knee acceleration and GRFs. The results of the study showed the significance of trunk movement in absorbing landing force. Even though pelvis and thigh acceleration were significant in some of the jump-landing tasks, foot accelerations were more demonstrated in the CON group. As was previously reported under the second objective, foot acceleration reduced to a greater extent in SH conditions compared to BF conditions, illustrating how footwear reduced the amount of perturbation at the foot region in a non-specific direction. The participants performed the jump-landing tasks in their netball training shoes, which accounted for the confounding variables of footwear variation.

Zifchock et al. (2011) observed that barefoot training for the habitually shod, could increase the tendency for reduced acceleration of the lower limbs during movement tasks. Therefore, the introduction of barefoot training would be productive if incremental conditioning is involved in the transitioning period. Moreover, it is important to note that barefoot training could recondition neuromuscular feedback mechanisms, through proprioceptive facilitation initiated from ground contact (Robbins & Hanna, 1987; Lieberman, 2012), to adjust for kinematic error margin at the lower extremities. It is possible that the barefoot intervention for the current study could aid kinematic adjustments for controlled acceleration at landing, although the CON group demonstrated a greater reduction in foot acceleration at follow-up testing. It is worthwhile considering that the excessive loading of the ankle joint (Sinclair, 2014), described as stiffness modulation (Shultz et al., 2012), at the expense of the shock-absorbing footwear, could indirectly increase the risk of ACL injury in any instance where there is a loss of motor control. Therefore, increases in foot acceleration could predispose one to an injury of the lower limb, if it exceeds the biomechanical limits of the kinetic chain.

Initial contact and peak angle

It was hypothesized that sagittal plane angle excursion (lumbar flexion, hip flexion, knee flexion and ankle dorsiflexion at initial contact and peak) for the jump-landing tasks would not be significantly different after the BF intervention; (a) between the EXP and CON group; (b) within the EXP and CON groups. The hypothesis was accepted in (a) and rejected in (b). There were no significant differences between the EXP and CON group. The peak lumbar flexion significantly increased in the CON group only. Hip and knee flexion at IC and peak angles were significantly greater within the EXP and CON groups after the intervention although the effects sizes were larger in the EXP group.

In the current study, hip flexion increased at IC and peak angles to a greater extent in the EXP group during the stop jump performance task. The converse was seen for the drop vertical jump task where the CON group increased hip flexion by more than the EXP group at IC and peak angles. Steele (1988) reported on the changes in hip flexion during landing when receiving passes of different heights. He found greater hip flexion at foot-strike after receiving a standard pass compared to receiving a high pass (33.7 deg vs 25.1 deg). At the maximum resultant force, hip flexion increased to 45.2 deg when receiving a standard pass compared to 32.1 deg when receiving a high pass. The post-test comparison of hip flexion at IC angles reported for the current study was the same in both groups (30.8 deg), however the EXP group displayed a greater increase in peak angles (49.1 deg vs 47 deg). The current study revealed that the EXP group had a greater increase in hip flexion and shock attenuation, as well as a greater decrease in pelvic acceleration, in comparison to the CON group. It is assumed that hip flexion influenced the changes in shock attenuation and acceleration in the region. Several studies have reported a range of degrees at initial contact and peak angles of hip and knee flexion during landing (Steele & Lafortune, 1989; Chappell, Yu, Kirkendall, & Garrett, 2002; Derrick, 2004; Chappell & Limpisvasti, 2008), to minimize the likelihood of a non-contact injury, although consensus on the precise ROM is yet to be fully established.

According to Ericksen et al. (2016), increasing the kinematics of hip and knee joint in the sagittal plane (more flexion angles), and decreasing impact forces, are parts of the main goal of jump-landing tasks. Hopper et al. (2017) emphasized that a well-designed neuromuscular injury prevention programme would lead to improved knee kinematics, and a reduction in landing forces. Yeow et al. (2011) described the greater joint kinematics demonstrated during bilateral landing from an increased height, as an attempt to adequately attenuate impact forces, and minimize the risk of injury to the lower limbs. The barefoot intervention had a significant impact on hip and knee flexion angles when reviewing the magnitude of the effect sizes reported for the EXP group. It is possible that the EXP group demonstrated greater hip and knee flexion angles as a means of absorbing more shock in the lower limbs.

Shultz et al., (2012) identified that increased energy utilization in drop landing and the drop jump is characterized by increased knee and hip flexion at IC and greater levels of muscle activation. Caster (1996) suggested that increases in knee flexion might be a utilized as part of the strategy to absorb landing momentum over longer periods of time, as height increases. Mendiguchia et al. (2011) noted that the manipulation of the gluteal muscles moments via the kinematics of the hip joint could create neuromuscular imbalance at the hip, which may spread to the knee. In a study on the expert versus novice interrater reliability and criterion validity of the landing error scoring system, Onate, Cortes, Welch and Van Lunen (2010) highlighted the need to improve clinical assessment of knee flexion and valgus angle at initial contact, which is essential in the prevention of ACL injury. In the current study, the significant increase in knee flexion seen in both groups is also reflected in the reduced GRFs after the completion of the intervention. The effect sizes were however, larger in the EXP group. Therefore, it is postulated that the intervention influenced certain biomechanical changes in sagittal plane excursion to a greater extent in the EXP group.

It was further hypothesized that frontal plane angles (hip abduction, knee abduction, ankle abduction and ankle inversion at initial contact and peak) for the jump-landing tasks would be significantly different after the BF intervention; (a) between the EXP and CON groups; (b) within the EXP and CON groups. The hypothesis was accepted in (a) and rejected in (b). There were no significant differences between the EXP and CON group. However, hip abduction, knee abduction and ankle inversion at IC angles were significantly greater in both groups. Peak knee abduction increased in both groups, while hip abduction significantly increased in the CON group.

Within the context of the current study, hip abduction increased slightly in both groups at IC and peak angles, with a significantly larger increase in knee shock attenuation, after the intervention. According to Hewett et al. (2005), excessive hip abduction and knee joint loading have been associated with the high incidence of ACL injuries in female athletes. Johnson et al. (2018), in a study on the relationship between the sensory organization performance test and landing characteristics, reported mean values for hip abduction during the double-leg stop-jump of -3.1 deg at IC, and -1.08 deg at the peak angle, respectively. The current study reported lower hip abduction at IC angles for all the jump-landing tasks in EXP and CON group compared to the study. The differences in both studies could be attributed to the jump-landing protocol. The current study incorporated an approach run into the stop jump task, while Johnson et al. modified the drop vertical jump into the double-leg stop-jump. The current study therefore agreed with Blackburn, Norcross and Mcgrath (2011) that the degree of knee displacement during landing would determine impact forces, and influence ankle dorsiflexion and knee valgus mobility.

Myer et al. (2015) identified increases in the knee abduction moment and angle as modifiable risk factors for ACL injury and patellofemoral pain among female populations. O'Kane et al. (2017) suggested that a reduction in the distance between the knees and increasing ankle distance in the form of knee abduction or knee valgus, have been associated with risk of knee injury. Even though both groups demonstrated increased knee flexion and abduction at IC and peak angles, the peak knee abduction decreased to a greater extent in the CON group. In the current study, both groups demonstrated a significant reduction in ankle eversion at IC angles, although increased minimally (< 1 deg) at peak angles after the intervention. Steele (1986) identified excessive ankle inversion (roll in), which is caused by strain to the lateral ankle ligaments, as the most common cause of ankle injury in netball. However, it is unclear whether the values for ankle inversion at IC and peak angles reported for both groups in the current study, would increase the risk of ankle sprain. It is proposed that changes in foot acceleration and ankle shock attenuation influenced the reduction in ankle inversion observed in both groups. The results of the current study suggest that greater sagittal plane excursion and an overall decrease in frontal plane excursion influenced the GRFs reported for the study. The current study was in agreement with Steele (1986) that there is a relationship between greater peak VGRF at IC, with less flexion of the ankle, hip and inward lean of the trunk.

Range of motion

It was hypothesized that sagittal plane angle ROM (hip flexion, knee flexion and ankle dorsiflexion ROM) for the jump-landing tasks would not be significantly different after the BF intervention; (a) between the EXP and CON groups; (b) within the EXP and CON groups. The hypothesis was accepted in (a) and rejected in (b). There were no significant differences between the EXP and CON group. However, hip and knee flexion ROM of all the jump-landing tasks increased in both groups after the intervention, with greater increases observed in the EXP group. With reference to IC and peak angles in the current study, hip and knee flexion was greater in the EXP group.

The current study is consistent with Yeow et al. (2011) who reported greater knee ROM for SH when compared with BF landing. The EXP group demonstrated a significant increase in knee flexion ROM after the intervention, although the magnitude of the change was lower than the CON group. A similar pattern between the two groups was also found with respect to shock attenuation within the knee joint. Both groups demonstrated a reduction in the peak resultant force, with the EXP group having a larger decrease. Time to peak was significantly greater in the CON group compared to the EXP group

It was hypothesized that frontal plane angle excursion (hip abduction, knee abduction, ankle abduction and ankle inversion ROM) of all the jump-landing tasks would be significantly different after the barefoot intervention; (a) between the EXP and CON groups; (b) within the EXP and CON groups. The hypothesis was accepted in (a) and rejected in (b). There were no significant differences between the EXP and CON groups. Hip abduction ROM increased significantly in both groups, although the CON group increased to a greater extent.

The mean difference showed that EXP group demonstrated greater hip abduction ROM, hip flexion ROM, knee flexion ROM, ankle dorsiflexion ROM and abduction ROM (within group comparison), even though post-test comparison between the two groups showed that CON group exhibited greater ROM These changes in lower limb kinematics at landing could increase the likelihood of injury. It is postulated that increases in lower limb sagittal plane excursion influences frontal plane excursion. This study also showed consistency with Ortiz et al. (2008) who reported greater hip flexion, hip abduction and knee flexion for drop jump in healthy compared to ACL group.

F. RESEARCH OBJECTIVE FIVE

To determine the effect of a six-week BF intervention on the performance of the Landing Error Scoring System (LESS) instrument.

The outcome of LESS showed that both groups demonstrated a reduction in likelihood for lower limb injury risk. LESS items were formulated to identify kinematics that could predispose an individual to lower limb injuries (Kowata, 2014). Even though LESS has been confirmed as a clinical tool that could be used to monitor risk of ACL injury and the development of injury prevention programme for an athlete or a sports team (Padua et al, 2009), the experience of the rater plays a significant role (Onate, Cortes, Welch & Van Lunen, 2010). For LESS assessments in the current study, no experienced raters could be found. The researcher had to train Sport Scientists to perform the ratings (blinded), which could have influenced the LESS ratings. The intra-rater reliability was reported as moderate (0.67). The outcome based on item by item do not show any notable changes or association with kinematic parameters obtained quantitatively in the current study.

G. RESEARCH OBJECTIVE SIX

To evaluate the subjective experience of netball players on barefoot intervention.

Subjective experience of barefoot intervention

Each participant in the EXP group completed a 3-item open-ended self-designed questionnaire after completion of the study to survey their perceptions of the BF intervention. Responses were categorized into injury risk, neuromuscular benefits, the comfort of the training surfaces and suitability of the type of drills for BF training. Feedback from the players indicated that most (78 %) of them preferred the BF training. A previous study by Du Plessis (2011) also reported that most of the participants (70 %) preferred BF training. It must be noted that participants in both studies came from a habitually barefoot background. Since there are no other research indicating the perceptions of participants on BF experience following intervention, it is not clear if the findings are a consequence of previous BF experiences. Some of the players had perceived injury risks experience (sensitive shins, sore feet and blisters) while a few others perceived that BF experience could facilitate neuromuscular benefits. This feedback correlates with the result of mLLCI in the current study, in which feet, calves, shins and ankles also showed more discomfort in the EXP group. Rothschild (2012a) identified that lower limb muscle pain or soreness was linked with the adverse reaction after BF running.

The outcome of BF intervention subjective experience increased the need for comfort index in footwear intervention to lower the risk of injury. The choice of training surfaces (barefoot on court, grass training and hard surface) formed part of the negative experience of the players while others preferred the choice of training surface. Perhaps, the significant kinetics and kinematics differences demonstrated by both groups were influenced by the surface selection for the intervention (BF condition on court and grass). The surface selection has been linked to the incidence of injury in spite of the rise in biomechanically modified footwear and orthotics (Mcgrath & Ozanne-smith, 1998). Drills, which formed the components of BF intervention, were not comfortable for some of the player (especially running barefoot), while others equally preferred the components of the drills. Two factors were assumed to be responsible for the varied response. First, training experience in SH condition could influence negative feeling for BF experience. Second, personal preference of comfort and sense of plantar protection provided by footwear. The aim of the short questionnaire was to get general feedback on the BF experience for application in future BF interventions. Due to the mixed responses, it is difficult to make conclusions in terms of surface choice, types of drills to perform on the various surfaces, and reasons why many players preferred BF training. It might be necessary to design a more detailed questionnaire. It was also not determined if players who could be classified as habitually barefoot, were more positive towards the intervention.

Previous barefoot experience

Before the intervention, the participants completed a questionnaire, specifically designed for the study to assess their previous BF experience. The questions were designed to assess the extent to which the players were accustomed to BF conditions before the intervention. The items were based on their primary school footwear experience and how frequently they chose to be BF at different times of the year as university athletes. The current study revealed that more than half of the players (65 %) experienced barefootness during primary school years though this experience might not translate to an adolescent period of life due to adaptation to footwear alternatives. The previous BF experience was not considered as a confounding variable for the study to be adjusted for, due to the small percentage of BF experience and the homogenous background of the players.

De Villiers (2017) reported in a study that BF ambulation is common in the South African community. And by extension, the BF culture is commonly practised by children in schools and during sports (Hollander et al., 2016). In addition, most of the players experienced BF during summer holidays. Possibly, this is influenced by the prevalent BF culture across age groups. However, Hollander et al. (2017a) in an epidemiological study on the influence of footwear on foot development in children and adolescents, identified that type of footwear use could affect foot morphology and movement pattern in later years.

H. RESEARCH OBJECTIVE SEVEN

To evaluate the barefoot intervention adaptation by the netball players Modified Lower Limb Comfort Index (mLLCI)

The mLLCI is modified from the earlier version of lower limb comfort index (Kinchington, 2011) with the inclusion of questions related to lower back and hip comfort. The instrument was adopted for the study to monitor the rate of adaptation to BF intervention programme. The mLLCI results showed significant differences in the feet, ankle, calves and shins between the EXP and CON groups. There were no significant differences in the Achilles, knee, hip and lower back between the EXP and CON group. In a running study on joint contact loading, Rooney and Derrick (2013) reported that greater ground contact during forefoot landing stimulates the contraction of plantar flexors and increases ankle joint loading which might pose an injury risk to the anatomical region. However, Lieberman (2012) noted that runners who efficiently transitioned into forefoot landing pattern develop stronger plantar flexors with controlled ankle mobility. The BF intervention adopted for the current study followed a progressive intensity to accommodate acute incidence of an injury risk to the participants. The current study is in line with Willson et al. (2014), who adopted the exercise intensity reduction to accommodate adverse effect during BF transition.

The initial painful discomfort experienced during BF intervention has been reported by other studies (Robbins & Gouw, 1991; Lieberman, 2012; Tam, Tucker, & Wilson, 2016). However, it is possible to continue the intervention if the discomfort is acute (Tam, Tucker, & Wilson, 2016). In the current study, none of the participants withdrew as a result of the intervention. The only case of injury reported had no connection with the intervention. Du Plessis (2011) in an experimental study, adopted an open-ended questionnaire to get feedback after BF intervention on the perception of discomfort.

Most of the discomfort felt (70 %) were around the foot region (the sole of the feet). Similarly, in the current study, both groups demonstrated a significant difference in the feet region with the largest effect size, of all the anatomical segments. The EXP group also experienced more discomfort compared to the CON group in the feet region but the mean value revealed that the shin region experienced the most discomfort during the intervention.

Furthermore, the result of the current study is in contrast with Schütte (2012), which reported LLCI significance for only the shin after 12 weeks of intervention for barefoot, minimalist and shod recreational runners. First, the average score of the LLCI index reported was higher than the average mean score of the present study for the EXP and CON group. The gender of the participants of the study (male) and the current study (female) might be responsible for the reported differences. Second, the study used recreational runners while the current study used well-trained university netball players. Third, the version of the instrument used for the current study was modified and expanded. Lower back and hip were added and footwear removed from the modified version. No study has ever used LLCI for only female participants or netball players. LLCI have been used for elite football players (Kinchington, Ball, & Naughton, 2010) and rugby players (Kinchington, Ball, & Naughton, 2011). However, Dreyer (2014) adopted LLCI for mixed gender (five women and six men) in a study on minimalist footwear and neuromuscular control for recreational runners. The study reported significant differences for Achilles, calf, ankle, foot and knee between EXP and CON after eight weeks of intervention. The current study is in agreement with Dreyer (2014) except for the changes in Achilles and knees. Gender factor might be responsible for the differences. There is a need for further investigation on the gender response to lower limb comfort index.

I. CONCLUSION

There is the notion that barefoot training could be implemented as a training modality to acquire a

There is the notion that barefoot training could be implemented as a training modality to acquire a number of possible benefits mentioned previously. Performing the same activity in two footwear conditions lead to varying outcomes, which have implications for the implementation of landing interventions. Due to the paucity of studies on the kinetics and kinematics of safe and effective landings in BF and SH conditions, findings of the current study have contributed to our knowledge in this research area. This objective on kinetics of landing in barefoot and shod condition provided further explanation to the composite effect of ground reaction forces on anatomical segment of lower limbs. The combination of shock attenuation and ground reaction forces provided a further explanation to the proportion of impact transmission in the lower extremities. In the same vein, the impact peak acceleration provided information on the rate of velocity of each anatomical segment of the lower limbs. The extraction of time to peak for all the components of ground reaction forces added meaningful explanation to the time component of force dynamics. The shock attenuation results showed that training barefoot could aid the neuromuscular conditioning towards kinetic and kinematics adjustment for injury risk reduction at landing.

Results from the current study lead to the following conclusions that:

1. Gradual conditioning of lower limbs for efficient anteroposterior force in dynamic movement without increasing the joint loading could progress with low intensity BF training before the introduction of high intensity movement pattern in SH condition. BF training would increase the activation of plantar flexors and allow for efficient distribution of load at the lower limb joints.
2. During the landing tasks in BF condition, the small and large muscles of the ankle joint contributed to the reduction in mediolateral force within the kinetic chain. Possibly, these variations were influenced by lower limb joint coordination and velocity of movement task. However, in relation to vertical force reduction, it would seem that SH landings would be regarded as safer.
3. Lower limb injury risk is associated with proportion of force-time and force-magnitude distribution. Possibly, the landing kinematics might be responsible for the force-time component modulations. Within the context of the current study, the mechanism of interaction between the force magnitude and time component in BF and SH conditions further explained the dynamics of movement pattern in relation to shock absorption.
4. The magnitude of impact absorbed by the plantar surface possibly increased the acceleration of the foot during ground contact in BF condition.
5. Greater hip abduction observed in the current study possibly serve as the landing strategy to control excessive frontal plane movement in BF condition.
6. The extrinsic factors such as foot disposition in the footwear, surface friction and kinematics parameters possibly influenced the time delay of GRFs in the current study.

Finally, safe and effective landings have been recognised as important aspects of injury prevention programmes. Understanding the dynamics of landing mechanics for injury prevention and performance enhancement will require profiling the components of ground reaction forces. Athletes who are involved in sports characterised by jump-landing activities should be specifically trained in multi-dimensional landing to reduce the incidence of lower limb injuries. Successful jump-landing training could be integrated with systematic progression for effective physical conditioning and adaptation to landing impact. BF training could form part of training modalities implemented to enhance safe and effective landings. Coaches need to be educated on the implementation of injury prevention programmes to possibly reduce the incidence of lower limb injuries in netball.

J. STUDY LIMITATIONS AND FUTURE RESEARCH

The use of the wearable technology like accelerometers to quantify movement has become popular in recent years and has some validation. However, the use of the marker-based optoelectronic system is considered the gold standard for human movement quantification. Moreover, both methods are still subject to experimental bias, devise malfunction and model variations. These wearable technology and devices could be validated by the use optoelectronic systems for clinical relevance.

Future research should look into adding EMG to the barefoot landing task to explore specific muscle activation and adaptation after the intervention. Female athlete's landing patterns and responses to neuromuscular training could be adopted as a prospective longitudinal study. Possible sex differences in this regard could be further investigated. There is a need to further investigate mediation and moderation of landing biomechanics in footwear conditions.

Running an intervention study in a competitive club setting posed specific challenges to the research process. Ideally, the researcher would have preferred to design and implement a customised training programme. Unfortunately, the consent of the coaching staff for a customised programme changed at the start of the intervention. The researcher could provide some guidelines on the type of drills which should be avoided, but no landing-specific drills were implemented. Future researchers could implement, for example, the six-week *Down to Earth: A practical guide to safe and effective landing in Netball* programme designed by Saunders, Otago and Peoples (2006), that was developed to coach (coach-directed training) and train (home-based training) for safe and effective landing in netball. The players could not be engaged in a controlled laboratory study or extended intervention study (longitudinal study) due to the university calendar and club commitments. It could be argued that an intervention can be implemented at the end of the netball season, but motivation and compliance might be a problem. Future studies might explore a longer intervention period during the off-season of professional netball players.

The jump tasks adopted for the current study mostly placed a submaximal demand on the musculoskeletal system, except for the stop-jump performance task, combining a self-paced acceleration with a maximum explosive jump for the overhead target. It would be difficult to test players BF at baseline during multiple jumps requiring maximal efforts. A possible solution would be to have a barefoot intervention a few weeks before data collection. This would, however, require a long commitment from participants.

Players did not complete a training log to document any additional training they did outside of their usual netball-related training. The possible influence of other training modalities used by players on the results of the current study cannot be accounted for. The current study experienced a ~27 % drop out (40 % in EXP and 13 % in CON group). Although the majority of players gave positive feedback about their perceptions and experiences of the barefoot training, it might be possible that some of the players dropped out because of negative experiences during the intervention. Players gave feedback anonymously and the researcher could not determine a possible relationship. Some players (33 %) did not prefer the training surface. Care needs to be taken in surface selection for BF intervention to avoid plantar sensitivity during training. Future studies could explore solutions to a negative perception of exercise in BF condition.

REFERENCES

Aerts, I., Cumps, E., Verhagen, E., & Meeusen, R. (2010). Efficacy of a 3-month training program on the jump-landing technique in jump-landing sports. Design of a cluster randomized controlled trial. *BMC Musculoskeletal Disorders*, *11*:281. http://doi.org/10.1186/1471-2474-11-281

Aerts, I., Cumps, E., Verhagen, E., Verschueren, J., & Meeusen, R. (2013). A systematic review of different jump-landing variables in relation to injuries. *Journal of Sports Medicine & Physical Fitness*, *53*(2), 509–519. http://doi.org/10.13140/RG.2.1.5129.4169

Aizawa, J., Ohji, S., Koga, H., Masuda, T., & Yagishita, K. (2016). Correlations between sagittal plane kinematics and landing impact force during single-leg lateral jump-landings. *Journal of Physical Therapy Science*, *28*(8), 2316–2321. http://doi.org/10.1589/jpts.28.2316

Ali, N., Gordon, D., Robertson, E., & Rouhi, G. (2014). Sagittal plane body kinematics and kinetics during single-leg landing from increasing vertical heights and horizontal distances: Implications for risk of non-contact ACL injury. *The Knee*, *21*, 38–46. http://doi.org/10.1016/j.knee.2012.12.003

Ali, N., Rouhi, G., & Robertson, G. (2013). Gender, vertical height and horizontal distance effects on single-leg landing kinematics: Implications for risk of non-contact acl injury. *Journal of Human Kinetics*, *37*(June), 27–38. http://doi.org/10.2478/hukin-2013-0022

Altman, A. R., & Davis, I. S. (2012). Barefoot running: Biomechanics and implications for running injuries. *Current Sports Medicine Reports*, *11*(5), 244–250. http://doi.org/10.1249/JSR.0b013e31826c9bb9

Altman, A. R., & Davis, I. S. (2016). Prospective comparison of running injuries between shod and barefoot runners. *British Journal of Sports Medicine*, *50*(8), 476–480. http://doi.org/10.1136/bjsports-2014-094482

An, W., Rainbow, M. J., & Cheung, R. T. H. (2015). Impacts of surface inclination on the vertical loading rates and landing pattern in novice barefoot runners. *BioMed Research International*, *101*, 1–7. http://doi.org/10.1016/j.physio.2015.03.198

Anza, R., Denis, M., & Silva, M. F. (2013). Analysis of physical fitness, anthropometry and prevalence of musculoskeletal symptoms in the youth volleyball category. *Revista Brasileira De Medicina Do Esporte*, *19*(1), 62–65.

Applequist, B. C. (2012). *Shock attenuation in landing*. University of Nevada, Las Vegas.

Araujo, S., Cohen, D., & Hayes, L. (2015). Six weeks of core stability training improves landing kinetics among female capoeira athletes: A pilot study. *Journal of Human Kinetics*, *45*(45), 27–37. http://doi.org/10.1515/hukin-2015-0004

Arulsingh, W., & Pai, G. (2015). A study of foot defects, deformities and diseases among shod and barefoot middle and long distance runners - cross sectional study. *International Journal of Current Ressearch & Review*, *6*(7), 15–23.

Azevedo, A. P. d S., Mezêncio, B., Amadio, A. C., & Serrao, J. C. (2016). 16 weeks of progressive barefoot running training changes impact force and muscle activation in habitual shod runners. *PLoS ONE*, *11*(December), 1–16. http://doi.org/10.1371/journal.pone.0167234.

Baker, R. (2001). Pelvic angles: A mathematically rigorous definition which is consistent with a conventional clinical understanding of the terms. *Gait & Posture*, *13*(1), 1–6. http://doi.org/10.1016/S0966-6362(00)00083-7.

Bartlett, R. (2007). *Introduction to Sports Biomechanics*. (Second ed). London & New York. Taylor & Francis. http://doi.org/10.4324/9780203476161.

Bates, N. A., Ford, K. R., Myer, G. D., & Hewett, T. E. (2013a). Timing differences in the generation of ground reaction forces between the initial and secondary landing phases of the drop vertical jump. Clinical Biomechanics, *28*(7), 796–799. http://doi.org/10.1016/j.clinbiomech.2013.07.004.

Bates, N. A., Ford, K. R., Myer, G. D., & Hewett, T. E. (2013b). Impact differences in ground reaction force and centre of mass between the first and second landing phases of a drop vertical jump and their implications for injury risk assessment. *Journal of Biomechanics*, *46*(7), 1237–1241. http://doi.org/10.1016/j.jbiomech.2013.02.024

Bell, D. R., Smith, M. D., Pennuto, A. P., Stiffler, M. R., & Olson, M. E. (2014). Jump-Landing Mechanics After Anterior Cruciate Ligament Reconstruction: A Landing Error Scoring System Study. *Journal of Athletic Training*, *49*(3), 435–441. http://doi.org/10.4085/1062-6050-49.3.21

Bishop, C., Read, P., Walker, S., & Turner, A. (2015). Assessing movement using a variety of screening tests. *Movement Screening*. Professional strength & conditioning / www.uksca.org.uk.

Bishop, M., Fiolkowski, P., Conrad, B., Brunt, D., & Horodyski, M. (2006). Athletic footwear, leg stiffness, and running kinematics. *Journal of Athletic Training*, *41*(4), 387–392. http://doi.org/10.1519/JSC.0b013e3181ddfcf8

Bisseling, R. W., Hof, A. L., Bredeweg, S. W., Zwerver, J., & Mulder, T. (2007). Relationship between landing strategy and patellar tendinopathy in volleyball. *British Journal of Sports Medicine*, *41*(7), e8. http://doi.org/10.1136/bjsm.2006.032565

Blackburn, T., Norcross, M., & Mcgrath, M. (2011). Ankle-dorsiflexion range of motion and landing biomechanics. *Journal of Athletic Training*, *46*(1), 5–10. http://doi.org/10.4085/1062-6050-46.1.5

Blackburn, T., & Padua, D. (2009). Sagittal-plane trunk position, landing forces, and quadriceps electromyographic activity. Journal of Athletic Training, (44)2, 174-179. http://doi.org/10.4085/1062-6050-44.2.174

Bleser, G., Steffen, D., Weber, M., Hendeby, G., Stricker, D., Fradet, L., … Carre, F. (2013). A personalized exercise trainer for the elderly. *Journal of Ambient Intelligence and Smart Environments*, *5*(6), 547–562. http://doi.org/10.3233/AIS-130234

Bonacci, J., Saunders, P. U., Hicks, A., Rantalainen, T., Vicenzino, B., Guglielmo, T., & Spratford, W. (2013). Running in a minimalist and lightweight shoe is not the same as running barefoot: a biomechanical study. *British Journal of Sports Medicine*, *47*(6), 387–392. http://doi.org/10.1136/bjsports-2012-091837

Bowser, B. J., Rose, W. C., McGrath, R., Salerno, J., Wallace, J., & Davis, I. S. (2017). Effect of Footwear on Dynamic Stability during Single-leg Jump Landings. *International Journal of Sports Medicine*, *38*(6), 481–486. http://doi.org/10.1055/s-0043-103090

Braunstein, B., Arampatzis, A., Eysel, P., & Brüggemann, G.-P. (2010). Footwear affects the gearing at the ankle and knee joints during running. *Journal of Biomechanics*, *43*(11), 2120–2125. http://doi.org/10.1016/j.jbiomech.2010.04.001

Bressel, E., & Cronin, J. (2005). The landing phase of a jump strategies to minimize injuries. *The Journal of Physical Education, Recreation & Dance*, *76*(2), 31–47.

Brewer, C. (2016). *Athletic Movement Skills: Training for Sport Performance* (1st ed.). United States of America: Human Kinetics.

Brizuela, G., Llana, S., Ferrandis, R., & Garcia-Belenguer, A. C. (1997). The influence of basketball shoes with increased ankle support on shock attenuation and performance in running and jumping. *Journal of Sports Sciences*, *15*, 505–515. http://doi.org/10.1080/026404197367146

Buhagiar, K., Shadmi, A., Schiller, L., Schwartzer, K., & Woychick, S. (2018). Differences in Sagittal Plane Joint Angles between Shod and Barefoot Landing from a Drop Jump.

Cameron, K. L., Peck, K. Y., Owens, B. D., Svoboda, S. J., DiStefano, L. J., Marshall, S. W., … Padua, D. A. (2014). Landing error scoring system (LESS) items are associated with the incidence rate of lower extremity stress fracture. *Orthopaedic Journal of Sports Medicine*, 2(2 suppl). http://doi.org/10.1177/2325967114S00080

Carcia, C. R., Kivlan, B. R., & Scibek, J. S. (2012). Time to peak force is related to frontal plane landing kinematics in female athletes. *Physical Therapy in Sport*, *13*(2), 73–79. http://doi.org/10.1016/j.ptsp.2011.06.003

Caster, B. L. (1996). *The Effect of height and post-landing movement task on landing performance*. University of Oregon.

Cavanagh, P. R., & Lafortune, M. A. (1980). Ground Reaction Forces in Distance Running. *Journal of Biomechanics*, *13*, 397–406. http://doi.org/10.1016/0021-9290(80)90033-0

Chappell, J. D. (2005). Effect of Fatigue on Knee Kinetics and Kinematics in Stop-Jump Tasks. *American Journal of Sports Medicine*, *33*(7), 1022–1029. http://doi.org/10.1177/0363546504273047

Chappell, J. D., & Limpisvasti, O. (2008). Effect of a neuromuscular training program on the kinetics and kinematics of jumping tasks. *The American Journal of Sports Medicine*, *36*(6), 1081–6. http://doi.org/10.1177/0363546508314425

Chappell, J. D., Yu, B., Kirkendall, D. T., & Garrett, W. E. (2002). A comparison of knee kinetics between male and female recreational athletes in stop-jump tasks. *The American Journal of Sports Medicine*, *30*(2), 261–267. http://doi.org/10.1177/03635465020300021901

Cho, J. R., Park, S. B., Ryu, S. H., Kim, S. H., & Lee, S. B. (2009). Landing impact analysis of sports shoes using 3-D coupled foot-shoe finite element model. *Journal of Mechanical Science and Technology*, *23*(10), 2583–2591. http://doi.org/10.1007/s12206-009-0801-x

Choukou, M. A., Laffaye, G., & Taiar, R. (2014). Reliability and validity of an accele-rometric system for assessing vertical jumping performance. *Biology of Sport*, *31*(1), 55–62. http://doi.org/10.5604/20831862.1086733

Cohen, J. (1992). Quantitative Methods in Psychology. *Psychological Bulletin*, *112*(1), 155–159. http://doi.org/10.1037/0033-2909.112.1.155

Cordova, M. L., Takahashi, Y., Kress, G. M., Brucker, J. B., & Finch, A. E. (2010). Influence of external ankle support on lower extremity joint mechanics during drop landings. *Journal of Sport Rehabilitation*, *19*(2), 136–148. http://doi.org/10.1123/jsr.19.2.136

Cortes, N., & Onate, J. (2013). Clinical assessment of drop-jump landing for determination of risk for knee injury. *International Journal of Athletic Therapy and Training*, *18*(3), 10–13.

Coventry, E., O'Connor, K. M., Hart, B. A., Earl, J. E., & Ebersole, K. T. (2006). The effect of lower extremity fatigue on shock attenuation during single-leg landing. *Clinical Biomechanics*, *21*(10), 1090–1097. http://doi.org/10.1016/j.clinbiomech.2006.07.004

Cowling, E. J., & Steele, J. R. (2001). Is lower limb muscle synchrony during landing affected by gender? Implications for variations in ACL injury rates. *Journal of Electromyography and Kinesiology*, *11*(4), 263–268. http://doi.org/10.1016/S1050-6411(00)00056-0

D'Aout, K., Pataky, T. C., De Clercq, D., & Aerts Ad, P. (2009). The effects of habitual footwear use: foot shape and function in native barefoot walkers. *Footwear Science*, *1*(2), 81–94.

http://doi.org/10.1080/19424280903386411

Dai, B., Garrett, W. E., Gross, M. T., Padua, D. a, Queen, R. M., & Yu, B. (2015). The effects of 2 landing techniques on knee kinematics, kinetics, and performance during stop-jump and side-cutting tasks. *The American Journal of Sports Medicine*, *43*(2), 466–74. http://doi.org/10.1177/0363546514555322

Dare, M. R. (2014). *Investigation of thoracic spine kinematics in adult sports participants with chronic groin pain*. Stellenbosch University.

De Villiers, J. E., & Venter, R. E. (2014). Barefoot training improved ankle stability and agility in netball players. *International Journal of Sports Science & Coaching*, *9*(3), 485-495.

Decker, M. J., Torry, M. R., Wyland, D. J., Sterett, W. I., & Steadman, J. R. (2003). Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. *Clinical Biomechanics*, *18*(7), 662–669. http://doi.org/10.1016/S0268-0033(03)00090-1

Derrick, T. R. (2004). The effects of knee contact angle on impact forces and accelerations. *Medicine & Science in Sports & Exercise*, *36*, 832–837. http://doi.org/10.1249/01.MSS.0000126779.65353.CB

DiStefano, L. J., Marshall, S. W., Padua, D. A., Peck, K. Y., Beutler, A. I., de la Motte, S. J., … Cameron, K. L. (2016). The Effects of an Injury Prevention Program on Landing Biomechanics Over Time. *The American Journal of Sports Medicine*, *44*(3), 767–776. http://doi.org/10.1177/0363546515621270

Divert, C., Mornieux, G., Baur, H., Mayer, F., & Belli, A. (2005). Mechanical comparison of barefoot and shod running. *International Journal of Sports Medicine*, *26*(7), 593–598. http://doi.org/10.1055/s-2004-821327

Dollard, M. D., Pontell, D., & Hallivis, R. (2006). Preconditioning principles for preventing sports injuries in adolescents and children. *Clinics in Podiatric Medicine and Surgery*, *23*, 191–207.

Donohue, M. R., Ellis, S. M., Heinbaugh, E. M., Stephenson, M. L., Zhu, Q., & Dai, B. (2015). Differences and correlations in knee and hip mechanics during single-leg landing, single-leg squat, double-leg landing, and double-leg squat tasks. *Research in Sports Medicine*, *23*(4), 394–

411. http://doi.org/10.1080/15438627.2015.1076413

Dreyer, S. (2014). *The effect of minimalist shoe training on the neuromuscular control of recreational distance runners*. Masters dissertation. Stellenbosch University.

Du Plessis, J. (2011). *The effect of barefoot training on speed, agility, power and balance in netball players*. Masters dissertation. Stellenbosch University.

Dufek, J. S., & Bates, B. T. (1990). The evaluation and prediction of impact forces during landings. *Medicine & Science in Sports & Exercise*, *22*(2), 370–377.

Dufek, J. S., & Bates, B. T. (1991). Biomechanical factors associated with injury during landing in jump sports. *Sports Medicine*, *12*(5), 326–337. http://doi.org/10.2165/00007256-199112050-00005

Dufek, J. S., & Bates, B. T. (1992). Lower extremity performance models for landing. *Human Movement Science*, *11*(3), 299–318. http://doi.org/10.1016/0167-9457(92)90002-S

Echarri, J. J., & Forriol, F. (2003). The development in footprint morphology in 1851 Congolese children from urban and rural areas, and the relationship between this and wearing shoes. *Journal of Pediatric Orthopedics. Part B*, *12*(2), 141–6. http://doi.org/10.1097/01.bpb.0000049569.52224.57

Edwards, H. (2000). Dynamically moderated shock attenuation system for footwear. United States of America. http://doi.org/10.1197/jamia.M1139.Adar

Edwards, S., Steele, J. R., Cook, J. L., Purdam, C. R., McGhee, D. E., & Munro, B. J. (2012). Characterizing patellar tendon loading during the landing phases of a stop-jump task. *Scandinavian Journal of Medicine and Science in Sports*, *22*(1), 2–11. http://doi.org/10.1111/j.1600-0838.2010.01119.x

Edwards, S., Steele, J. R., & McGhee, D. E. (2010). Does a drop landing represent a whole skill landing and is this moderated by fatigue? *Scandinavian Journal of Medicine and Science in Sports*, *20*(3), 516–523. http://doi.org/10.1111/j.1600-0838.2009.00964.x

Eerkes, K. (2012). Volleyball injuries. *Current Sports Medicine Reports*, *11*(5), 251–256.

https://doi.org/10.1249/JSR.0b013e3182699037

Elphinston, J., & Hardman, S. L. (2006). Effect of an integrated functional stability program on injury rates in an international netball squad. *Journal of Science and Medicine in Sport*, *9*(1–2), 169–176. http://doi.org/10.1016/j.jsams.2005.11.002

Elvin, N. G., Elvin, A. A., & Arnoczky, S. P. (2007). Correlation Between Ground Reaction Force and Tibial Acceleration\nin Vertical Jumping. *Journal of Applied Biomechanics*, *23*(1996), 180–189.

Ericksen, H. M., Thomas, A. C., Gribble, P. A., Armstrong, C., Rice, M., & Pietrosimone, B. (2016). Jump-landing biomechanics following a 4-week real-time feedback intervention and retention. *Clinical Biomechanics*, *32*(2016), 85–91. http://doi.org/10.1016/j.clinbiomech.2016.01.005

Etnoyer, J., Cortes, N., Ringleb, S. I., Van Lunen, B. L., & Onate, J. A. (2013). Instruction and jump-landing kinematics in college-aged female athletes over time. *Journal of Athletic Training*, *48*(2), 161–171. http://doi.org/10.4085/1062-6050-48.2.09

Faigenbaum, A. D. (2001). Preseason conditioning for high school athletes. *Strength and Conditioning Journal*, *23*(1), 70. http://doi.org/10.1519/00126548-200102000-00017

Ferreira, M. A., & Spamer, E. J. (2010). Biomechanical, anthropometrical and physical profile of elite university netball players and the relationship to musculoskeletal injuries. *South African Journal for Research in Sport, Physical Education, and Recreation*, *32*(1), 57–67. http://doi.org/10.4314/sajrs.v32i1.54100

Fong, C. M., Blackburn, J., Norcross, M. F., McGrath, M., & Padua, D. A. (2011). Ankle-Dorsiflexion Range of Motion and Landing Biomechanics. *Journal of Athletic Training*, *46*(1), 5–10.

Fong, D. T. P., Lam, M. H., Lai, P. K., Yung, P. S. H., Fung, K. Y., & Chan, K. M. (2014). Effect of anticipation on knee kinematics during a stop-jump task. *Gait and Posture*, *39*(1), 75–79. http://doi.org/10.1016/j.gaitpost.2013.05.027

Ford, K. R., Myer, G. D., Smith, R. L., Byrnes, R. N., Dopirak, S. E., & Hewett, T. E. (2005). Use of an overhead goal alters vertical jump performance and biomechanics. *Journal of Strength &*

Conditioning Research, *19*(2), 394–399. http://doi.org/10.1519/15834.1

Forthomme, B. (2005). Factors correlated with volleyball spike velocity. *American Journal of Sports Medicine*, *33*(10), 1513–1519. http://doi.org/10.1177/0363546505274935

Fox, A. S., Bonacci, J., McLean, S. G., Spittle, M., & Saunders, N. (2016). A systematic evaluation of field-based screening methods for the assessment of anterior cruciate ligament (ACL) injury risk. *Sports Medicine*, *46*(5), 715–735. http://doi.org/10.1007/s40279-015-0443-3

Franklin, S., Grey, M. J., Heneghan, N., Bowen, L., & Li, F. X. (2015). Barefoot vs common footwear: A systematic review of the kinematic, kinetic and muscle activity differences during walking. *Gait and Posture*, *42*(3), 230–239. http://doi.org/10.1016/j.gaitpost.2015.05.019

Fransz, D. P., Huurnink, A., de Boode, V. A., Kingma, I., & van Dieen, J. H. (2016). Time series of ground reaction forces following a single-leg drop jump landing in elite youth soccer players consist of four distinct phases. *Gait and Posture*, *50*, 137–144. http://doi.org/10.1016/j.gaitpost.2016.09.002

Fredericks, W., Swank, S., Teisberg, M., Hampton, B., Ridpath, L., & Hanna, J. B. (2015). Lower extremity biomechanical relationships with different speeds in traditional, minimalist, and barefoot footwear. *Journal of Sports Science and Medicine*, *14*(2), 276–283.

Garthe, I., Raastad, T., & Sundgot-Borgen, J. (2011). Long-term effect of weight loss on body composition and performance in elite athletes. *International Journal of Sport Nutrition and Exercise Metabolism*, *21*, 426–435.

Gathercole, R., Sporer, B., & Stellingwerff, T. (2015). Countermovement jump performance with increased training loads in elite female rugby athletes. *International Journal of Sports Medicine*, *36*(9), 722–728. http://doi.org/10.1055/s-0035-1547262

Gomes, J. L. E., de Castro, J. V., & Becker, R. (2008). Decreased hip range of motion and noncontact injuries of the anterior cruciate ligament. *Arthroscopy - Journal of Arthroscopic and Related Surgery*, *24*(9), 1034–1037. http://doi.org/10.1016/j.arthro.2008.05.012

Goss, D. L., & Gross, M. T. (2012). Relationships among self-reported shoe type, foot-strike pattern, and injury incidence. *U.S. Army Medical Department Journal*, 25–30. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/23007933

Greene, A. J., Stuelcken, M. C., Smith, R. M., & Vanwanseele, B. (2014). The effect of external ankle support on the kinematics and kinetics of the lower limb during a side step cutting task in netballers. *BMC Sports Science, Medicine and Rehabilitation*, *6*(1), 42. http://doi.org/10.1186/2052-1847-6-42

Gross, T. S., & Nelson, R. C. (1988). The shock attenuation role of the ankle during landing from a vertical jump. *Medicine and Science in Sports and Exercise*, *20*(5), 506–514.

Hackney, J. M., Clay, R. L., & James, M. (2016). Force-displacement differences in the lower extremities of young healthy adults between drop jumps and drop landings. *Human Movement Science*, *49*, 79–86. http://doi.org/10.1016/j.humov.2016.06.008

Hamill, J. (1999). Evaluation of shock attenuation. In *Proceedings of Fourth Symposium on Footwear Biomechanics.*

Hammett, J. B., & Hey, W. T. (2003). Neuromuscular adaptation to short-term (4 weeks) ballistic training in trained high school athletes. *Journal of Strength and Conditioning Research*, *17*(3), 556–560. http://doi.org/10.1519/1533-4287(2003)017<0556:NATSWB>2.0.CO;2

Hart, P. M., & Smith, D. R. (2008). Preventing Running Injuries Through Barefoot Activity. *JOPERD: The Journal of Physical Education, Recreation & Dance*, *79*(4), 50–53. http://doi.org/10.1080/07303084.2008.10598165

Hauschildt, M. (2018). Landing Mechanics : What , Why , and When. *NSCA's Performance Training Journal*, *7*(1), 13–16. Retrieved from www.nsca-lift.org

Headon, R., & Curwen, R. (2001). Recognizing movements from the ground reaction force. *Proceedings of the 2001 Workshop on Percetive User Interfaces - PUI '01*, 1. http://doi.org/10.1145/971478.971523

Heebner, N. R., Rafferty, D. M., Wohleber, M. F., Simonson, A. J., Lovalekar, M., Reinert, A., & Sell, T. C. (2017). Landing kinematics and kinetics at the knee during different landing tasks. *Journal of Athletic Training*, *52*(12), 1062–6050–52.11.25. http://doi.org/10.4085/1062-6050-52.11.25

Heidt, R. S., Sweeterman, L. M., Carlonas, R. L., Traub, J. A., & Tekulve, F. X. (2000). Avoidance of soccer injuries with preseason conditioning. *American Journal of Sports Medicine*, *28*(5), 659–662. http://doi.org/10.1177/03635465000280050601

Herman, D. C., Weinhold, P. S., Guskiewicz, K. M., Garrett, W. E., Yu, B., & Padua, D. A. (2008). The effects of strength training on the lower extremity biomechanics of female recreational athletes during a stop-jump task. *The American Journal of Sports Medicine*, *36*(4), 733–740. http://doi.org/DOI: 10.1177/036354650731160

Hewett, T. E., Lindenfeld, T. N., Riccobene, J. V, & Noyes, F. R. (1999). The effect of neuromuscular training on the incidence of knee injury in female athletes: A prospective study. *American Journal of Sports Medicine*, *27*(6), 699–706. http://doi.org/10.1177/03635465990270060301

Hewett, T. E., Myer, G. D., Ford, K. R., Heidt, R. S., Colosimo, A. J., McLean, S. G., … Succop, P. (2005). Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: A prospective study. *American Journal of Sports Medicine*, *33*(4), 492–501. http://doi.org/10.1177/0363546504269591

Hewett, T. E., Stroupe, A. L., Nance, T. A., & Noyes, F. R. (1996). Plyometric training in female athletes: Decreased impact forces and increased hamstring torques. *American Journal of Sports Medicine*, *24*(6), 765–773. http://doi.org/10.1177/036354659602400611

Hollander, K., Argubi-Wollesen, A., Reer, R., & Zech, A. (2015). Comparison of minimalist footwear strategies for simulating barefoot running: A randomized crossover study. *PLoS ONE*, *10*(5), 1-11. http://doi.org/10.1371/journal.pone.0125880

Hollander, K., De Villiers, J. E., Sehner, S., Wegscheider, K., Braumann, K. M., Venter, R., & Zech, A. (2017a). Growing-up (habitually) barefoot influences the development of foot and arch morphology in children and adolescents. *Scientific Reports*, *7*(1), 1–9. https://doi.org/10.1038/s41598-017-07868-4

Hollander, K., Heidt, C., Van Der Zwaard, B. C., Braumann, K. M., & Zech, A. (2017b). Long-term effects of habitual barefoot running and walking: A systematic review. *Medicine and Science in Sports and Exercise*, *49*(4), 752–762. http://doi.org/10.1249/MSS.0000000000001141

Hollander, K., van der Zwaard, B. C., de Villiers, J. E., Braumann, K.-M., Venter, R., & Zech, A.

(2016). The effects of being habitually barefoot on foot mechanics and motor performance in children and adolescents aged 6-18 years: study protocol for a multicenter cross-sectional study (Barefoot LIFE project). *Journal of Foot and Ankle Research*, *9*(1), 36. https://doi.org/10.1186/s13047-016-0166-1

Hood, S., McBain, T., Portas, M. D., & Spears, I. R. (2016). Measurement in sports biomechanics. *Measurement & Control*, *45*(6), 182–186.

Hopper, A. J., Haff, E. E., Joyce, C., Lloyd, R. S., & Haff, G. G. (2017). Neuromuscular training improves lower extremity biomechanics associated with knee injury during landing in 11-13 year old female netball athletes: A randomized control study. *Frontiers in Physiology*, *8*(NOV). http://doi.org/10.3389/fphys.2017.00883

Hopper, D., & Elliott, B. (1993). Lower limb and back injury patterns of elite netball players. *Sports Medicine: Evaluations of Research in Exercise Science and Sports Medicine*, *16*(2), 148–162. http://doi.org/10.2165/00007256-199316020-00006

Hopper, D., Elliott, B., & Lalor, J. (1995). A descriptive epidemiology of netball injuries during competition: a five year study. *British Journal of Sports Medicine*, *29*(4), 223–228. http://doi.org/10.1136/bjsm.29.4.223

Hopper, D., Lo, S. K., Kirkham, C., & Elliott, B. C. (1992). Landing patterns in netball: analysis of an international game. *British Journal of Sports Medicine*, *26*(2), 101–106. http://doi.org/10.1136/bjsm.26.2.101

Hopper, D., McNair, P., & Elliott, B. C. (1999). Landing in netball: effects of taping and bracing the ankle. *British Journal of Sports Medicine*, *33*(6), 409–13. http://doi.org/10.1136/bjsm.33.6.409

Hryvniak, D., Dicharry, J., & Wilder, R. (2014). Barefoot running survey: Evidence from the field. *Journal of Sport and Health Science*, *3*(2), 131–136. http://doi.org/10.1016/j.jshs.2014.03.008

Iverson, M., Grootwassink, T., Hanson, A., Bouchard, C., Stenson, M., & Fischer, D. (2010). A Comparison of Injury Risk Determined by Laboratory and Field Tests. http://doi.org/10.1177/0363546509343200.

James, J., Ambegaonkar, J. P., Caswell, S. V., Onate, J., & Cortes, N. (2016). Analyses of landing mechanics in division i athletes using the landing error scoring system. *Sports Health*, *8*(2), 182–186. http://doi.org/10.1177/1941738115624891

Janssen, K. W., van Mechelen, W., & Verhagen, E. A. L. M. (2014). Bracing superior to neuromuscular training for the prevention of self-reported recurrent ankle sprains: a three-arm randomised controlled trial. *British Journal of Sports Medicine*, *48*(16), 1235–9. http://doi.org/10.1136/bjsports-2013-092947

Jenkins, D. W., & Cauthon, D. J. (2011). Barefoot running claims and controversies: a review of the literature. *Journal of the American Podiatric Medical Association*, *101*(3), 231–246. http://doi.org/101/3/231 [pii]

Johnson, C. D., Williams, V. J., Heebner, N. R., Wohleber, M. F., Simonson, A. J., Rafferty, D. M., … Sell, T. C. (2018). Relationship of performance on the sensory organization test to landing characteristics. *J Sports Sci*, *36*(10), 1155–1161. http://doi.org/10.1080/02640414.2017.1363402

Kaplan, Y. (2014). Barefoot versus shoe running: from the past to the present. *The Physician and Sportsmedicine*, *42*(1), 30–5. http://doi.org/10.3810/psm.2014.02.2045

Kavanagh, J. J., & Menz, H. B. (2008). Accelerometry: A technique for quantifying movement patterns during walking. *Gait & Posture*, *28*, 1–15. http://doi.org/10.1016/j.gaitpost.2007.10.010

Khowailed, I. A., Petrofsky, J., Lohman, E., & Daher, N. (2015). Six weeks habituation of simulated barefoot running induces neuromuscular adaptations and changes in foot strike patterns in female runners. *Medical Science Monitor : International Medical Journal of Experimental and Clinical Research*, *21*, 2021–30. http://doi.org/10.12659/MSM.893518

Kinchington, M. (2011). *An investigation into associations between lower extremity comfort , injury and performance in elite footballers*. Victoria University, Melbourne, Australia Associate.

Kinchington, M. (2010). Reliability of an instrument to determine lower limb comfort in professional football. *Open Access Journal of Sports Medicine*, 77. http://doi.org/10.2147/OAJSM.S11209

Kinchington, M., Ball, K., & Naughton, G. (2010). Monitoring of lower limb comfort and injury in elite football. *Journal of Sports Science and Medicine*, *9*(4), 652–663.

Kinchington, M., Ball, K., & Naughton, G. (2011). Effects of footwear on comfort and injury in professional rugby league. *Journal of Sports Sciences*, *29*(13), 1407–1415. http://doi.org/10.1080/02640414.2011.593041

Kobal, R., Nakamura, F. Y., Kitamura, K., Abad, C. C. C., Pereira, L. A., & Loturco, I. (2017). Vertical and depth jumping performance in elite athletes from different sports specialties. *Science & Sports*, 32(5), e191-e196. http://doi.org/10.1016/j.scispo.2017.01.007

Kowata, H. (2014). *Landing technique assessment utilizing laboratory-based landing and simulated basketball landing tasks*. Electronic Theses & Dissertations. Georgia Southern University.

Krabak, B. J., Hoffman, M. D., Millet, G. Y., & Chimes, G. P. (2011). Barefoot running. *PM and R*, *3*(12), 1142–1149. http://doi.org/10.1016/j.pmrj.2011.11.001

Krosshaug, T., Steffen, K., Kristianslund, E., Nilstad, A., Mok, K., Myklebust, G., … Bahr, R. (2016). The vertical drop jump is a poor screening test for acl injuries in female elite soccer and handball players. *The American Journal of Sports Medicine,* *44*(4), 874–883. http://doi.org/10.1177/0363546515625048

Kulas, A., Zalewski, P., Hortobagyi, T., & DeVita, P. (2008). Effects of added trunk load and corresponding trunk position adaptations on lower extremity biomechanics during drop-landings. *Journal of Biomechanics*, *41*(1), 180–185. http://doi.org/10.1016/j.jbiomech.2007.06.027

Langeveld, E., Coetzee, D., & Holtzhausen, L. (2014). Training habits , training surface and injuries among south african netball players. *South African Journal for Research in Sport, Physical Education and Recreation*, *36*(3), 39–49.

Laughlin, W. A., Weinhandl, J. T., Kernozek, T. W., Cobb, S. C., Keenan, K. G., & O'connor, K. M. (2011). The effects of single-leg landing technique on ACL loading. *Journal of Biomechanics*, *44*(10), 1845–1851. http://doi.org/10.1016/j.jbiomech.2011.04.010

Lavipour, D. (2009). *Development of a Netball Specific Dynamic Balance Assessment*. AUT University.

Leppänen, M., Pasanen, K., Kujala, U. M., Vasankari, T., Kannus, P., Äyrämö, S., & Krosshaug, T. (2017). Stiff landings are associated with increased acl injury risk in young female basketball and floorball players. *The American Journal of Sports Medicine*, 45(2), 386-393. http://doi.org/10.1177/0363546516665810

Lesinski, M., Prieske, O., Borde, R., Beurskens, R., & Granacher, U. (2018). Effects of different footwear properties and surface instability on neuromuscular activity and kinematics during jumping. *Journal of Strength & Conditioning Research*, *00*(00), 1–12.

Lessi, G. C., & Serrão, F. V. (2017). Effects of fatigue on lower limb, pelvis and trunk kinematics and lower limb muscle activity during single-leg landing after anterior cruciate ligament reconstruction. *Knee Surgery, Sports Traumatology, Arthroscopy*, *25*(8), 2550–2558. http://doi.org/10.1007/s00167-015-3762-x

Levangie, P. K., & Norkin, C. C. (2011). *Joint structure and function: A conprehensive analysis*. *F. A. Davis Company* (5th ed.). http://doi.org/10.1017/CBO9781107415324.004

Lieberman, D. E. (2012). What we can learn about running from barefoot running. *Exercise and Sport Sciences Reviews*, *40*(2), 63–72. http://doi.org/10.1097/JES.0b013e31824ab210

Lieberman, D. E., Castillo, E. R., Otarola-Castillo, E., Sang, M. K., Sigei, T. K., Ojiambo, R., … Pitsiladis, Y. (2015). Variation in foot strike patterns among habitually barefoot and shod runners in Kenya. *Plant Molecular Biology Reporter*, *10*(7). http://doi.org/10.6084/m9

Lieberman, D. E., Venkadesan, M., Werbel, W. A., Daoud, A. I., D'Andrea, S., Davis, I. S., … Pitsiladis, Y. (2010). Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature*, *463*, 531–5. http://doi.org/10.1038/nature08723

Lin, C. F., Liu, H., Garrett, W. E., & Yu, B. (2008). Effects of a knee extension constraint brace on selected lower extremity motion patterns during a stop-jump task. *Journal of Applied Biomechanics*, *24*(2), 158–165.

Liu, K., Dierkes, C., & Blair, L. (2016). A new jump-landing protocol identifies differences in healthy, coper, and unstable ankles in collegiate athletes. *Sports Biomechanics*, 15(3), 245-54. http://doi.org/10.1080/14763141.2016.1158859

Liu, K., & Heise, G. D. (2013). The effect of jump-landing directions on dynamic stability. *Journal of Applied Biomechanics*, *29*(5), 634–638.

Lobietti, R., Coleman, S., Pizzichillo, E., & Merni, F. (2010). Landing techniques in volleyball, *28*(November), 1469–1476. http://doi.org/10.1080/02640414.2010.514278

Logan, S., Hunter, I., Hopkins, J. T., Feland, J. B., & Parcell, A. C. (2010). Ground reaction force differences between running shoes, racing flats, and distance spikes in runners. *Journal of Sports Science and Medicine*, *9*(1), 147–153. http://doi.org/10.1055/s-0033-1338501

Lohman, E. B., Balan Sackiriyas, K. S., & Swen, R. W. (2011). A comparison of the spatiotemporal parameters, kinematics, and biomechanics between shod, unshod, and minimally supported running as compared to walking. *Physical Therapy in Sport*, *12*(4), 151–163. http://doi.org/10.1016/j.ptsp.2011.09.004

Lopes, T. J. A., Simic, M., Myer, G. D., Ford, K. R., Hewett, T. E., & Pappas, E. (2018). The effects of injury prevention programs on the biomechanics of landing tasks: A systematic review with meta-analysis. *American Journal of Sports Medicine*, *46*(6), 1492–1499. https://doi.org/10.1177/0363546517716930

Lythgo, N., Wilson, C., & Galea, M. (2009). Basic gait and symmetry measures for primary school-aged children and young adults whilst walking barefoot and with shoes. *Gait & Posture*, *30*(4), 502–506. http://doi.org/10.1016/j.gaitpost.2009.07.119

Mason-Mackay, A. R., Whatman, C., Reid, D., & Lorimer, A. (2016). The effect of ankle bracing on landing biomechanics in female netballers. *Physical Therapy in Sport*, *20*, 13–18. http://doi.org/10.1016/j.ptsp.2015.11.002

Mathewson, E. (2016). *Foot Posture in School Children from the Western Cape : Differences between footwear use , gender and race*. Masters dissertation. Stellenbosch University.

Mathison, S. (2005). *Encyclopedia of evaluation*. Sage. Retrieved from https://uk.sagepub.com/engb/afr/encyclopedia-of-evaluation/book220777

McClay, I. S., Robinson, J. R., Andriacchi, T. P., Frederick, E. C., Gross, T., Martin, P., … Cavanagh, P. R. (1994). A profile of ground reaction forces in professional basketball. *Journal of Applied Biomechanics*, *10*(3), 222–236. http://doi.org/10.1123/jab.10.3.222

Mcgrath, A. C., & Ozanne-Smith, J. (1998). Attacking the goal of netball injury prevention: a review of the literature, (130), 123.

McLean, S. G., Walker, K., Ford, K. R., Myer, G. D., Hewett, T. E., & Van Den Bogert, A. J. (2005). Evaluation of a two dimensional analysis method as a screening and evaluation tool for anterior cruciate ligament injury. *British Journal of Sports Medicine*, *39*(6), 355–362. http://doi.org/10.1136/bjsm.2005.018598

McMaster, D. T. W., Gill, N. D., Cronin, J. B., & MCGuigan, M. R. (2013). Is wireless accelerometry a viable measurement system for assessing vertical jump performance? *Sports Technology*, *6(2)*, 86-96. http://doi.org/10.1080/19346182.2013.816311

McNair, P. J., & Prapavessis, H. (1999). Normative data of vertical ground reaction forces during landing from a jump. *J Sci Med Sport*, *2*(1), 86–88.

McNair, P. J., Prapavessis, H., & Callender, K. (2000). Decreasing landing forces: effect of instruction. *British Journal of Sports Medicine*, *34*(4), 293–296. http://doi.org/10.1136/bjsm.34.4.293

Mcnitt-Gray, J. L. (1993). Kinetics of the lower-extremities during drop landings from three heights. *Journal of Biomechanics*, *26*(9), 1037–1046. http://doi.org/10.1016/S0021-9290(05)80003-X

Mei, Q., Fernandez, J., Fu, W., Feng, N., & Gu, Y. (2015). A comparative biomechanical analysis of habitually unshod and shod runners based on a foot morphological difference. *Human Movement Science*, *42*, 38–53. http://doi.org/10.1016/j.humov.2015.04.007

Mendiguchia, J., Ford, K. R., Quatman, C. E., Alentorn-Geli, E., & Hewett, T. E. (2011). Sex differences in proximal control of the knee joint. *Sports Medicine*, *41*(7), 541–557. http://doi.org/10.2165/11589140-000000000-00000

Milner, C. E., Westlake, C. G., & Tate, J. J. (2011). Test-retest reliability of knee biomechanics during stop-jump landings. *Journal of Biomechanics*, *44*(9), 1814–1816. http://doi.org/10.1016/j.jbiomech.2011.04.005

Mitchell, L. C. J., Ford, K. R., Minning, S., Myer, G. D., Mangine, R. E., & Hewett, T. E. (2008). Medial foot loading on ankle and knee biomechanics. *North American Journal of Sports Physical Therapy : NAJSPT*, *3*(3), 133–140. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/20379384

Mok, K. M., Petushek, E., & Krosshaug, T. (2016). Reliability of knee biomechanics during a vertical drop jump in elite female athletes. *Gait and Posture*, *46*, 173–178. http://doi.org/10.1016/j.gaitpost.2016.03.003

Moreno-Hernández, A., Rodríguez-Reyes, G., Quiñones-Urióstegui, I., Núñez-Carrera, L., & Pérez-SanPablo, A. I. (2010). Temporal and spatial gait parameters analysis in non-pathological Mexican children. *Gait & Posture*, *32*(1), 78–81. http://doi.org/10.1016/j.gaitpost.2010.03.010

Morio, C., Lake, M. J., Gueguen, N., Rao, G., & Baly, L. (2009). The influence of footwear on foot motion during walking and running. *Journal of Biomechanics*, *42*(13), 2081–2088. http://doi.org/10.1016/j.jbiomech.2009.06.015

Mothersole, G. (2013). *Ground Reaction Force Profiles of Specific Jump - Landing Tasks in Females : Development of a systematic and progressive jumping-landing model*. Auckland University of Technology.

Mothersole, G., Cronin, J. B., & Harris, N. K. (2014). Jump-landing program for females: Development of a systematic progression model. *Strength and Conditioning Journal*, *36*(4), 52–64. http://doi.org/10.1519/SSC.0000000000000078

Mothersole, G., Cronin, J., & Harris, N. (2013). Key prerequisite factors influencing landing forces in netball. *Strength & Conditioning …*, *35*(2), 47–54. http://doi.org/10.1519/SSC.0b013e318289b79e

Mulcahy, R., & Crowther, R. (2013). The effects of an 8 week supplemented plyometric exercise training program on leg power, agility and speed in adolescent netball players. *Journal of Australian …*, *21*(3), 31–36.

Mullen, S., Cotton, J., Bechtold, M., & Toby, E. B. (2014). The Effects of an 8-Week Barefoot Training Program. *The Orthopaedic Journal of Sports Medicine*, *2*(3), 1–5. http://doi.org/10.1177/2325967114525582

Munro, A., Herrington, L., & Carolan, M. (2012). Reliability of 2-dimensional video assessment of frontal-plane dynamic knee valgus during common athletic screening tasks. *Journal of Sport Rehabilitation*, *21*(1), 7–11. http://doi.org/2010-0019 [pii]

Myer, G. D., Chu, D. A., Brent, J. L., & Hewett, T. E. (2008). Trunk and Hip Control Neuromuscular Training for the Prevention of Knee Joint Injury. *Clinics in Sports Medicine*, *27*(3), 425–448. http://doi.org/10.1016/j.csm.2008.02.006

Myer, G. D., Ford, K. R., Di Stasi, S. L., Foss, K. D. B., Micheli, L. J., & Hewett, T. E. (2015). High knee abduction moments are common risk factors for patellofemoral pain (PFP) and anterior cruciate ligament (ACL) injury in girls: Is PFP itself a predictor for subsequent ACL injury? *British Journal of Sports Medicine*, *49*(2), 118–22. http://doi.org/10.1136/bjsports-2013-092536

Myer, G. D., Ford, K. R., Palumbo, J. P., & Hewett, T. E. (2005). Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *Journal of Strength and Conditioning Research*, *19*(1), 51–60. http://doi.org/10.1519/13643.1.

Myer, G. D., Sugimoto, D., Thomas, S., & Hewett, T. E. (2013). The influence of age on the effectiveness of neuromuscular training to reduce anterior cruciate ligament injury in female athletes: a meta-analysis. *The American Journal of Sports Medicine*, *41*(1), 203–15. http://doi.org/10.1177/0363546512460637.

Nagano, Y., Sasaki, S., Higashihara, A., & Ichikawa, H. (2016). Relationships between trunk and knee acceleration and the ground reaction force during single limb landing. In *34th International Conference on Biomehcanics in Sports* (pp. 875–878). Tsukuba, Japan.

Nearman, S. (2011). The Science of Barefoot Running. *AMAA Journal*, *24*(2), 5–6.

Nessler, T., Denney, L., & Sampley, J. (2017). ACL injury prevention: What does research tell us? *Current Reviews in Musculoskeletal Medicine*, *10*(3), 281–288. http://doi.org/10.1007/s12178-017-9416-5

Netball Australia. (2015). The Knee Program: Coaching Manual.

Nigg, B. (2009). Biomechanical considerations on barefoot movement and barefoot shoe concepts. *Footwear Science*, *1*(2), 73–79. http://doi.org/10.1080/19424280903204036

Nigg, B. (2001). The role of impact forces and pronation: a new paradigm. *Clin J Sports Med*, *11*(1), 2–9.

Nigg, B., Baltich, J., Hoerzer, S., & Enders, H. (2015). Running shoes and running injuries: mythbusting and a proposal for two new paradigms: 'preferred movement path' and 'comfort filter.' *British Journal of Sports Medicine*. 49(20), 1290-4. http://doi.org/10.1136/bjsports-2015-095054

Nigg, B., & Enders, H. (2013). Barefoot running – some critical considerations. *Footwear Science*, *5*(1), 1–7. http://doi.org/10.1080/19424280.2013.766649

Nordin, A. D., & Dufek, J. S. (2017). Load accommodation strategies and movement variability in single-leg landing. *Journal of Applied Biomechanics*, *33*(4), 241–247. http://doi.org/10.1123/jab.2016-0097

Nordin, M., & Frankel, V. H. (2001). *Basic biomechanics of the musculoskeletal system*. Lippincott Williams & Wilkins.

O'Kane, J. n W., Neradilek, M., Polissar, N., Sabado, L., Tencer, A., & Schiff, M. A. (2017). Risk factors for lower extremity overuse injuries in female youth soccer players. *Orthopaedic Journal of Sports Medicine*, *5*(10), 1–8. http://doi.org/10.1177/2325967117733963

Oeffinger, D., Brauch, B., Cranfill, S., Hisle, C., Wynn, C., Hicks, R., & Augsburger, S. (1999). Comparison of gait with and without shoes in children. *Gait and Posture*, *9*(2), 95–100. http://doi.org/10.1016/S0966-6362(99)00005-3

Onate, J., Cortes, N., Welch, C., & Van Lunen, B. (2010). Expert versus novice interrater reliability and criterion validity of the landing error scoring system. *Journal of Sport Rehabilitation*, *19*, 41–56. http://doi.org/10.1123/jsr.19.1.41

Onwaree, I. (2015). The 4-week of barefoot training on kinematics of lower extremities at initial foot strike between male and female. In *“Moving Forward to a Prosperous and Sustainable Community.”* Burapha: Burapha University.

Ortiz, A., Olson, S., Libby, C. L., Trudelle-Jackson, E., Kwon, Y.-H., Etnyre, B., & Bartlett, W. (2007). Landing mechanics between noninjured women and women with anterior cruciate ligament reconstruction during 2 jump tasks. *The American Journal of Sports Medicine*, *36*(1), 149–157. http://doi.org/10.1177/0363546507307758

Otago, L. (2004). Kinetic analysis of landings in netball is a footwork rule.pdf. *Journal of Science and Medicine in Sport*, *7*(1), 85–95.

Padua, D. A. (2012). Identification of risk factors for ACL injury and re-injury: implications for prevention and rehabilitation. *Eastern Athletic Trainers’ Association 64th Annual.*

Padua, D. A., Boling, M. C., Distefano, L. J., Onate, J. a, Beutler, A. I., & Marshall, S. W. (2011). Reliability of the landing error scoring system-real time, a clinical assessment tool of jump-landing biomechanics. *Journal of Sport Rehabilitation*, *20*(2), 145–156.

Padua, D. A., DiStefano, L. J., Beutler, A. I., De La Motte, S. J., DiStefano, M. J., & Marshall, S. W. (2015). The landing error scoring system as a screening tool for an anterior cruciate ligament injury-prevention program in elite-youth soccer athletes. *Journal of Athletic Training*, *50*(6), 589–595. http://doi.org/10.4085/1062-6050-50.1.10

Padua, D. A, Marshall, S. W., Boling, M. C., Thigpen, C. a, Garrett, W. E., & Beutler, A. I. (2009). The Landing Error Scoring System (LESS) Is a valid and reliable clinical assessment tool of jump-landing biomechanics: The JUMP-ACL study. *The American Journal of Sports Medicine*, *37*(10), 1996–2002. http://doi.org/10.1177/0363546509343200

Pappas, E., & Carpes, F. P. (2012). Lower extremity kinematic asymmetry in male and female athletes performing jump-landing tasks. *Journal of Science and Medicine in Sport*, *15*(1), 87–92. http://doi.org/10.1016/j.jsams.2011.07.008

Patel, B. A., Anastassiou, C. A., & O’Hare, D. (2006). Biosensor design and interfacing. In G.-Z. Yang (Ed.), *Body Sensor Networks* (pp. 41–82). London: Springer.

Patel, J. H. (2013). *Role of the lumbopelvic-hip complex in bipedal acceleration*. Auburn University.

Pefanis, N., Papaharalampous, X., Tsiganos, G., Papadakou, E., & Baltopoulos, P. (2009). The effect of Q angle on ankle sprain occurrence. *Foot & Ankle Specialist*, *2*(1), 22–26. http://doi.org/10.1177/1938640008330769.

Perkins, K. P., Hanney, W. J., & Rothschild, C. E. (2014). The Risks and Benefits of Running Barefoot or in Minimalist Shoes: A Systematic Review. *Sports Health*, *6*(6), 475–480. https://doi.org/10.1177/1941738114546846

Pfile, K. R., Hart, J. M., Herman, D. C., Hertel, J., Kerrigan, D. C., & Ingersoll, C. D. (2013). Different exercise training interventions and drop-landing biomechanics in high school female athletes. *Journal of Athletic Training*, *48*(4), 450–462. http://doi.org/10.4085/1062-6050-48.4.06

Phan, X., Grisbrook, T. L., Wernli, K., Stearne, S. M., Davey, P., & Leo, N. G. (2017). Running quietly reduces ground reaction force and vertical loading rate and alters foot strike technique. *Journal of Sports Sciences*, *35(16)*, 1636-1642. http://doi.org/10.1080/02640414.2016.1227466

Plowman, S. A., & Smith, D. L. (2014). *Exercise Physiology for Health, Fitness, and Performance* (fourth). Philadelphia: Wolters Kluwer Lippincott WIlliams & Wilkins.

Pouliot-Laforte, A., Veilleux, L. N., Rauch, F., & Lemay, M. (2014). Validity of an accelerometer as a vertical ground reaction force measuring device in healthy children and adolescents and in children and adolescents with osteogenesis imperfecta type I. *Journal of Musculoskeletal Neuronal Interactions*, *14*(2), 155–161.

Powell, D. W., Hanson, N. J., Long, B., & Williams, D. S. B. (2012). Frontal plane landing mechanics in high- arched compared with low-arched female athletes. *Clinical Journal of Sport Medicine*, *22*(5), 430–435. http://doi.org/10.1097/JSM.0b013e318257d5a1

Pupo, J. D., & Detanico, D. (2011). Kinetic parameters as determinants of vertical jump performance. *Brazilian Journal of Kinanthropometry and Human Performance*, *14*(1), 41–51. http://doi.org/10.5007/19800037.2012v14n1p41

Qu, H. (2016). *Effects of synthetic turf and shockpads on impact attenuation related biomechanics during drop landing*. University of Tennes, Knoxville.

Quammen, D., Cortes, N., Van Lunen, B. L., Lucci, S., Ringleb, S. I., & Onate, J. (2012). Two different fatigue protocols and lower extremity motion patterns during a stop-jump task. *Journal of Athletic Training*, *47*(1), 32–41.

Rao, U., & Joseph, B. (1992). The influence of footwear on the prevalence of flat foot. A survey of 2300 children. *The Journal of Bone and Joint Surgery. British Volume*, *74–B*(4), 525–527. http://doi.org/10.1302/0301-620X.74B4.1624509

Rezaimanesh, D., Amiri-Farsani, P., & Saidian, S. (2011). The effect of a 4 week plyometric training period on lower body muscle EMG changes in futsal players. *Procedia - Social and Behavioral Sciences*, *15*, 3138–3142. http://doi.org/10.1016/j.sbspro.2011.04.260

Richards, C. E., Magin, P. J., Callister, R., & Richards, C. (2009). Is your prescription of distance running shoes evidence-based? *Br J Sports Med*, *43(3)*, 159–162. http://doi.org/10.1136/bjsm.2008.046680

Rixe, J. A., Gallo, R. A., & Silvis, M. L. (2012). The barefoot debate: Can minimalist shoes reduce running-related injuries? *Current Sports Medicine Reports*, *11*(3), 160–165. http://doi.org/10.1249/JSR.0b013e31825640a6

Robbins, S. E., & Gouw, G. J. (1991). Athletic footwear: unsafe due to perceptual illusions. *Med Sci Sports Exerc*, *23*(2), 217–224. http://doi.org/10.1249/00005768-199102000-00012

Robbins, S. E., & Hanna, A. M. (1987). Running-related injury prevention through barefoot adaptations. *Medicine and Science in Sports and Exercise*, *19*(2), 148–56. http://doi.org/10.1249/00005768-198904000-00004

Robbins, S. E., & Waked, E. (1997). Balance and vertical impact in sports: Role of shoe sole materials. *Archives of Physical Medicine and Rehabilitation*, *78*(5), 463–467. https://doi.org/10.1016/S0003-9993(97)90157-X

Rooney, B. D., & Derrick, T. R. (2013). Joint contact loading in forefoot and rearfoot strike patterns during running. *Journal of Biomechanics*, *46*(13), 2201–2206. http://doi.org/10.1016/j.jbiomech.2013.06.022

Root, H., Trojian, T., Martinez, J., Kraemer, W., & DiStefano, L. J. (2015). Landing technique and performance in youth athletes after a single injury-prevention program session. *Journal of Athletic Training*, *50*(11), 1149–1157. http://doi.org/10.4085/1062-6050-50.11.01

Rothschild, C. E. (2012a). Primitive running: A survey analysis of runners' interest, participation, and implementation. *Journal of Strength and Conditioning Research*, *26*(8), 2021–2026. http://doi.org/10.1519/JSC.0b013e31823a3c54

Rothschild, C. (2012b). Running barefoot or in minimalist shoes. *Strength and Conditioning Journal*, *34*(2), 8–17. http://doi.org/10.1519/SSC.0b013e318241b15e

Rowley, K. M., & Richards, J. G. (2015). Increasing plantarflexion angle during landing reduces vertical ground reaction forces, loading rates and the hip's contribution to support moment within participants. *Journal of Sports Sciences*, *33*(18), 1922–1931. http://doi.org/10.1080/02640414.2015.1018928

Salci, Y., Kentel, B. B., Heycan, C., Akin, S., & Korkusuz, F. (2004). Comparison of landing maneuvers between male and female college volleyball players. *Clinical Biomechanics*, *19*(6), 622–628. http://doi.org/10.1016/j.clinbiomech.2004.03.006

Saunders, N., Otago, L., Romiti, M., Donaldson, A., White, P., & Finch, C. (2010). Coaches' perspectives on implementing an evidence-informed injury prevention programme in junior community netball. *Br.J Sports Med*, *44*(15), 1128–1132. http://doi.org/10.1136/bjsm.2009.069039

Saxby, L. (2011). Proprioception: Making Sense Of Barefoot Running. *Terra Plana International*, 1–32.

Schutte, K. H. (2012). *The effect of minimalist shoe training on lower limb kinematics and kinetics in experienced shod runners*. Stellenbosch University.

Schütte, K. H., Aeles, J., De Beéck, T. O., van der Zwaard, B. C., Venter, R., & Vanwanseele, B. (2016). Surface effects on dynamic stability and loading during outdoor running using wireless trunk accelerometry. *Gait & Posture*, *48*(June), 220–225. http://doi.org/10.1016/j.gaitpost.2016.05.017

Schütte, K. H., & Venter, R. E. (2013). Effect of minimalist shoe training on lower limb joint moments. *Footwear Science*, *5*(sup1), S52–S53. http://doi.org/10.1080/19424280.2013.799551

Schütte, K., Miles, K., Venter, R., & Van Niekerk, S. (2011). Acute differences in sagittal plane lower limb kinematics between barefoot, minimalistic shoes, and shod running in male athletes. In *ISB 2011*.

Seegmiller, J. G., & McCaw, S. T. (2003). Ground reaction forces among gymnasts and recreational athletes in drop landings. *Journal of Athletic Training*, *38*(4), 311–314.

Sell, T. C., Akins, J. S., Opp, A. R., & Lephart, S. M. (2014). Relationship between tibial acceleration and proximal anterior tibia shear force across increasing jump distance. *Journal of Applied Biomechanics*, *30*(1), 75–81. http://doi.org/10.1123/jab.2012-0186

Shih, Y., Lin, K. L., & Shiang, T. Y. (2013). Is the foot striking pattern more important than barefoot or shod conditions in running? *Gait and Posture*, *38*(3), 490–494. http://doi.org/10.1016/j.gaitpost.2013.01.030

Shorten, M. R., & Winslow, D. S. (1992). Spectral analysis of impact shock during running. *International Journal of Sport Biomechanics*, *8(4)*, 288–304.

Shu, Y., Mei, Q., Fernandez, J., Li, Z., Feng, N., & Gu, Y. (2015). Foot morphological difference between habitually shod and unshod runners. *PLoS ONE*, *10*(7).

Shultz, S. J., Schmitz, R. J., Tritsch, A. J., & Montgomery, M. M. (2012). Methodological considerations of task and shoe wear on joint energetics during landing. *Journal of Electromyography and Kinesiology*, *22*(1), 124–130. http://doi.org/10.1016/j.jelekin.2011.11.001

Sim-Fook, L., & Hodgson, A. R. (1958). A comparison of foot forms among the non-shoe and shoe-wearing Chinese population. *The Journal of Bone and Joint Surgery. American Volume*, *40–A*(5), 1058–62. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/13587573

Sinclair, J. (2014). Effects of barefoot and barefoot inspired footwear on knee and ankle loading during running. *Clinical Biomechanics*, *29*(4), 395–399. http://doi.org/10.1016/j.clinbiomech.2014.02.004

Sinclair, J. (2016). The effects of barefoot and barefoot inspired footwear running on tibiofemoral kinetics, *17*(3), 176–180. http://doi.org/10.1515/humo-2016-0022

Sinclair, J., Atkins, S., Richards, J., & Vincent, H. (2015). Modelling of muscle force distributions during barefoot and shod running. *Journal of Human Kinetics*, *47*(1), 9–17. http://doi.org/10.1515/hukin-2015-0057

Sinclair, J., Greenhalgh, A., Brooks, D., Edmundson, C. J., & Hobbs, S. J. (2013). The influence of barefoot and barefoot-inspired footwear on the kinetics and kinematics of running in comparison to conventional running shoes. *Footwear Science*, *5*(1), 45–53. http://doi.org/10.1080/19424280.2012.693543

Sinsurin, K., Vachalathiti, R., Jalayondeja, W., & Limroongreungrat, W. (2016). Knee muscular control during jump landing in multidirections. *Asian Journal of Sports Medicine*, *7*(2). http://doi.org/10.5812/asjsm.31248

Smith, H. C., Johnson, R. J., Shultz, S. J., Tourville, T., Holterman, L. A., Slauterbeck, J., … Beynnon, B. D. (2012). A prospective evaluation of the Landing Error Scoring System (LESS) as a screening tool for anterior cruciate ligament injury risk. *The American Journal of Sports Medicine*, *37*(3), 1996–2002. http://doi.org/10.1177/0363546511429776

Smith, R., Damodaran, A. K., Swaminathan, S., Campbell, R., & Barnsley, L. (2005). Hypermobility and sports injuries in junior netball players. *British Journal of Sports Medicine*, *39*, 628–632. http://doi.org/10.1136/bjsm.2004.015271

Stasinopoulos, D. (2004). Comparison of three preventive methods in order to reduce the incidence of ankle inversion sprains among female volleyball players, *38*, 182–185. http://doi.org/10.1136/bjsm.2002.003947

Steele, J. R. (1986). *An analysis of netball landing techniques: implication for injury prevention and shoe design*. School of Health Science, University of Wollongong.

Steele, J. R. (1988). *The effect of changes to passing height on the mechanics of landing in netball.* National Sports Research Centre, Australia.

Steele, J. R. (1990). Biomechanical factors affecting performance in netball. Implications for improving performance and injury reduction. *Sports Medicine (Auckland, N.Z.)*, *10*(2), 88–102.

Steele, J. R., & Lafortune, M. A. (1989). A kinetic analysis of footfall patterns at landing in netball. *Human Movement and Sports Science*, 101–112.

Steele, J. R., & Milburn, P. D. (1987). Kinematic analysis of netball landing techniques. *The Austrialian Journal of Science and Medicine in Sport*, 23–27.

Stewart, A., Marfell-Jones, M., & Olds, T. (2011). International standards for anthropometric assessment. *Lower Hutt, New Zealand: International Society for the Advancement of Kinanthropometry*, 125f.

Stobierski, L. M., Fayson, S. D., Minthorn, L. M., Valovich McLeod, T. C., & Welch, C. E. (2015). Reliability of clinician scoring of the functional movement screen to assess movement patterns. *Journal of Sport Rehabilitation*, *24*(2), 219–22. http://doi.org/10.1123/jsr.2013-0139

Stuelcken, M., Greene, A, Smith, R., & Vanwanseele, B. (2013). Knee loading patterns in a simulated netball landing task. *European Journal of Sport Science*, *13*(5), 475–482. http://doi.org/10.1080/17461391.2012.752038

Suglmoto, D., Myer, G. D., McKeon, J. M., & Hewett, T. E. (2014). Evaluation of the effectiveness of neuromuscular training to reduce acl injury in female athletes. *National Institue of National Health*, *46*(14), 979–988. http://doi.org/10.1136/bjsports-2011-090895.

Tam, N., Tucker, R., & Wilson, A. J. L. (2016). Individual responses to a barefoot running program: insight into risk of injury. *The American Journal of Sports Medicine*, *44*(3), 777–784. http://doi.org/10.1177/0363546515620584

Tam, N., Tucker, R., Wilson, A. J. L., & Santos-Concejero, J. (2015). Effect on oxygen cost of transport from 8-weeks of progressive training with barefoot running. *International Journal of Sports Medicine*, *36*(13), 1100–1105. http://doi.org/10.1055/s-0035-1548888

Tamura, A., Akasaka, K., Otsudo, T., Sawada, Y., Okubo, Y., Shiozawa, J., … Yamada, K. (2016). Fatigue Alters landing shock attenuation during a single-leg vertical drop jump. *Orthopaedic Journal of Sports Medicine*, *4*(1). http://doi.org/10.1177/2325967115626412

Te Wierike, S. C. M., van der Sluis, A., van den Akker-Scheek, I., Elferink-Gemser, M. T., & Visscher, C. (2012). Psychosocial factors influencing the recovery of athletes with anterior cruciate ligament injury: A systematic review. *Scandinavian Journal of Medicine & Science in Sports*, *23*, 527–540. http://doi.org/10.1111/sms.12010

Ter Stege, M. H. P., Dallinga, J. M., Benjaminse, A., & Lemmink, K. A. P. M. (2014). Effect of interventions on potential, modifiable risk factors for knee injury in team ball sports: A systematic review. *Sports Medicine*, *44*(10), 1403–1426. http://doi.org/10.1007/s40279-014-0216-4

Thomas, C., Comfort, P., Jones, P. A., & Dos'Santos, T. (2017). Strength and conditioning for netball: a needs analysis and training recommendations. *Strength and Conditioning Journal*, *39*(4), 10–21. http://doi.org/10.1519/SSC.0000000000000287

Thompson, A. L. T., & Zipfel, B. (2005). The unshod child into womanhood - Forefoot morphology in two populations. *Foot*, *15*(1), 22–28. http://doi.org/10.1016/j.foot.2004.10.002

Thompson, J. A., Tran, A. A., Gatewood, C. T., Shultz, R., Silder, A., Delp, S. L., & Dragoo, J. L. (2017). Biomechanical effects of an injury prevention program in preadolescent female soccer athletes. *American Journal of Sports Medicine*, *45*(2), 294–301. http://doi.org/10.1177/0363546516669326

Thompson, M. A., Seegmiller, J., & McGowan, C. P. (2016). Impact accelerations of barefoot and shod running. *International Journal of Sports Medicine*, 364–368. http://doi.org/10.1055/s-0035-1569344

Tran, J., Netto, K., Aisbett, B., & Gastin, P. (2010). Validation of accelerometer data for measuring impacts during jumping and landing tasks. *International Symposium on Biomechanics in Sports: Conference Proceedings Archive*, *28*(January), 1–4.

Tsai, Y. J., & Lin, S. I. (2013). Older adults adopted more cautious gait patterns when walking in socks than barefoot. *Gait and Posture*, *37*(1), 88–92. http://doi.org/10.1016/j.gaitpost.2012.06.034

Tsang, G. C. K. (2000). *Ground reaction force analysis of a variety of jumping activities in growing children*. University of British Columbia.

Van Der Worp, H., Vrielink, J. W., & Bredeweg, S. W. (2016). Do runners who suffer injuries have higher vertical ground reaction forces than those who remain injury-free? A systematic review and meta-analysis. *British Journal of Sports Medicine*, *50*(8), 450–457. http://doi.org/10.1136/bjsports-2015-094924

Venter, R., Masterson, C., Tidbury, G. B., & Krkeljas, Z. (2017). The relationship between functional movement screening and performance tests in high-level university female netball players. *South African Journal for Research in Sport, Physical Education and Recreation*, *39*(1), 189-198.

Wade, M., Campbell, A., Smith, A., Norcott, J., & O'Sullivan, P. (2012). Investigation of spinal posture signatures and ground reaction forces during landing in elite female gymnasts. *Journal of Applied Biomechanics*, *28*(6), 677–686. http://doi.org/10.1123/jab.28.6.677

Wagner, H., Tilp, M., Von Duvillard, S. P. V, & Mueller, E. (2009). Kinematic analysis of volleyball spike jump. *International Journal of Sports Medicine*, *30*(10), 760–765. http://doi.org/10.1055/s-0029-1224177

Walker, A. W., & Subic, A. (2010). Horizontal and vertical reaction force testing for synthetic sports surfaces surfaces. *Sports Technology*, *3*(1), 34–42. http://doi.org/10.1080/19346190.2010.504277

Walton, P. D., & French, D. P. (2016). What do people think about running barefoot/with minimalist footwear? A thematic analysis. *British Journal of Health Psychology*, *21*(2), 451–468. https://doi.org/10.1111/bjhp.12180

Wang, L. I. (2011). The lower extremity biomechanics of single- and double-leg stop-jump tasks. *Journal of Sports Science and Medicine*, *10*(1), 151–156.

Warburton, M. (2001). Barefoot Running. *Sportscience*, *5*(3), sportsci.org/jour/0103/mw.htm. http://doi.org/10.1016/j.pmrj.2011.11.001

Warne, J. P., Kilduff, S. M., Gregan, B. C., Nevill, A. M., Moran, K. A., & Warrington, G. D. (2014). A 4-week instructed minimalist running transition and gait-retraining changes plantar pressure and force. *Scandinavian Journal of Medicine and Science in Sports*, *24*(6), 964–973. http://doi.org/10.1111/sms.12121

Warne, J. P., & Warrington, G. D. (2014). Four-week habituation to simulated barefoot running improves running economy when compared with shod running. *Scandinavian Journal of Medicine and Science in Sports*, *24*(3), 563–568. http://doi.org/10.1111/sms.12032

Warnock, C. (2013). *Barefoot Running : Feeling the World Through Your Feet*. University of Ottawa.

Weltin, E., Gollhofer, A., & Mornieux, G. (2016). Effect of gender on trunk and pelvis control during lateral movements with perturbed landing. *European Journal of Sport Science*, *16*(2), 182–189. http://doi.org/10.1080/17461391.2014.992478

Weltin, E., Gollhofer, A., & Mornieux, G. (2017). Effects of perturbation or plyometric training on core control and knee joint loading in women during lateral movements. *Scandinavian Journal of Medicine and Science in Sports*, *27*(3), 299–308. http://doi.org/10.1111/sms.12657

Wernli, K., Leo, N., Phan, X., Davey, P., & Grisbrook, T. (2016). The relationship between landing sound, vertical ground reaction force, and kinematics of the lower limb during drop landings in healthy men. *The Journal of Orthopaedic and Sports Physical Therapy*, *46*(3), 194. http://doi.org/10.2519/jospt.2016.6041

Wesley, C. A., Aronson, P. A., & Docherty, C. L. (2015). Lower extremity landing biomechanics in both sexes after a functional exercise protocol. *Journal of Athletic Training*, *50*(9), 914–920. http://doi.org/10.4085/1062-6050-50.8.03

Willson, J. D., Bjorhus, J. S., Williams, D. S. B., Butler, R. J., Porcari, J. P., & Kernozek, T. W. (2014). Short-term changes in running mechanics and foot strike pattern after introduction to minimalistic footwear. *The American Academy of Physical Medicine and Rehabilitation*, *6*(1), 34–43. http://doi.org/10.1016/j.pmrj.2013.08.602

Wit, B. De, Clercq, D. De, & Aerts, P. (2000). Biomechanical analysis of the stance phase during barefoot and shod running. *Journal of Biomechanics*, *33*(3), 269–278. http://doi.org/10.1016/S0021-9290(99)00192-X

Wirth, B., Hauser, F., & Mueller, R. (2011). Back and neck muscle activity in healthy adults during barefoot walking and walking in conventional and flexible shoes. *Footwear Science*, *3*(3), 159–167. http://doi.org/10.1080/19424280.2011.633104

Wolf, S., Simon, J., Patikas, D., Schuster, W., Armbrust, P., & Doderlein, L. (2008). Foot motion in children shoes-A comparison of barefoot walking with shod walking in conventional and flexible shoes. *Gait and Posture*, *27*(1), 51–59. http://doi.org/10.1016/j.gaitpost.2007.01.005

Wright, W. G., Ivanenko, Y. P., & Gurfinkel, V. S. (2012). Foot anatomy specialization for postural sensation and control. *Journal of Neurophysiology*, *107*(5), 1513–1521. http://doi.org/10.1152/jn.00256.2011

Yeadon, M. R., & Challis, J. H. (1994). The future of performance-related sports biomechanics research. *Journal of Sports Sciences*, *12*(February), 3–32. http://doi.org/10.1080/02640419408732156

Yeow, C. H., Lee, P. V. S., & Goh, J. C. H. (2009). Effect of landing height on frontal plane kinematics, kinetics and energy dissipation at lower extremity joints. *Journal of Biomechanics*, *42*(12), 1967–1973. http://doi.org/10.1016/j.jbiomech.2009.05.017

Yeow, C. H., Lee, P. V. S., & Goh, J. C. H. (2011). Shod landing provides enhanced energy dissipation at the knee joint relative to barefoot landing from different heights. *Knee*, *18*(6), 407–411. http://doi.org/10.1016/j.knee.2010.07.011

Yin, L., Sun, D., Mei, Q. C., Gu, Y. D., Baker, J. S., & Feng, N. (2015). The kinematics and kinetics analysis of the lower extremity in the landing phase of a stop-jump task. *The Open Biomedical Engineering Journal*, 31(*9*), 103–107. http://doi.org/10.2174/1874120701509010103

Yom, J. P., Simpson, K. J., Arnett, S. W., & Brown, C. N. (2014). The effects of a lateral in-flight perturbation on lower extremity biomechanics during drop landings. *Journal of Applied Biomechanics*, *30*(5), 655–662. http://doi.org/10.1123/JAB.2013-0331

Yu, B., Lin, C. F., & Garrett, W. E. (2006). Lower extremity biomechanics during the landing of a stop-jump task. *Clinical Biomechanics*, *21*(3), 297–305. http://doi.org/10.1016/j.clinbiomech.2005.11.003

Zazulak, B. T., Hewett, T. E., Reeves, N. P., Goldberg, B., Cholewicki, J., Zahradnik, D., … La, C. (2016). Knee injury patterns among young basketball players in Cape Town. *The American Journal of Sports Medicine*, *28*(2), 13–18. http://doi.org/10.1080/02640414.2010.514278

Zhang, S., Clowers, K., Kohstall, C., & Yu, Y. J. (2005). Effects of various midsole densities of basketball shoes on impact attenuation during landing activities. *Journal of Applied Biomechanics*, *21*(1), 3–17.

Zhang, S., Derrick, T. R., Evans, W., & Yu, Y. (2008). Shock and impact reduction in moderate and strenuous landing activities. *Sports Biomechanics*, *7*(2), 296–309. http://doi.org/10.1080/14763140701841936

Zhang, X., Paquette, M. R., & Zhang, S. (2013). A comparison of gait biomechanics of flip-flops, sandals, barefoot and shoes. *Journal of Foot and Ankle Research*, *6*(1), 1–8. http://doi.org/10.1186/1757-1146-6-45

Zifchock, R. A., Zaferiou, A. M., Brown, A. M., Hafer, J. F., & Hillstrom, H. J. (2011). Comparison of Hip , Knee , and Hindfoot Kinematics During Barefoot and Shod Jumping. In *ORS Annual Meeting*.

APPENDIX A: Informed consent forms

Title of Research Project: The effects of barefoot intervention programme on the landing kinetics and kinematics of netball players

You are asked to participate in a research study conducted by **Boluwaji Jaiyesimi** (PhD in Sport Science) under the supervision of **Prof R. E. Venter**, from the **Department of Sport Science** at Stellenbosch University. You were selected as a possible participant in this study because you are a healthy netball player and completed pre-season club strength and conditioning programme.

1. AIM OF THE STUDY

The purpose of this study to determine the effect of a **six-week barefoot training intervention on the landing kinetics and kinematics of netball players.**

2. PROCEDURES

Week	Research Procedures
1-2	Pre-test protocol
3-8	Barefoot intervention
9-10	Post-test protocol

Testing

The following tests will be performed **before the training programme and after the** training programme:

1.1.Drop landing

You will perform single-leg drop landing by steeping off a 30cm platform of support and land on a **force plate** on dominant and non-dominant leg at different times, keeping the position for 5sec. Three trials will be recorded.

1.2.Drop Jump

Drop jump (DJ) involves **a jump forward from 30cm platform to the force plate (distance of 50% of your height**) and land to take off immediately to jump as high as possible. You will perform three trials. The jump will be captured by high speed motion camera.

1.3. Stop-jump performance task (SJPT)

You will run at your pace on a 10m runway and disengage a suspended ball, land on your **preferred leg** upon landing pass the ball at chest level to a receiver 5m away. This trial will be repeated three times. An active rest recovery of 2 minutes will be allowed after each stage of the jump.

1.4.Lower limb comfort index (LLCI)

You will be monitored throughout the training programme to make sure that you are recovered and adapted to the training load before we progress with the training programme. You will be asked to complete the LLCI **(simple rating on the comfort of your legs and lower back)** before every training week as feedback to the researcher on your readiness to perform the training session. Your feedback will be used to make a decision on whether to progress or not.

3. POTENTIAL RISKS AND DISCOMFORTS

There will be no serious risks involved in the study. The potential risks will be minimised as much as possible by thoroughly explaining the procedure to you and carefully monitoring all the test and training sessions. All measurements are **within your health and fitness capacity.** If an injury or adverse event occurs, the test will be terminated immediately and you will receive specific supervision from the researcher who is qualified to perform basic medical aid. There will be a basic life support (BLS) qualified healthcare professionals available at all times to perform cardiopulmonary resuscitation (CPR). Should any emergency arise, you will be stabilized and then immediately transported to the emergency room at Stellenbosch Medi-Clinic.

4. POTENTIAL BENEFITS TO SUBJECTS AND/OR TO SOCIETY

You will receive information on your performance parameters as it relates to biomechanical and clinical implications. This study will help coaches and athletes to understand the link between dynamic movement landing and related injury risk. It will also provide insight to the inclusion of barefoot condition in training programme.

5. PAYMENT FOR PARTICIPATION

As a participant you will not receive any financial reimbursement or payment to participate in the study. **Any financial cost in terms of transportation to the testing lab or any other related logistics will be covered by the investigator.**

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 filed and stored in a locked room and on a password protected personal computer and will only be accessed by the researcher and promoter. All information obtained in the study will not be disclosed, unless published, in which case it will be treated as not to identify anyone.

7. PARTICIPATION AND WITHDRAWAL

You can choose whether to take part in this study or not. If you volunteer to participate 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 discontinued if you fail to comply with the testing protocol. 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; Boluwaji Jaiyesimi (061 511 2911; 19573316@sun.ac.za); or the promoter, Prof. R. E. Venter (021 808 4915 or 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; 021 808 4622] at the Division for Research Development.

The information above was described to me by Boluwaji Jaiyesimi (researcher) in English and I am in command of this language. 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

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

____ ______________

Signature of Investigator (Boluwaji Jaiyesimi) Date

SIGNATURE OF INVESTIGATOR

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

UNIVERSITEIT•STELLENBOSCH•UNIVERSITY
jou kennisvennoot • your knowledge partner

STELLENBOSCH UNIVERSITEIT

TOESTEMMING OM AAN NAVORSING DEEL TE NEEM

Titel van Navorsingsprojek: Kaalvoetoefening as 'n metode om biomotoriese vaardighede en landingskinematika en kinetika in spansportspelers te verbeter

Jy word uitgenooi om aan 'n navorsingsprojek deel te neem. Hierdie studie word deur **Jaiyesimi Boluwaji** (PhD in Sportwetenskap) onder die leiding van **Prof R. E Venter**, van die **Departement Sportwetenskap** aan Universiteit Stellenbosch gedoen. Jy is as moontlike deelnemer gekies omdat jy 'n gesonde netbalspeler is en jou klub se voorseisoen krag- en kondisioneringsprogramme gedoen het.

1. DOEL VAN DIE STUDIE

Die doel van die studie is om te bepaal of kaalvoetoefening as 'n metode kan dien om biomotoriese vaardighede en landingskinematika en kinetika in spansportspelers te verbeter.

2. PROSEDURES

Week	Navorsingsprodures
1	Voor- en na-intervensie toetsprotokol
2-7	Oefenprogramme (kaalvoet of skoene)
8	Voor- en na-intervensie toetsprotokol

Toetsing

Die volgende toetse sal voor en na die oefenprogramme programme gedoen word:

2.1.Tree-landing

Jy sal vanaf ‘n 50cm hoë bankie aftree en op eenbeen op ‘n drukplaat land en die posisie vir drie sekondes hou. Jy sal drie pogings op jou linker- en regterbeen doen.

2.2.Land-en spring

Jy sal vanaf ‘n 50cm bankie aftree en dan dadelik so hoog as moontlik in die lug spring. Jy sal dit driekeer doen. Jou spronge sal met ‘n hoëspoedkamera opgeneem word vir latere evaluering volgens die landingsfoutsisteem.

2.3.Stop-spring prestasietaak (SPPT)

Jy sal oor ‘n afstand van 10m hardloop. Jy sal ‘n bal wat in die lug hang vang, land op jou linker- of regterbeen en dan die bal borshoogte gooi na ‘n vanger wat 5m weg staan. Jy sal hierdie toets driekeer doen.

2.4.Gemaksindeks vir onderste ledemate

Jy sal tydens die oefenprogramme gemonitor word om seker te maak dat jy voldoende herstel en aangepas het by die oefenlading voordat jou oefensessies moeiliker gemaak word. Jy sal gevra word om die gemaksindeks vir onderste ledemate voor elke oefensessie in te vul as terugvoer aan die navorser oor jou gereedheid vir die oefensessie. Jou terugvoer sal gebruik word om te besluit of jou oefensessie moeiliker moet wees of nie.

3. MOONTLIKE RISIKOS EN ONGEMAK

Daar is geen ernstige risiko’s aan die studie verbonde nie. Jy mag ongemak ervaar gedurende die toetssessies omdat jy nie gewoond mag wees aan die toetse of oefeninge nie. Moontlike risiko’s sal sover moontlik verminder word deurdat die prosedures aan jou verduidelik sal word en jy gemonitor sal word.

Alle metings is **nie-indringend.** Indien enige besering oor negatiewe insident voorkom, sal die toetsing onmiddellik gestaak word en sal jy noodhulp, ontvang. Indien ŉ noodsituasie ontstaan, sal jy gestabilir word en onmiddellik na die noodeenheid by Stellenbosch Medikliniek geneem word.

4. MOONTLIKE VOORDELE VIR DEELNEMERS EN/OF VIR DIE GEMEENSKAP

Jy sal inligting in verband met jou persoonlike prestasie en tegniek en die biomeganiese en kliniese implikasies. Hierdie studie kan spelers, afrigters en navorsers help om die verband tussen dinamiese landings en risiko op van beserings te verstaan. Die studies al ook meer inligting gee oor moontlike insluiting van kaalvoetoefeninge in ‘n oefenprogramme.

5. BETALING VIR DEELNAME

Geen betaling vir deelname aan hierdie studie word aan enige deelnemer gedoen nie. Daar is ook geen laste betrokke vir deelname in hierdie studie nie

6. VERTROULIKHEID

Enige inligting wat tydens hierdie studie verkry word en wat jou kan identifir, sal vertroulik gehou word. Dit sal net met jou toestemming bekend gemaak word of soos die wet dit vereis. Vertroulikheid sal behou word deur gebruik te maak van 'n getalle sisteem wat 'n nommer aan alle resultate koppel. Dus sal jou naam nooit bekend gemaak word aan enige party nie. Data sal veilig toegesluit word in 'n kantoor, waar dit vir 'n minimum van drie jaar gehou word indien jy enige verifikasie of bewys van enige gepublirde informasie en uitkomstes sou verlang. Behalwe vir die navorsers en die studieleier, sal geen ander persoon toegang tot enige data hê nie. Daar is 'n moontlikheid dat hierdie studie gepublir mag word in 'n tydskrif.

7. DEELNAME EN ONTTREKKING

Deelname aan hierdie studie is vrywillig en kan jy die uitnodiging om deel te neem, weier. As jy vrywilliglik instem, kan jy enige tyd van die studie onttrek sonder enige nagevolge. Jy mag ook weier om enige van die vrae te beantwoord en nog steeds aan die studie deelneem. Die navorsers mag jou van die studie onttrek as enige omstandighede dit verg.

8. IDENTIFIKASIE VAN NAVORSERS

As jy enige vrae het, moet asseblief nie huiwer om die volgende persone te kontak nie: Boluwaji Jaiyesimi (061 511 2911; 19573316@sun.ac.za) of promoter Prof. R. E. Venter (021 808 4915 of rev@sun.ac.za).

9. REGTE VAN DEELNEMERS

Jy mag jou toestemming enige tyd tydens die studie onttrek en jou deelname staak sonder enige nagevolge. Jou deelname aan hierdie navorsingsprojek oortree geen wetlike eise, regte of drastiese maatreëls nie. Kontak gerus Me. Maléne Fouché [mfouche@sun.ac.za; 021 808 4622] by die Afdeling van Navorsingsontwikkeling vir enige vrae oor jou regte as deelnemer in navorsing.

HANDTEKENING VAN DEELNEMER

Die bogenoemde informasie was in Engels deur die Boluwaji Jaiyesimi (navorser) aan my verduidelik. Ek verstaan Engels. Genoeg geleentheid is aan my gegun om enige vrae te vra en hierdie vrae is bevredigend beantwoord.

Hiermee stem ek vrywilliglik in om aan hierdie studie deel te neem. Ek het 'n afskrif van hierdie dokument ontvang.

____

Naam van deelnemer

____ _______________

Handtekening van deelnemer Datum

____

HANDTEKENING VAN NAVORSER

Ek verklaar dat die gegewe inligting in hierdie dokument verduidelik is aan ___________________ _____________________. Hy was aangemoedig en genoeg tyd gegun om my enige vrae te vra. Hierdie gesprek was in Afrikaans gevoer en geen vertaler was benodig nie.

____ _______________

Handtekening van navorser (Boluwaji Jaiyesimi) Datum

APPENDIX B: Ethical approval for the study

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot • your knowledge partner

Approved with Stipulations

New Application

24-Apr-2017

Jaiyesimi, Boluwaji B.G.

Proposal #: SU-HSD-003784

Title: BAREFOOT TRAINING AS A MODALITY TO IMPROVE LANDING KINETICS, KINEMATICS AND BIOMOTOR ABILITIES IN TEAM ATHLETES

Dear Mr Boluwaji Jaiyesimi,

Your **New Application** received on **03-Mar-2017**, was reviewed

Please note the following information about your approved research proposal:

Proposal Approval Period: **24-Apr-2017 -23-Apr-2018**

This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki and the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health). Annually a number of projects may be selected randomly for an external audit.

National Health Research Ethics Committee (NHREC) registration number REC-050411-032.

We wish you the best as you conduct your research.

If you have any questions or need further help, please contact the REC office at 218089183.

Included
Documents:
DESC Report

REC: Humanities New Application

Sincerely,
Clarissa Graham
REC Coordinator
Research Ethics Committee: Human Research (Humanities)

APPENDIX C: Physical activity readiness questionnaire

PERSONAL INFORMATION

Name and surname: ____

Team: __________________ Date of birth: _______________ Age: _______

Address: ____

____ Code: ___________

Cell phone nr: ____________________ e-mail address:____________________

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?

I hereby declare that the information is true and correct

__________________ ________________

Signature Participant Date

APPENDIX D: Pre-participation health and history screening questionnaire

Tick any YES statement

SECTION 1

History:

a heart attack

__ heart surgery

__ cardiac catheterization

__ coronary angioplasty (PTCA)

__ pacemaker/implantable cardiac defibrillator/rhythm disturbance

__ heart valve disease

__ heart failure

__ heart transplantation

__ congenital heart disease

Symptoms:

__ Participant has experienced chest discomfort with exertion.
__ Participant experiences unreasonable breathlessness.
__ Participant experiences dizziness, fainting, blackouts.
__ Participant takes heart medications.

Other health issues:
__ Participant has musculoskeletal problems.
__ Participant has concerns about the safety of exercise.
__ Participant takes prescription medication(s).
__ Participant is pregnant.

If any statements in this section are marked, a physician or appropriate health care provider should be consulted before engaging in exercise and documentation of this consultation should remain on file.

SECTION 2: CARDIOVASCULAR RISK FACTORS

__ Participant smokes.

__ Participant's blood pressure is > 140/90.

__ Participant's blood pressure is not known.

__ Participant takes blood pressure medication.

__ Participant's blood cholesterol level is > 240 mg/dl.

__ Participant's cholesterol is not known.

__ Participant has a close blood relative who had a heart attack; before age 55

__ Participant is physically inactive (< 30 minutes of physical activity on at least 3 days per week).

__ Participant is > 20 pounds overweight.

If two or more statements in this section are marked, a physician or appropriate health care provider should be consulted before engaging in exercise and documentation of this consultation should remain on file.

SECTION 3: NO HISTORY, SYMPTOMS, HEALTH ISSUES, OR CARDIOVASCUALAR FACTORS

__ None of the items in sections 1 and 2 above are true.

Participant should be able to exercise safely without consulting their healthcare provider.

Study Team Leader Completing the Form: ___________________________________

APPENDIX E: Previous barefoot experience questionnaire

Wat was die slegste van die kaalvoetoefening? / *What was the worst of the barefoot training*?

………
………………………………………………..

Wat was die beste van die kaalvoetoefening? / *What was the best of the barefoot training?*

………
……………………………………………….

Sal jy weer aan so 'n projek deelneem? Motiveer. / *Will you participate in this type of project again? Motivate.*

………
……………………………………………….

APPENDIX F: Personal information sheet

Surname/ Van: ______________________________ Name/ Naam:__________________________

Age/Ouderdom: _________________ Playing position/ Speelposisie: ____

Team/ Span (Maties / Vics / etc.): _______________________

Highest level played in previous 12 months / Hoogste vlak van deelname die afgelop 12 maande:

____

How many years have you been playing netball? / Hoeveel jaar speel jy netball?

____

Have you done any barefoot training in the previous six months ? / Het jy enige kaalvoet-oefening die afgelop ses maande gedoen? (barefoot running, barefoot training in a gymnasium, etc.)

Yes / Ja ____ No / Nee ___

If Yes, please describe / Indien Ja, verduidelik:

____

____

Indicate with a cross on the line below how often you walk barefoot. / Trek 'n kruisie op die lyn hieronder om te wys hoe baie jy kaalvoet loop.

Nooit	Partykeer	Dikwels	Baie keer	Altyd
Never	Sometimes	Often	Many times	Always

I I I I I I I I I I

1 10

APPENDIX G: Modified lower limb comfort index (mLLCI)

ID:	**Place a score 0 to 6 in each box**											
Lower extremity Comfort: Rank each body area from 0-6 using the comfort descriptors	Fore foot	Medial foot	Hind foot	Medial ankle	Lateral ankle	Calf Achilles	Medial Shin	Lateral Shin	Medial Knee	Lateral Knee	Lower back	Sum Comfort
												/60 maximum score
COMFORT DESCRIPTORS **0 = EXTREMELY UNCOMFORTABLE** (unable to run or jump) **1** **2** **3 = neither uncomfortable or comfortable** (neutral) **4** **5** **6 = zero discomfort** (extremely comfortable; best ever feel)												

Heel aan die begin van die projek (Maart)/ *Right at the start of the project (March)*

	0 Baie erg; kan nie hardloop/ spring *Very bad; cannot run or jump*	1	2	3 Tussenin *In-between*	4	5	6 Voel baie goed *Feeling great*
Voete / *Feet*							
Enkels / *Ankles*							
Achilles / *Achilles*							
Kuite/ *Calves*							
Onderbene *Shins*							
Knieë /							

Knees							
Heupe / *Hips*							
Lae-rug / *Low-back*							

In die middeldeel van die projek (April) / *In the middle part of the project (April)*

	0 Baie erg; kan nie hardloop/ spring *Very bad; cannot run or jump*	1	2	3 Tussenin *In-between*	4	5	6 Voel baie goed *Feeling great*
Voete / *Feet*							
Enkels / *Ankles*							
Achilles / *Achilles*							
Kuite/ *Calves*							
Onderbene *Shins*							
Knieë / *Knees*							
Heupe / *Hips*							
Lae-rug / *Low-back*							

Teen die einde van die projek (Mei) / *At the end of the project (May)*

	0 Baie erg; kan nie hardloop/ spring *Very bad; cannot run or jump*	1	2	3 Tussenin *In-between*	4	5	6 Voel baie goed *Feeling great*
Voete / *Feet*							
Enkels / *Ankles*							
Achilles / *Achilles*							
Kuite/ *Calves*							

Onderbene *Shins*							
Knieë / *Knees*							
Heupe / *Hips*							
Lae-rug / *Low-back*							

APPENDIX H: Landing error scoring system (LESS)

Item	Correct	Error
------------Sagittal View------------		
Evaluated at IC		
Knee Flexion: >30 degrees	Yes-0	No-1
Hip Flexion: Hips are flexed	Yes-0	No-1
Trunk Flexion: Trunk is flexed on hips	Yes-0	No-1
Ankle Plantar Flexion: Toes to heel	Yes-0	No-1
Evaluated between IC and moment of MKF		
Knee Flexion Displacement: > than 45 degrees	Yes-0	No-1
Trunk Flexion: Greater than at contact	Yes-0	No-1
Hip Flexion: Greater than at contact	Yes-0	No-1
Overall		
Sagittal plane joint displacement	Soft-0	Avg-1, Stiff-2
------------Frontal View------------		
Evaluated at IC		
Lateral Trunk Flexion: Trunk flexed to left or right	No-0	Yes-1
Knee Valgus: Knees over the midfoot	Yes-0	No-1
Initial Foot Contact: Symmetric	Yes-0	No-1
Evaluated at Entire Foot Contact w/ Ground		
Foot Position: Toes pointing out >30 degrees	No-0	Yes-1
Foot Position: Toes pointing out <30 degrees	No-0	Yes-1
Stance Width: Less than shoulder width	No-0	Yes-1
Stance Width: Greater than shoulder width	No-0	Yes-1
Evaluated between IC and moment of MKF		
Knee Valgus Displacement: Knees inside of large toe	No-0	Yes-1
Overall		
Overall Impression	Excellent-0	Avg-1. Poor-2
	Total	

APPENDIX I: Subjective experience of barefoot activities

Kaalvoetgewoontes / *Barefoot habits*

1. Trek 'n kruisie op die lyn hieronder om te wys hoe baie jy kaalvoet loop.
   Indicate with a cross on the line below how often you walk barefoot.

IN DIE SOMERVAKANSIE / DURING SUMMER HOLIDAYS

Partykeer Dikwels Baie keer Altyd

Nooit

Sometimes *Often* *Many times* *Always*

Never

1 10

IN DIE WINTERVAKANSIE/ DURING WINTER HOLIDAYS

Partykeer Dikwels Baie keer Altyd

Nooit

Sometimes *Often* *Many times* *Always*

Never

1 10

IN DIE SOMER BY DIE UNIVERSITEIT / DURING SUMMER AT UNIVERSITY

Partykeer Dikwels Baie keer Altyd

Nooit

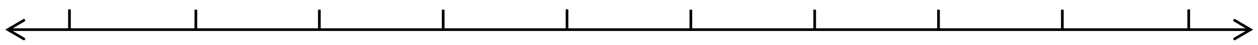
Sometimes *Often* *Many times* *Always*

Never

1 10

IN DIE WINTER BY DIE UNIVERSITEIT/ DURING WINTER AT UNIVERSITY

Nooit	Partykeer	Dikwels	Baie keer	Altyd
Never	*Sometimes*	*Often*	*Many times*	*Always*



1 10

2. Het jy ooit op laerskool kaalvoet skool toe gegaan? Ja ___ Nee ___
   Have you ever gone to school barefoot while in primary school? Yes___ No ____

Naam en Van / *Name and Surname*: ____________________ Span / Team: ___________

Baie dankie! Thank you!

APPENDIX J: Variables checklist (BF VS SH)

Summary indication of increase and decrease of kinetic and kinematic variables of the jump-landing tasks in BF and SH conditions

VARIABLE	CATEGORY	SUB-CATEGORY	SLR		SLL		DVJ		SJPT	
			BF	SH	BF	SH	BF	SH	BF	SH
Kinetics	GRFs (BW)	PRF	↑	↓	↑	↓	↑	↓	↑	↓
		VGRF	↑	↓	↑*	↓*	↑	↓	↑	↓
		MGRF	↓	↑	↓*	↑*	↓*	↑*	↓	↑
		AGRF	↓	↑	↓	↑	↑*	↓*	↑	↓
	GRFtp (s)	PRFtp	↑	↓	↓	↑	↓	↑	↓	↑
		VGRFtp	↓	↑	→	→	↑	↓	→	→
		MGRFtp	↑*	↓*	↑*	↓*	↓	↑	↑	↓
		AGRFtp	↓	↑	↓	↑	↓*	↑*	↓*	↑*
	SA (%)	Hip_{SA}	↑*	↓*	↑*	↓*	↑	↓	↓	↑
		$Knee_{SA}$	↑	↓	↑	↓	↑	↓	↑	↓
		$Ankle_{SA}$	↑	↓	↓	↑	↓*	↑*	↓*	↑*
Kinematics	IPA (g)	$Pelvis_{accl}$	↓*	↑*	↓*	↑*	↓	↑	↓	↑
		$Thigh_{accl}$	↑	↓	↑*	↓*	↓	↑	↓	↑
		$Shank_{accl}$	↑*	↓*	↑*	↓*	↓	↑	↓	↑
		$Foot_{accl}$	↑	↓	↑*	↓*	↑*	↓*	↑*	↓*
	IC ANGLES (deg)	Lumbar flexion	↑	↓	↑	↓	↑	↓	↓	↑
		Hip flexion	↓	↑	↓	↑	↓	↑	↑	↓
		Hip abduction	↓	↑	↑	↓	↓	↑	↑	↓
		Knee flexion	↓	↑	↑	↓	↓	↑	↑	↓
		Knee Abduction	↓	↑	↑	↓	↓	↑	↑*	↓*
		Ankle dorsiflexion	↑*	↓*	↑	↓	↑*	↓*	↑	↓
		Ankle inversion	↑*	↓*	↓	↑	↑	↓	↑	↓
		Ankle abduction	↑	↓	↑*	↓*	↑*	↓*	↑	↓
	PEAK ANGLES (deg)	Lumbar flexion	↑	↓	→	→	↓	↑	↓	↑
		Hip flexion	↓	↑	↓	↑	↓	↑	↑	↓
		Hip abduction	↓	↑	↑	↓	↑	↓	↑	↓
		Knee flexion	↑	↓	↑	↓	↓	↑	↑	↓
		Knee Abduction	↓	↑	↓	↑	↓	↑	↓	↑
		Ankle dorsiflexion	↓	↑	→	→	↓	↑	↓	↑
		Ankle inversion	↓	↑	↓	↑	↑	↓	↑	↓
		Ankle abduction	↑	↓	↓*	↑*	↓	↑	↓	↑
	ROM (deg)	Hip flexion	↓	↑	↓	↑	↓	↑	↓	↑
		Hip abduction	↓	↑	↓	↑	↓	↑	↑	↓
		Knee flexion	↑	↓	↑	↓	↓	↑	↓	↑
		Knee Abduction	↑	↓	↑	↓	↑	↓	→	→
		Ankle dorsiflexion	↑*	↓*	↑*	↓*	↓	↑	↓*	↑*
		Ankle inversion	↓	↑	↑	↓	↓*	↑*	↓*	↑*
		Ankle abduction	↓	↑	↓	↑	↓*	↑*	↓	↑

↑ increase ↓ decrease → no change

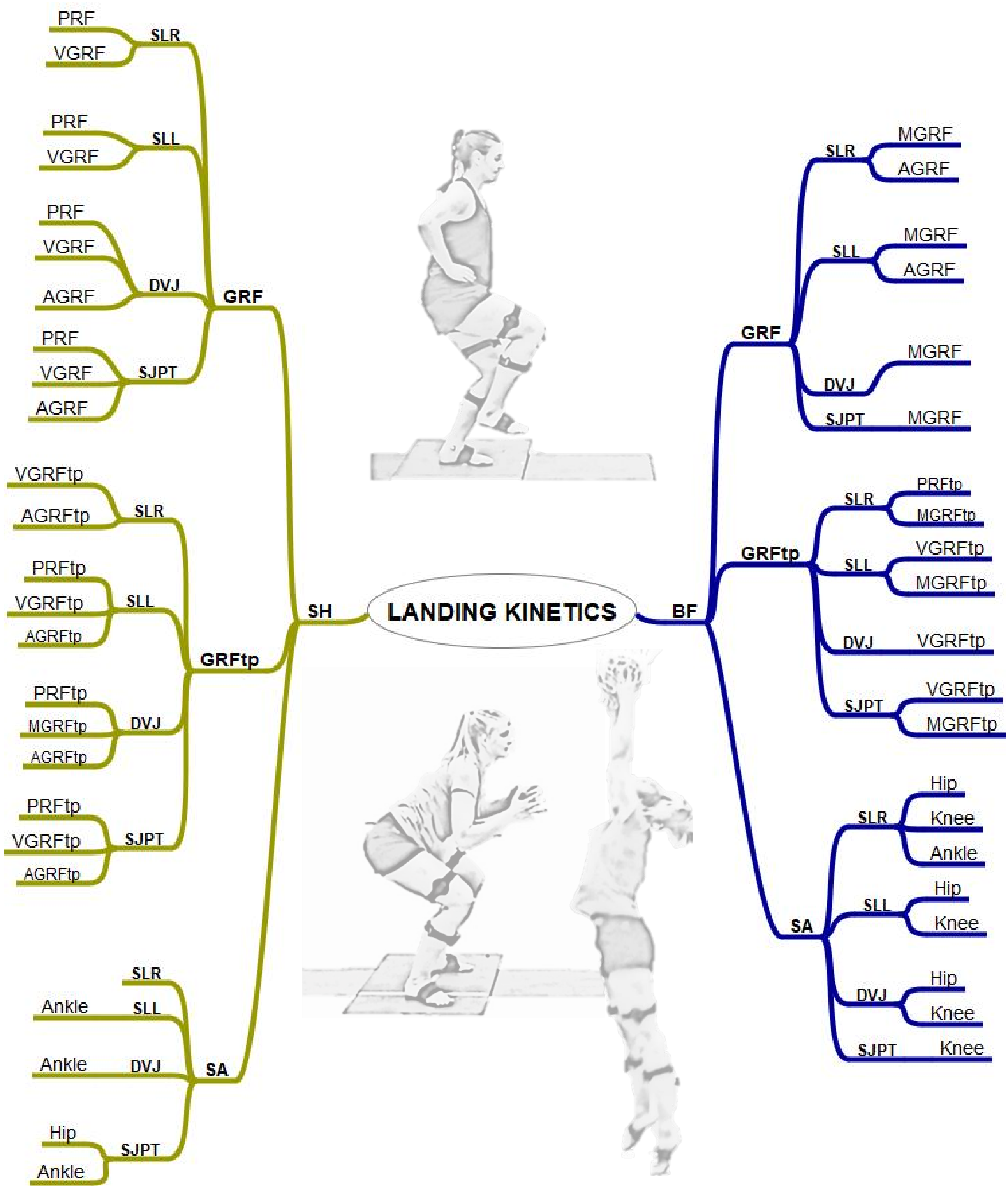
APPENDIX K: Variables checklist (EXP VS CON)

Summary indication of increase and decrease of kinetic and kinematic variables of the jump-landing tasks between EXP and CON groups

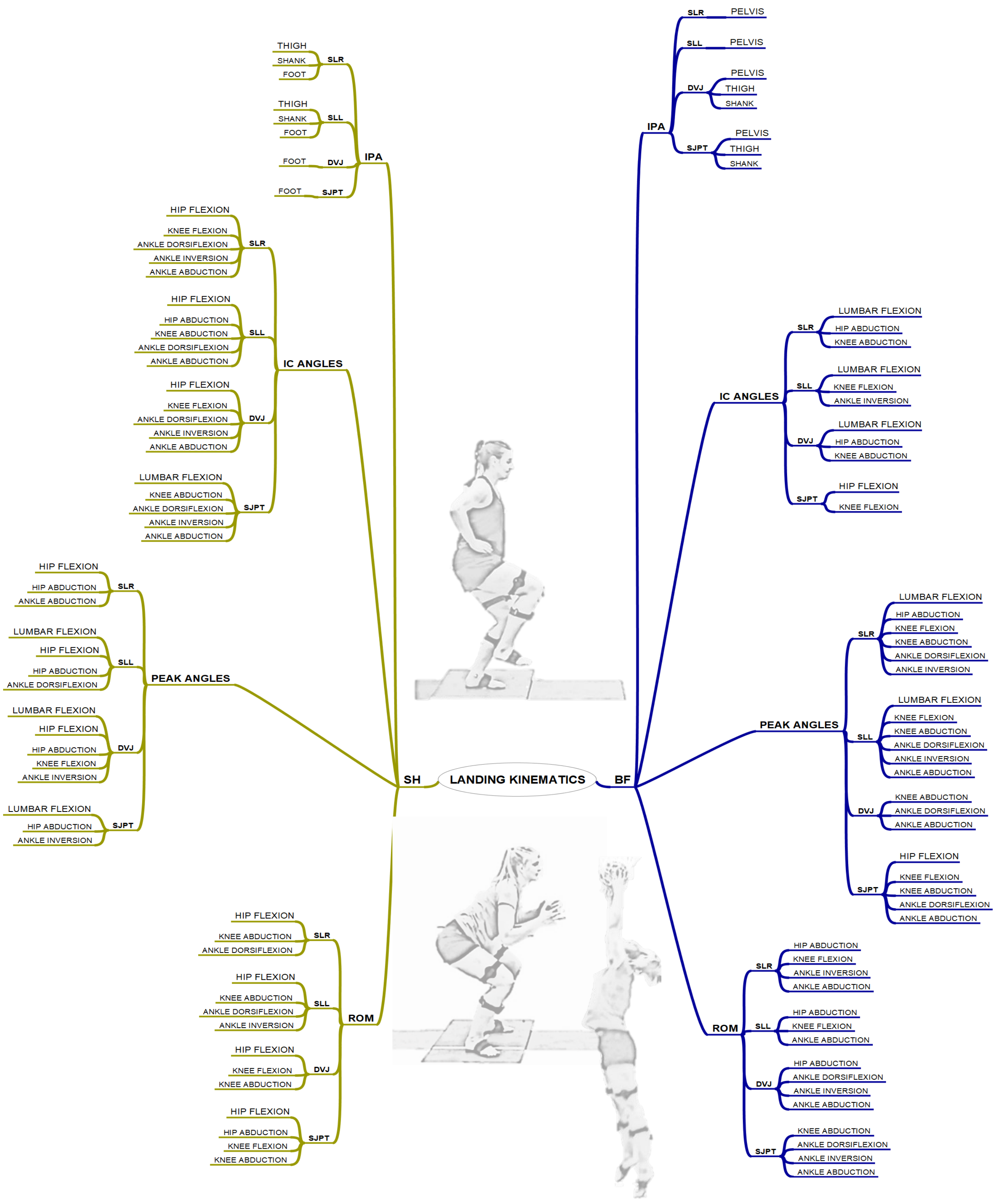
VARIABLE	CATEGORY	SUB-CATEGORY	PRE (EXP)	PRE (CON)	POST (EXP)	POST (CON)
Kinetics	GRFs (BW)	PRF	↑*	↓*	↓*	↑*
		VGRF	↑*	↓*	↓*	↑*
		MGRF	↓*	↑*	↓*	↑*
		AGRF	↑*	↓*	→*	→*
	GRFtp (s)	PRFtp	↑	↓*	↓	↑*
		VGRFtp	↓	↑	→	→
		MGRFtp	↓	↑	↓	↑
		AGRFtp	↑	↓*	↓	↑*
	SA (%)	Hip_{SA}	↑	↓	↑	↓
		$Knee_{SA}$	↓*	↑*	↓*	↑*
		$Ankle_{SA}$	↑	↓*	↓	↑*
Kinematics	IPA (g)	$Pelvis_{accl}$	↑*	↓*	↓*	↑*
		$Thigh_{accl}$	↑*	↓*	↑*	↓*
		$Shank_{accl}$	↑	↓	↓	↑
		$Foot_{accl}$	↓	↑*	↑	↓*
	IC ANGLES (deg)	Lumbar flexion	↓	↑	↓	↑
		Hip flexion	↓*	↑	→*	→
		Hip abduction	↑*	↓	↑*	↓
		Knee flexion	↓*	↑	↑*	↓
		Knee Abduction	↓*	↑	↓*	↑
		Ankle dorsiflexion	↓*	↑	↓*	↑
		Ankle inversion	↑*	↓	↑*	↓
		Ankle abduction	↑	↓	↑	↓
	PEAK ANGLES (deg)	Lumbar flexion	↑	↓*	↓	↑*
		Hip flexion	↓*	↑*	↑*	↓*
		Hip abduction	↑	↓*	↑	↓*
		Knee flexion	↓*	↑*	↑*	↓*
		Knee Abduction	↓*	↑*	↑*	↓*
		Ankle dorsiflexion	↓*	↑*	↓*	↑*
		Ankle inversion	↓	↑	↑	↓
		Ankle abduction	↓	↑	↓	↑
	ROM (deg)	Hip flexion	↓*	↑	↓*	↑
		Hip abduction	↓*	↑*	↓*	↑*
		Knee flexion	↓*	↑	↓*	↑
		Knee Abduction	↓	↑*	→	→*
		Ankle dorsiflexion	↓	↑	↓	↑
		Ankle inversion	↓	↑*	↑	↓*
		Ankle abduction	↓*	↑	↑*	↓

↑ increase ↓ decrease → no change

APPENDIX L: Landing kinetics of BF vs SH



APPENDIX M: Landing kinematics of BF vs SH



APPENDIX N: Training characteristics

Warm-up

Exercise	Description	Reps/laps	Set	Duration	Intensity
Slow jogging	Court width	3	-	-	50%
Quick feet	On the spot	3	-	15secs	50%
High knees	Knee raised to 45 deg	2	-	-	50%
Butt kicks	Heel touches the butt	2	-	-	50%
High knee rotation	High knee rotation forward	1	-	-	50%
High knee rotations	High knee rotations backward	1	-	-	50%
Diagonal hop	Diagonal hop with landing on one leg	1	-	-	50%
Frog jumps		1	-	-	50%
Deep squat	Bilateral Deep squat	20	-	-	50%
Single-leg squat	Single-leg squat of each legs	5	2	-	20%
Ankle rotation	Ankle rotation of each foot	3	2	-	20%

Plyometric drills

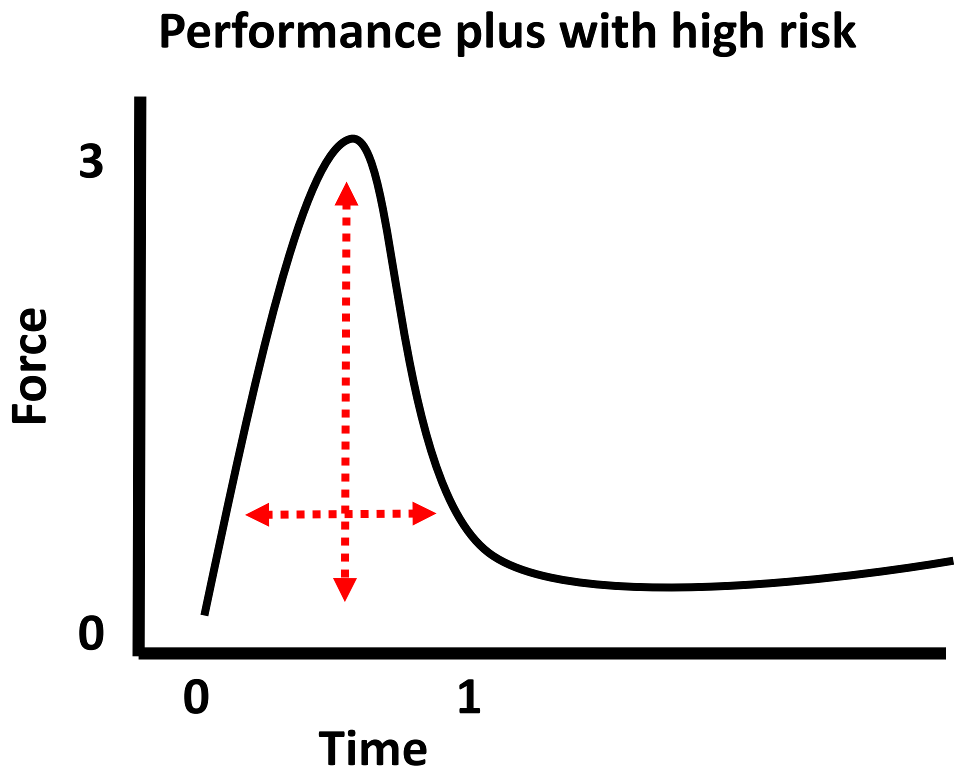
Exercise	Description	Reps/laps	Set	Duration	Intensity
Hurdle jump	Double leg landing, 10m sprint and single-leg landing	6 reps alternated with forward and lateral jump per cycle	2	-	50%
Two legged maximum jumps	5 maximum jumps	3	2	15secs	70%
One-legged maximum jump	7 maximum jumps	2	2	-	60%
Regular plank hold	Continuous alternating from push up to plank position Hold each position for 5 seconds	5	-	-	70%
Sprints	Sprints to half court from different starting positions (facing backward, sitting facing forward legs straight)	3	2	-	70%

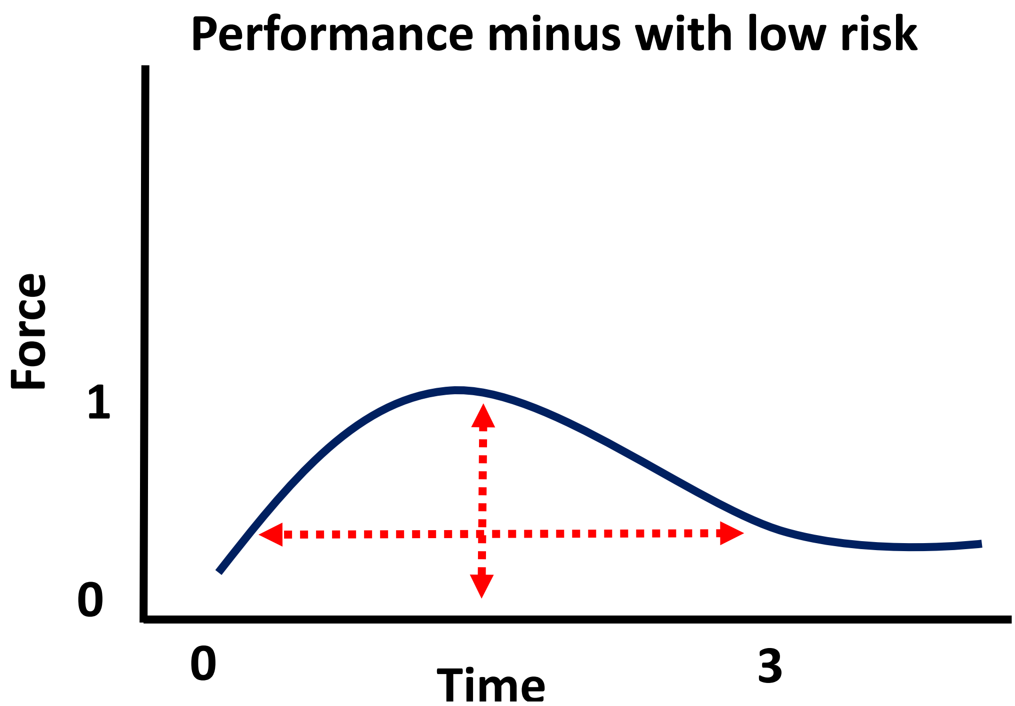
Drop jumps	Drop jumps from 30m box and sprint 5m	3	2	-	70%
Sprint with jump-landing	Players sprint from starting line and before reaching each 1/3 line of the court have to do a jump-landing with two feet	2	2		70%
Elastic band runs	Elastic band runs (with a partner) Forward sprint with high knees Backward run while staying low Lateral jumps - face sideways, jump laterally and land on both feet.	2	2		70%

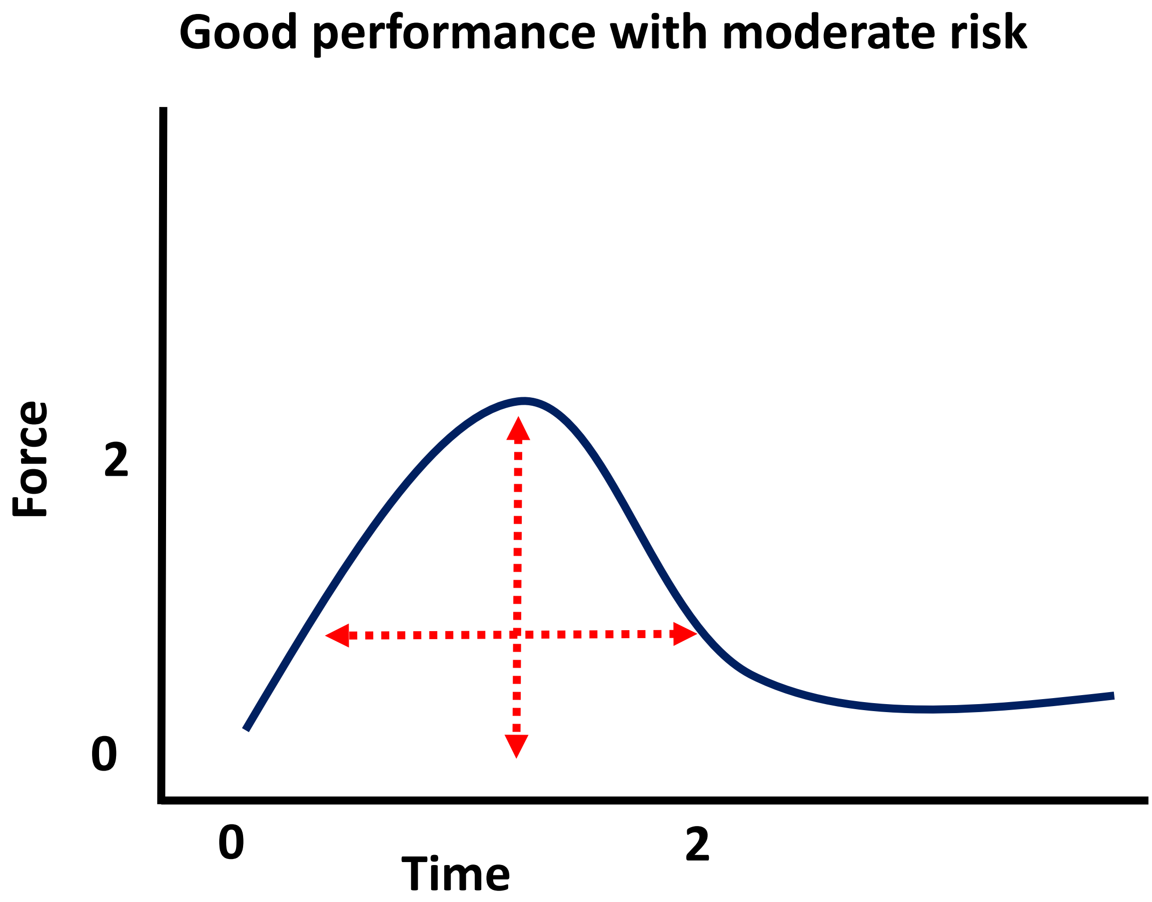
Ball drills

Exercise	Description	Reps/laps	Set	Duration	Intensity
Star passing drill	Start with one ball (5 min continuous pass Then move to two balls alternate landing during catching (two feet, right-left, left-right)	3	2	-	70%
Quick run and pass drill	Two opposite groups facing each other 5-6 players in each line. Pass high ball (above chest level) for the other players to jump and catch.	3	2	-	70%
Diamond ball drill	Players are lined in position 1 and 2. Players passes to player 2, runs to position 3 where it receives pass, Passes back to position 2, runs to position 4 where it receives the pass, And then passes to position 1, and makes a sprint to the half court.	3	2	-	50%
Line passing sprint	Five players line out along the side line of the court Player with the ball standing 2-3 meters away, sprints forward and passes to each player, who then immediately pass back	5	2	-	60%

APPENDIX O: Proposed force-magnitude and time relationship






Good performance with moderate risk
Force
2
0
0
2
Time

APPENDIX P: Proposed shock attenuation pattern