# The Effects of Instruction and Feedback on Lower Limb Kinematics and Kinetics During Landing in Female Novice Netball Players

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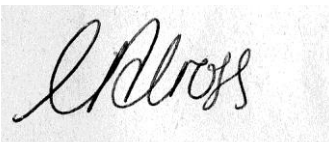
## Attestation of Authorship

“I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning."

Candidate:  Date: 20 March, 2013

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## Confidential Material

All confidential material, including the participant assent forms, the parent/guardian consent forms, the screening questionnaire and the raw data (videos, Qualysis motion analysis) will be stored in a locked cabinet within the Health and Rehabilitation Research Institute (HRRI) at AUT University Akoranga campus for a period of ten years after which time all research material will be destroyed.

## Glossary of Abbreviations

**1-2 foot landing**: one to two foot landing style

**3-D:** three dimensional

**ACC:** Accident Compensation Corporation

**ACL:** anterior cruciate ligament

**AIM:** Automatic Identification of Markers (system of marker identification)

**AMTI:** Advanced Medical Technology Incorporated (force plate brand)

**ANOVA:** Analysis of variance (statistical test)

**APGRF:** antero-posterior ground reaction forces

**ASCII:** American Standard Code for Information Interchange (text file format)

**AUT:** Auckland University of Technology

**AUTEC:** Auckland University of Technology Ethics Committee

**BW:** body weight (normalisation of kinetic data to a multiple of body weight)

**C3D:** a standard file format for three dimensional data

**COM:** Centre of mass

**HRRI:** Health and Rehabilitation Research Institute

**IBM:** International Business Machines (Computer company)

**ICC:** Intra-class correlation coefficient

**LON:** "Left On" representing the event marker where the left foot contacts force plate one

**RON:** "Right On" representing the event marker where the right foot contacts force plate two

**SPSS:** Statistical Package for the Social Sciences (statistical analysis software)

**STAND:** Event marker representing the completion of a land

**TOFF: "**Take-off" representing the event marker at take-off to land

**VGRF:** vertical ground reaction forces

## Abstract

**Introduction:** Netball is the largest female participation sport in New Zealand and Australia. Lower limb injuries, in particular to the ankle and knee, are common during landing in netball. Instruction and feedback on landing technique are often implemented in lower limb injury prevention programmes; however, these programmes commonly involve multiple neuromuscular training techniques such as proprioception, strength, balance, speed and plyometric training. The effect of instruction and feedback within specific sporting populations has not been widely researched. Although guidelines for landing are in use within New Zealand netball, these guidelines have not been evaluated. The aim of this study was to determine the effect of instruction and feedback (based on NetballSmart Netball New Zealand guidelines) on sagittal ankle and knee joint kinematics and kinetics during landing in female novice netball players.

**Methods:** Thirty-nine netball players (mean age 12 years) were allocated by school to either an instruction or control group. In a laboratory setting, participants completed two netball landing styles; double foot and one-to-two foot, after running forwards to catch a netball. Following baseline testing, the instruction group received instruction and feedback on their landing technique for 20 minutes while the control group practiced repeated landings while catching a ball without any instruction during the same time period. Three-dimensional motion analysis (Qualysis Medical, Sweden) was used to record movement and floor mounted force plates were used to record forces during landing. Sagittal ankle and knee joint angles, joint reaction forces, joint moments and ground reaction forces were assessed prior to and following instruction and feedback or landing practice. Repeated measures 2 x 2 analysis of variance was used to investigate kinematic and kinetic differences between the instruction and control group due to instruction and feedback on landing technique.

**Results:** The instruction group demonstrated significantly greater peak ankle dorsiflexion and peak knee flexion during landing, following instruction and feedback, for both landing styles ($p < 0.001$). They significantly reduced peak vertical joint reaction forces at the ankle and knee ($p < 0.001$), as well as peak anterior joint reaction forces at the ankle ($p < 0.01$). Furthermore, peak antero-posterior ground reaction forces ($p < 0.05$) as well as peak vertical ground reaction forces were significantly reduced ($p < 0.001$). The control group did not significantly alter their landing mechanics following landing practice.

**Conclusion:** Instruction and feedback on landing technique, based on the key principles of the NetballSmart landing guidelines, had a significant effect on landing biomechanics in female novice netball players. The kinematic and kinetic changes observed were consistent with reducing known risk factors associated with lower limb joint injury during landing. Instruction and feedback are simple and inexpensive techniques that can be easily disseminated to coaches and players in the netball community. This study provides the basis for further research to investigate the potential long term benefits of instruction and feedback in netball players. Addressing landing biomechanics in novice female netball players has the potential to reduce lower limb injuries in later adolescence.

# Chapter One

## Introduction

### 1.1 Background

Netball is a dynamic sport involving rapid changes of direction, multiple jumps and abrupt landings in order to manoeuvre a ball or defend an opponent. It is the most popular female team sport in New Zealand (Sport and Recreation New Zealand, 2008) and Australia (Australian Bureau of Statistics, 2010) enjoyed by youth and adults. Despite its popularity, netball has gained a reputation as being a sport associated with ankle and knee injuries (Steele, 1990). Epidemiological research from both New Zealand and Australian netball populations confirm that sprains to the lower limb, namely the ankle and knee, are the most common injuries (Finch, Da Costa, Stevenson, Hamer, & Elliott, 2002; Hopper, Elliott, & Lalor, 1995; Hume, 1993; McKay, Payne, Goldie, Oakes, & Stanley, 1996; McManus, Stevenson, & Finch, 2006; Otago & Peake, 2007).

Netball players complete between 63 and 111 landings during a netball game, depending on the playing position (Ferdinand, Beilby, Black, Law, & Tomlinson, 2008, April) and landing is a leading mechanism of lower limb injury (Hume & Steele, 2000). In a study of consecutive netball seasons, players reported that incorrect landings were the main cause of their injuries (Hopper et al., 1995). Injury surveillance of similar team sports involving multiple landings such as basketball, volleyball and handball concur that landing is a leading cause of ankle and knee injury (Agel, Palmieri-Smith, Dick, Wojtys, & Marshall, 2007; Bahr, Karlsen, Lian, & Ovrebo, 1994; McKay, Goldie, Payne, & Oakes, 2001; Olsen, Myklebust, Engebretsen, & Bahr, 2006).

Prospective studies have identified biomechanical determinants of ankle and knee injury (Hadzic et al., 2009; Hewett et al., 2005). For example, volleyball players who sustained an ankle sprain were shown to have greater plantar flexion strength and reduced ankle dorsiflexion range of motion compared to non-injured controls (Hadzic et al., 2009). With respect to the knee, female athletes sustaining an injury to the anterior cruciate ligament (ACL) were shown to have significantly reduced peak knee flexion during landing and land with greater vertical ground reaction forces (VGRF) than those who had not sustained an injury (Hewett et al., 2005).

Controlled trials using instructional neuromuscular training programmes have demonstrated that the rate of ankle and knee injury can be reduced in landing sports such as handball, basketball, volleyball and soccer (Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Myklebust et al., 2003; Olsen, Myklebust, Engebretsen, Holme, & Bahr, 2005; Petersen et al., 2005). These studies, however, used multimodal training programmes which included a combination of plyometric, balance, agility or strength training in conjunction with instruction on landing technique. Laboratory studies have shown that landing instruction, with or without feedback, can alter biomechanical risk factors of ankle and knee injury by reducing peak VGRF (Cowling, Steele, & McNair, 2003; Cronin, Bressel, & Finn, 2008; Herman et al., 2009; McGrath, 2009; McNair, Prapavessis, & Callender, 2000; Onate et al., 2005; Onate, Guskiewicz, & Sullivan, 2001; Prapavessis & McNair, 1999; Prapavessis, McNair, Anderson, & Hohepa, 2003) and increasing peak knee flexion angles (Cowling et al., 2003; Herman et al., 2009; Mizner, Kawaguchi, & Chmielewski, 2008; Onate et al., 2005). Of these studies, only one investigated the effect of instruction alone within a group of netball players.

It has been suggested that it is important to target injury prevention strategies at an early age prior to the incidence of sporting injuries and prior to forming established movement habits that may predispose an athlete to injury (Hass et al., 2003). At the age of seven the premotor cortex is sufficiently developed and children are able to reconstruct specific motor sequences required to learn a motor task (Berger, 2003). Cognitive formal operational thinking, according to the Swiss developmental psychologist and philosopher Piaget, where adolescents begin to hypothesise and draw deductions from a motor task, begins at age 11 (Thomas, 2000). Therefore, considering the developmental stages of the motor and cognitive brain areas involved in learning a motor task, injury prevention strategies should be aimed at children around a pre-pubertal age. No literature could be identified that examined young netball players learning a landing motor task.

Since 2000 Netball New Zealand has worked closely with the Accident Compensation Corporation (ACC), a government administered insurance body providing no fault personal injury cover to all New Zealanders and visitors to New Zealand (Accident Compensation Corporation, 2008), to develop injury prevention strategies in netball. Current injury prevention guidelines, termed “NetballSmart for coaches” (NetballSmart, 2007) were developed in 2007 by ACC staff and Netball New Zealand coaches and physiotherapists (M. Crockett, personal communication, September 10, 2009). The guidelines are in a printed booklet format and are disseminated to coaches, secondary schools, regional netball centres and at netball tournaments. In section four of the booklet the correct methods and common errors involved in netball landings are shown pictorially and discussed (NetballSmart, 2007). Despite these guidelines representing best practice, there is limited empirical evidence to support their use or impact on landing risk factors.

### 1.2 Purpose of the study

The aim of this preliminary study was to investigate whether landing instruction and feedback using the "NetballSmart for coaches" booklet as a guide, can influence the lower limb biomechanics of young female novice netball players in a manner that is considered beneficial towards reducing lower limb injury. Specifically, this study compared an instruction and control group to identify whether instruction and feedback on landing technique can lead to short term changes in sagittal lower limb kinematics and lower limb kinetics, namely to the ankle and knee, as well as ground reaction forces.

Additionally, this study will contribute to the existing literature examining the effects of instruction (with or without feedback) on landing technique and will provide data on the landing biomechanics of novice female netball players; a demographic which has been given little attention in the literature.

### 1.3 Significance of the study

This study has implications for coaches involved in netball and sports medicine providers who work with young netball players. Potentially, the study may validate the use of instruction and feedback as simple tools towards altering the biomechanics of young netball players in a way that may reduce the risks associated with ankle and knee injury. In the long term, the dissemination of such information amongst coaches and players involved in the sport of netball may lead to a reduction in lower limb injuries. The implications of this would mean a potential reduction in healthcare costs, a reduction in long term morbidity and greater participation in netball, a popular physical activity with positive health benefits.

# Chapter Two

## Literature Review

### 2.1 Introduction

This chapter begins by describing the landing characteristics of netball players and discussing the use of instruction and feedback during skill acquisition. This is followed by a systematic review of the literature where instruction (with or without feedback) on landing technique has been used to influence biomechanical factors during landing. The methodological differences of these studies and the reliability and validity of motion analysis systems used to measure the biomechanics of landing will be discussed. Landing biomechanics specific to netball players, including kinematics and kinetics of the ankle and knee as well as ground reaction forces will be reported and finally, the chapter will conclude with the aim, objective and hypothesis for the present study.

### 2.2 Landing characteristics of netball players

#### *2.2.1 Abrupt landing*

Netball is a unique sport in which players arrest forward motion abruptly when they land in possession of the ball and are not permitted to take additional steps. The first landing leg, or an elected leg when landing simultaneously, may not be dragged, slid or re-grounded and acts as a pivot while the other leg may move any number of times within the three seconds permitted to release the ball (International Federation of Netball, 2008).

#### *2.2.2 Landing styles*

In a study of elite netball players viewed on video during competitive play, the two most common landing styles identified were a one-two (1-2) foot landing (39%) or a double foot landing (38%). Run through (10%), unsighted (8%) and single foot (5%) landing styles were least used (Ferdinand, Beilby, Black, Law, & Tomlinson, 2008). The most common approach to landing in netball is a leap approach where players land on the leg opposite to their take-off leg (Steele & Milburn, 1987b).

#### *2.2.3 Footfall patterns in netball players*

Landing describes the return of a limb to the ground after a jumping airborne phase (Dufek & Bates, 1991). Several footfall patterns during landing have been described in the literature including toe to heel, flatfoot, heel or toe only patterns (Dufek & Bates, 1991). Although unclear, the footfall pattern of netball players appears to depend on the height of a pass (Steele, 1990), the motion a player performs prior to landing (Neal & Sydney-Smith, 1992) and their natural landing style. In a laboratory setting, netball players wearing footwear were observed to land with initial contact of the heel 93% of the time and the forefoot 5% of the time after replicating a netball manoeuvre to get past a defender (Steele & Milburn, 1987b). In contrast, video observation of netball players during an international match identified that 57% of the time players initially landed on the forefoot and only 8% of the time the heel contacted the ground first (Kirkham, 1989). In a small sample of 10 netball players, it was determined that a forefoot landing pattern was more common when receiving a high pass whereas initial contact with the heel was more common when receiving a chest pass (Steele & Milburn, 1989). In a controlled laboratory experiment the type of pass and the motion performed prior to landing is commonly standardised whereas a netball game allows a variation of movements.

### 2.3 Instruction and feedback

Instruction is defined as "a direction, order, command" or "a set of detailed guidelines" or "teaching" (Manser & Thomson, 1995). Within the context of skill acquisition, instruction can be further defined as "information given to athletes by the coach prior to practice or during practice but independently of performance" (Hodges & Franks, 2002). Feedback, on the other hand, is defined as "information given during or after performance" (Hodges & Franks, 2002). Hodges and Franks (2002) note that instruction can be delivered in many forms. Examples include verbal instruction through a coach or recorded segment; visual instruction through video, physical demonstration or diagrams; or in written form within books, pamphlets or internet sites. Feedback can be divided into either augmented or sensory subcategories. Augmented feedback (extrinsic) provides knowledge of performance of a skill and gives additional information to a learner that is above and beyond what is naturally available (Onate et al., 2005; Prapavessis & McNair, 1999). Sensory feedback (intrinsic) provides self-generated feedback from the sensory systems of the individual (Prapavessis & McNair, 1999).

Hodges and Franks (2002) suggest that instruction and feedback are integral skills used by coaches in sport to teach a specific motor task. Furthermore, they suggest that the effectiveness of instruction and feedback are dependent on the existing skills of the learner and the type of task or skill being taught. With respect to the motor skill of landing and altering kinematic and kinetic variables, both instruction and augmented feedback used conjointly have been shown to have an effect (Cronin et al., 2008; Gervais, 1997; Herman et al., 2009; Mizner et al., 2008; Onate et al., 2005; Onate et al., 2001), as has verbal instruction alone without any feedback (Cowling et al., 2003; McGrath, 2009; McNair et al., 2000; Prapavessis & McNair, 1999; Prapavessis et al., 2003; Walsh, Waters, & Kersting, 2007). Instruction and feedback are therefore important methods of landing skill acquisition and their effectiveness towards altering kinematic and kinetic variables warrants further investigation.

## 2.4 Systematic literature review

A systematic literature review was undertaken to determine the effect of instruction (with or without feedback) on landing technique. The purpose of the systematic literature review was to identify and critique the body of knowledge surrounding the use of instruction (with or without feedback) on landing technique and the influence that instruction has on altering specific kinematic and kinetic variables.

## 2.5 Methodology

### *2.5.1 Search strategy*

A comprehensive literature search was conducted between the 6th and 14th of December 2010. Four databases covering a wide range of health topics were selected and included:

- Ebsco Health comprising Biomedical Reference Collection: Basic, CINAHL, Health Business elite, Health source Consumer edition, Health source Nursing/Academic edition, Medline, Psychology and Behavioural Sciences Collection and Sport Discus;
- OVID comprising AMED, ERIC, Evidence Based Medicine Reviews including the Cochrane Library, Health and Psychosocial Instruments, Lippincott 100 Nursing and Health Science Collection, Lippincott Nursing Book Collection, MEDLINE, Mental Measurements Yearbook, PsycArticles and PsycInfo;
- PEDro, a Physiotherapy based database comprising of randomised controlled trials and systematic reviews;
- Scopus which searches 14,000 peer-reviewed titles from over 4,000 international publishers.

The primary key words used to search for articles, derived from the purpose of the review, were “land*” and “instruct*”or “educat*” or “feedback”. When a search resulted in more than 1000 articles the key words “biomechan*”or “kinetic*” or “kinematic*” were also used. The truncation function was used to encompass all words with a common stem. In Ebsco Health and Scopus databases, a proximity search involving the function “N”, which searches for two words in close proximity to each other, was also used.

### *2.5.2 Study selection*

Inclusion criteria for the review were:

- An experimental trial.
- Use of instruction (with or without feedback) as the intervention.
- Articles written or translated in the English language.
- Studies reporting on sagittal lower limb kinematics and/or kinetic outcome variables.

No restrictions were placed on the year of publication, study design or the study population with respect to the skill, age, sporting background and the number of sessions where participants were evaluated. Potential studies were identified, duplicates removed and the abstracts screened for inclusion criteria. Studies meeting the inclusion criteria for the review were selected and their reference lists assessed to determine if further pertinent studies were present.

### *2.5.3 Methodological quality assessment*

Studies meeting the inclusion criteria for the review were critiqued and evaluated for methodological quality by two independent assessors using the Downs and Black checklist (Downs & Black, 1998). Both assessors were qualified physiotherapists with post-graduate qualifications and experience using the checklist. The Downs and Black checklist was used as it evaluates both randomised and non-randomised studies. It has been shown to have high internal consistency, good inter-rater reliability and validity for both types of studies (Downs & Black, 1998). The Downs and Black checklist comprises 27 questions with a maximum score of 32 (refer to Appendix A for the full checklist). It has three key subsections based on the reporting of the main elements of the study (11 points), the external validity (3 points) and internal validity (13 points) of a study as well as a single question based on the power of a study (5 points). In the event that the assessors did not agree on the quality rating ascribed to a study, mutual discussion took place between the reviewers to come to an agreement.

#### *2.5.4 Data extraction*

Information from studies meeting the inclusion criteria for the review was collated and tabulated under the headings "Participants", "Landing task", "Landing instruction/feedback", "Relevant outcome measures", "Main findings" and "Quality score".

### 2.6 Results

#### *2.6.1 Study selection*

Eleven published articles and one doctoral thesis met the inclusion criteria for the review. A search of the reference lists of the 12 included studies failed to find any additional relevant studies (refer to Figure 2.1 for a summary of the search process).

#### *2.6.2 Methodological quality*

The two independent assessors agreed on 317 points out of a total of 384 for all 12 studies reviewed (Refer to Table 2.1 for a summary of the methodological quality of each study). Overall agreement between the reviewers was 83% indicating a high level of agreement and supporting the good inter-rater reliability reported for the Downs and Black checklist (Downs & Black, 1998). The mean quality score for the reviewed studies was 15 (range 12-18) out of a possible 32 points. Based on the distribution of scores, a low quality study was deemed to have an overall rating of 0-13, a medium quality study 14-17 and a high quality study 18-32 points. Studies were generally similar in three of the four Downs and Black subsections. Although the studies scored well in the reporting section; the external validity and power sections were poor. The internal validity scores were largely what differentiated the studies. Two of the 12 studies considered the reliability of the measurement instruments (McNair et al., 2000; Prapavessis et al., 2003).

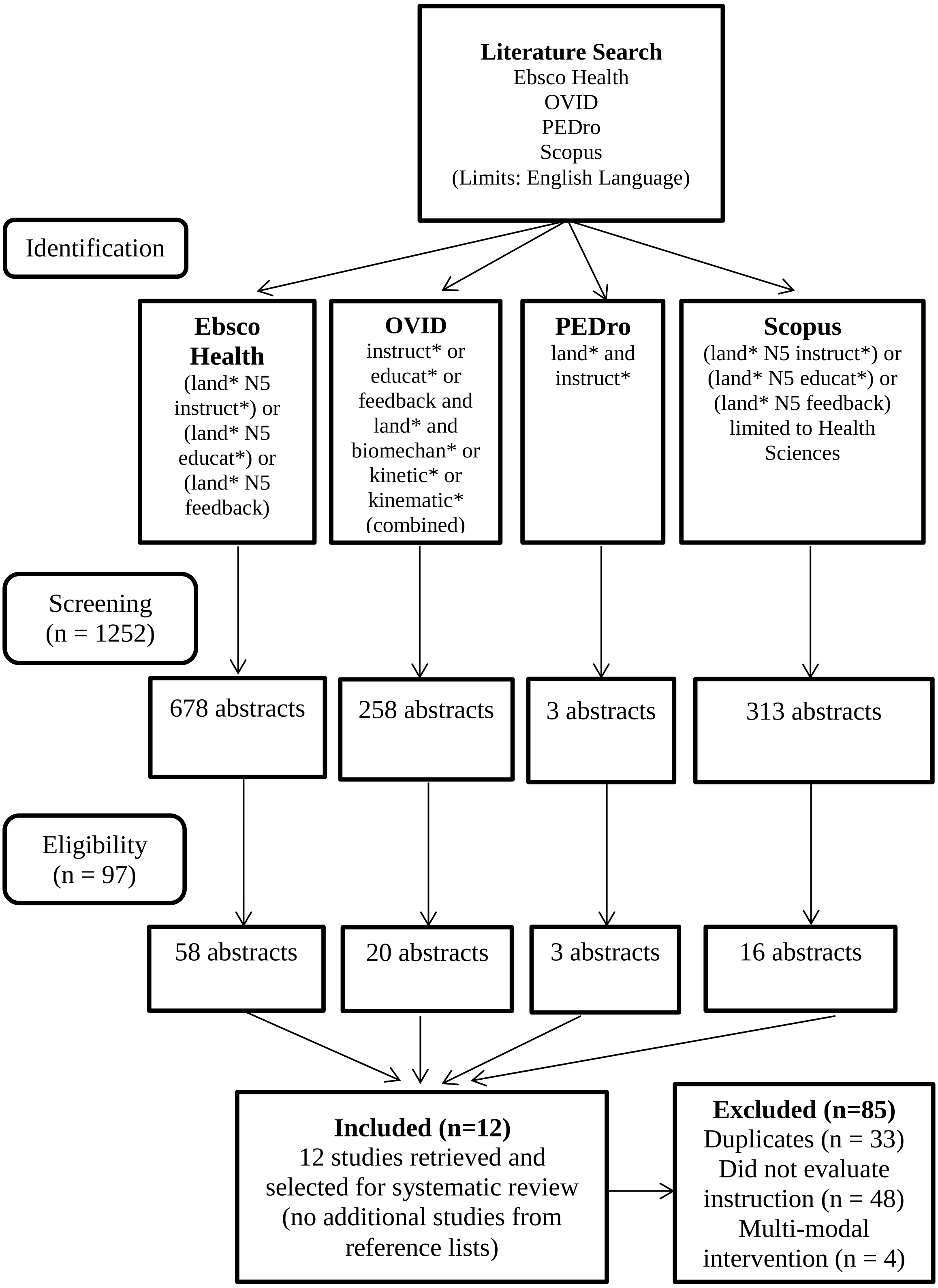



*Figure 2.1***:** Flow diagram for the selection of studies for systematic review. Adapted from "The PRISMA Statement for Reporting Systematic Reviews and Meta-Analyses of Studies That Evaluate Health Care Interventions: Explanation and Elaboration," by A. Liberati et al., 2009, *Annals of Internal Medicine*, *151*, p.68.

Table 2.1

*Summary of Study Methodological Quality*

| Study (Author and year) | Quality (Downs and Black Score) | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Question | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | Overall |
| Herman et al. (2009) | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 18/32 |
| McGrath (2009) | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 18/32 |
| Onate et al. (2005) | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 18/32 |
| Onate et al. (2001) | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 17/32 |
| Gervais (1997) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 16/32 |
| Mizner et al. (2008) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 15/32 |
| Prapavessis & McNair (1999) | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 15/32 |
| Cronin et al. (2008) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 14/32 |
| Prapavessis et al. (2003) | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 14/32 |
| Cowling et al. (2003) | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 13/32 |
| Walsh et al. (2007) | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 13/32 |
| McNair et al. (2000) | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 12/32 |

### *2.6.3 Study characteristics*

*Participants*

Nine of the studies investigated adult populations with a mean age of between 19-24 years (Cowling et al., 2003; Cronin et al., 2008; Herman et al., 2009; McGrath, 2009; McNair et al., 2000; Mizner et al., 2008; Onate et al., 2005; Onate et al., 2001; Walsh et al., 2007). One study investigated an adolescent population with an average age of 16 years (Prapavessis & McNair, 1999) and the remaining two studies investigated children with an average age of eight or nine years (Gervais, 1997; Prapavessis et al., 2003). The majority of the studies included both male and female participants; however four were specifically female only (Cowling et al., 2003; Cronin et al., 2008; Herman et al., 2009; Mizner et al., 2008) and one did not state the gender of its participants (Gervais, 1997). The majority of the studies analysed recreational or club level athletes. Three studies, however, investigated a specific elite sporting population including basketball (Walsh et al., 2007), volleyball (Cronin et al., 2008) and netball (Cowling et al., 2003). Two studies included novice athletes; one population were novice gymnasts (Gervais, 1997) while the other population had no previous sporting experience (Prapavessis et al., 2003).

*Landing task*

The majority of the studies were conducted in a laboratory environment with the exception of Gervais (1997) who assessed gymnasts landing on both feet from a 29 cm box jump while attending a gymnastics camp. Six studies, although laboratory based, assessed a functional movement task such as landing double foot from a maximal jump (Onate et al., 2001), running forwards to stop and land double foot (Herman et al., 2009; Onate et al., 2005), landing double foot from a volleyball spike (Cronin et al., 2008), running forwards to catch a netball landing primarily on the dominant limb (Cowling et al., 2003) and jumping a hurdle to land on the dominant limb followed by an unanticipated cutting manoeuvre (McGrath, 2009). The remaining five studies assessed a double foot land from a 29-31cm drop box (McNair et al., 2000; Mizner et al., 2008; Prapavessis & McNair, 1999; Prapavessis et al., 2003; Walsh et al., 2007) with two of these studies asking participants to perform a vertical jump upon landing (Mizner et al., 2008; Walsh et al., 2007)

*Intervention*

All studies used instruction to provide information to participants on landing technique. The majority of the studies used verbal instruction encouraging participants to bend at the knees as the main intervention (Cowling et al., 2003; Cronin et al., 2008; Gervais, 1997; McNair et al., 2000; Mizner et al., 2008; Prapavessis & McNair, 1999; Prapavessis et al., 2003; Walsh et al., 2007). Three of these studies provided additional verbal feedback during landing practice (Cronin et al., 2008; Gervais, 1997; Mizner et al., 2008) while the remainder provided no feedback. Several studies used a written instruction checklist given to participants; however the main intervention was the feedback given to participants from video footage of landing and verbal feedback from researchers (Herman et al., 2009; Onate et al., 2005; Onate et al., 2001). Of note, five studies asked participants, including controls, to minimise the stress of landing or "land softly" (McNair et al., 2000; Onate et al., 2005; Onate et al., 2001; Prapavessis & McNair, 1999; Prapavessis et al., 2003). This may have altered the natural manner in which these populations would normally land. Conversely, three studies specifically used the word "softly" in their verbal instruction intervention (McGrath, 2009; Mizner et al., 2008; Walsh et al., 2007). In the majority of studies, the instruction (with or without feedback) was given by researchers; however two studies employed coaches to deliver instruction and feedback (Cronin et al., 2008; Gervais, 1997).

*Controls*

The majority of the studies included a control group who received no instruction or feedback regarding landing technique (McGrath, 2009; McNair et al., 2000; Onate et al., 2005; Onate et al., 2001; Prapavessis & McNair, 1999; Prapavessis et al., 2003; Walsh et al., 2007). Herman et al. (2009), who scored highest in study quality, evaluated the effect of a nine week strength training programme, as well as instruction on landing technique. The control group in this study did not receive strength training; however both groups received landing instruction.

Refer to Table 2.2 for a full summary of the characteristics for each study.

Table 2.2

*Summary of Study Characteristics*

| Study | Participants | Landing task | Landing instruction/feedback | Relevant outcome measures | Main findings | Quality score |
|---|---|---|---|---|---|---|
| Herman et al. (2009) | 58 ♀ university students (recreational athletes)<br>Mean age 22.5 ± 3.05 years | Double foot stop land (2x force plates)<br>Four step approach run<br>5x trials (pre/post instruction) | Written instruction<br>Verbal, written and combination video (expert and self) feedback<br>Given by researchers<br>Group 1: 9 week strength training programme<br>Group 2: 9 week no strength training | Peak knee flexion angle (sampled at peak anterior knee joint force)<br>Peak anterior knee joint reaction force, peak knee extension moment and peak VGRF (sampled at peak anterior knee joint force) | Increased peak knee flexion angle groups 1 and 2<br>Reduced peak VGRF groups 1 and 2<br>Reduced peak anterior knee joint reaction force and peak VGRF group 1 versus group 2 | 18/32 (56%)<br>High |
| McGrath (2009) | 61 (30♀ 31♂) university students (competitive athletes)<br>Mean age 19.75 ± 1.6 years | Dominant single leg land (1x force plate)<br>17cm hurdle jump approach then unanticipated contra/ipsilateral cutting manoeuvre<br>5x trials (pre/post instruction) | Group 1: verbal instruction (30 seconds) post 20-25 minute fatigue protocol<br>Group 2: no instruction post 20-25 minute fatigue protocol<br>Given by researchers | Peak anterior knee joint reaction force, peak knee extension moment and peak VGRF | No change peak anterior knee joint reaction force, reduced peak knee extension moment and reduced peak VGRF group 1<br>Increased peak anterior knee joint reaction force and peak VGRF group 2 | 18/32 (56%)<br>High |

| Study | Participants | Landing task | Landing instruction/feedback | Relevant outcome measures | Main findings | Quality score |
|---|---|---|---|---|---|---|
| Onate et al. (2005) | Kinetic analyses 51 (32♀ 19♂) recreational college athletes<br>Mean age 20.38 ± 1.41 years<br>Kinematic analyses Subset of 40 (25♀ 15♂)<br>Mean age 20.17 ± 1.46 years | Double foot stop land (2x force plates)<br>4m approach run, left foot take off simulating grabbing a basketball<br>5x trials (pre/post instruction and 1 week) | Verbal and written instruction<br>Group 1: verbal, written and video (expert) feedback<br>Group 2: verbal, written and video (self) feedback<br>Group 3: verbal, written and combination video (expert and self) feedback<br>Group 4: control<br>Given by researchers | Peak knee flexion angle<br>Peak anterior knee joint reaction force and peak VGRF | Increased peak knee flexion angle post instruction and 1 week all groups; greatest increase groups 2 and 3<br>Reduced peak VGRF all groups post instruction and one week; greatest reduction in groups 2 and 3 | 18/32 (56%)<br>High |
| Onate et al. (2001) | 63 (42♀ 21♂) non-elite college athletes<br>Mean age 20.57 ± 1.94 years | Double foot land (2x force plates)<br>Approach from maximal vertical jump<br>5x trials (pre/post instruction 2 min and one week) | Verbal and written instruction<br>Group 1: verbal, written and video (self) feedback<br>Group 2: Internal sensory experience<br>Group 3: Control<br>Group 4: Control (pre/post 1 week only)<br>Given by researchers | Peak VGRF | Reduced peak VGRF group 1 post instruction and one week | 17/32 (53%)<br>Medium |

| Study | Participants | Landing task | Landing instruction/feedback | Relevant outcome measures | Main findings | Quality score |
|---|---|---|---|---|---|---|
| Gervais (1997) | 10 novice gymnasts<br>Mean age 8.4 ± 1.5 years | Double foot land (concrete floor)<br>Approach from jump over 29 cm box<br>1x trial (pre/post instruction 4 days) | Verbal instruction and verbal feedback over 4 days<br>Given by certified national coach | Peak ankle dorsiflexion and peak knee flexion angle (measured at participants lowest centre of gravity)<br>Peak average vertical force | No change peak ankle dorsiflexion angle or peak knee flexion angle<br>No change peak average vertical force | 16/32 (50%)<br>Medium |
| Mizner et al. (2008) | 37 ♀ collegiate athletes experienced in cutting and pivoting sports<br>Mean age 19.5 ± 1.2 years | Double foot drop land and vertical jump (2x force plates)<br>Drop from 31cm box<br>3x trials (pre/post instruction) | Verbal instruction and visual demonstration of poor and desired technique<br>Feedback (verbal and visual)<br>Given by researchers | Peak ankle dorsiflexion and peak knee flexion angle<br>Peak external dorsiflexion moment, peak external knee flexion moment, and peak VGRF | Increased peak knee flexion angle<br>Reduced peak VGRF | 15/32 (47%)<br>Medium |
| Prapavessis & McNair (1999) | 91 (35♀ 56♂) high school students (recreational or competitive athletes)<br>Mean age 16.07 ± 1.27 years | Double foot drop land (1x force plate)<br>Approach jump from 30cm box<br>1x trial (pre/post instruction) | Group 1: verbal instruction<br>Group 2: self-sensory feedback<br>Given by researchers | Peak VGRF | Reduced peak VGRF group 1 | 15/32 (47%)<br>Medium |

| Study | Participants | Landing task | Landing instruction/feedback | Relevant outcome measures | Main findings | Quality score |
|---|---|---|---|---|---|---|
| Cronin et al. (2008) | 15 ♀ elite volleyball players<br>Mean age 21.3 ± 2.4 years | Double foot stop land (one foot on 1x force plate)<br>Four step approach volleyball spike<br>5x trials (pre/post instruction) | Verbal instruction and visual demonstration<br>Verbal feedback<br>Given by coach | Peak APGRF, medio-lateral and VGRF | Reduced peak VGRF | 14/32 (44%)<br>Medium |
| Prapavessis et al. (2003) | 61 (41♀ 20♂) novice non-athletes<br>Mean age 9 ± 0.89 years | Double foot land (1x force plate)<br>Step from 30 cm box<br>4x trials (pre/post instruction days 1, 3, 5 & approx. 3 months) | Group 1: Verbal instruction<br>Group 2: control<br>Given by researchers | Peak VGRF | Reduced peak VGRF group 1 at day 1, day 3 and day 5 | 14/32 (44%)<br>Medium |
| Cowling et al. (2003) | 24 ♀ A-grade elite netball players<br>Mean age 21.8 ± 4.7 years | Dominant single leg land (1x force plate)<br>3 step approach run (catching ball)<br>10x trials 2x pre/2x post instruction same day | Verbal instructions x2 (1st kinematic instruction, 2nd muscular instruction)<br>Given by researchers | Peak knee flexion (sampled at peak resultant ground reaction forces)<br>Peak APGRF, medio-lateral and VGRF | Increased peak knee flexion angle 1st and 2nd instruction<br>Reduced peak APGRF and VGRF 1st instruction<br>Increased peak VGRF for 2nd instruction | 13/32 (41%)<br>Low |

| Study | Participants | Landing task | Landing instruction/feedback | Relevant outcome measures | Main findings | Quality score |
|---|---|---|---|---|---|---|
| Walsh et al. (2007) | 25 (12♀ 13♂) elite collegiate basketball players<br>Mean age 19.5 ± 1.2 years | Double foot drop land and vertical jump (1x force plate)<br>Drop from 30.5cm box<br>3x trials (pre/post instruction) | Group 1: verbal instruction<br>Group 2: control<br>Given by researchers | Peak right knee flexion angle<br>Peak VGRF | No change peak right knee flexion angle<br>Reduced peak VGRF group 1 (females only) | 13/32 41%<br>Low |
| McNair et al. (2000) | 80 (53♀ 27♂) recreational athletes not involved in jumping sports<br>Mean age 24 ± 7 years | Double foot drop land (1x force plate)<br>Step from 30 cm box<br>8x trials (pre/post instruction) | Group 1: verbal instruction<br>Group 2: self-assessment of sound on landing<br>Group 3: metaphoric imagery<br>Group 4: control<br>Given by researchers | Peak VGRF | Reduced peak VGRF groups 1 and 2 | 12/32 (38%)<br>Low |

*Note.* ♀ = female participants, ♂ = male participants, ± = standard deviation, APGRF = antero-posterior ground reaction forces, VGRF = vertical ground reaction forces, x = number of trials and number of force plates.

### *2.6.4 Effect of instruction on joint kinematics*

*Ankle*

Two studies reported on the effect of instruction and feedback on ankle joint angles during landing (Gervais, 1997; Mizner et al., 2008). Although McGrath (2009) assessed the relative ankle angles, these were converted to a mean absolute relative phase value as a measure of co-ordination and function of the neuromuscular system and were not a comparable measure as joint angles were not provided (McGrath, 2009). Gervais (1997) and Mizner et al. (2008) reported non-significant changes in peak dorsiflexion angle following instruction with one reporting an increase of 1° of dorsiflexion (Mizner et al., 2008) and the other reporting a reduction of 3° of dorsiflexion with dorsiflexion being measured at the point where the participants centre of gravity was lowest, not the peak angle (Gervais, 1997). These studies demonstrated that prior to instruction and feedback the mean ankle dorsiflexion angle during landing ranged from 22-29° and following instruction this ranged from 20-30° (Gervais, 1997; Mizner et al., 2008). From the limited research, evidence would suggest that instruction and feedback on landing technique has no effect on peak dorsiflexion angle.

*Knee*

Six of the studies reported on the effect of instruction (with or without feedback) on knee joint angles during landing (Cowling et al., 2003; Gervais, 1997; Herman et al., 2009; Mizner et al., 2008; Onate et al., 2005; Walsh et al., 2007). Consistently, all studies reported an increase in knee joint flexion following instruction and this was significant in four of the six studies (Cowling et al., 2003; Herman et al., 2009; Mizner et al., 2008; Onate et al., 2005). Of the studies which measured peak knee joint flexion during landing (Mizner et al., 2008; Onate et al., 2005; Walsh et al., 2007) as opposed to the angle at peak force or lowest centre of gravity (Cowling et al., 2003; Gervais, 1997; Herman et al., 2009), a significant increase in peak knee joint flexion angle ranged from 27-42° degrees (Onate et al., 2005) and 12° (Mizner et al., 2008) following instruction and feedback. These studies demonstrated that prior to instruction and feedback, the mean peak knee joint flexion angle during landing ranged from 55-86° and following instruction and feedback this ranged from 84-99° (Mizner et al., 2008; Onate et al., 2005). From the research it appears that instruction and feedback is able to influence sagittal knee kinematics and increase peak knee flexion angle during landing.

### *2.6.5 Effect of instruction on joint kinetics*

*Ankle*

There were no identified studies that reported on the effect of instruction (with or without feedback) on ankle joint reaction forces during landing. Only one study reported on the effect of instruction and feedback on ankle joint moments during landing (Mizner et al., 2008). The authors concluded that instruction and feedback during landing significantly reduced peak ankle external dorsiflexion moments (or peak ankle internal plantar flexion moments) where external moments are equal and opposite to internal moments (Mizner et al., 2008). They reported a reduction in average peak ankle dorsiflexion moment from 1.5 $Nmkg^{-1}$ to 1.38 $Nmkg^{-1}$. From only one study, the effect of instruction (with or without feedback) on ankle joint moments during landing is inconclusive.

*Knee*

Three studies investigated the effect of instruction (with or without feedback) on peak anterior knee joint reaction forces, which are often referred to as peak anterior tibial shear forces (Herman et al., 2009; McGrath, 2009; Onate et al., 2005). Within the literature, joint reaction forces as well as ground reaction forces are commonly expressed as a unit of body weight (BW) in order to make comparisons between study participants. Onate et al. (2005) reported no significant differences in peak anterior knee joint reaction forces following instruction and feedback in their study. Similarly, Herman et al. (2009) found no significant changes in peak anterior knee joint reaction forces during double foot landing across all participants in their study who received instruction and feedback. However, when they analysed their two groups separately and compared a group who had undergone a nine week strength training programme with a group who had not performed strength training, the strength training group significantly reduced their peak anterior knee joint reaction forces while the non-strength training group increased theirs. To add to this finding, McGrath (2009) examined a predominantly single foot land and reported no significant reduction in peak anterior knee joint reaction forces after a 20-25 minute fatigue protocol followed by instruction on landing. In the same study a control group, who received no instruction following a 20-25 minute fatigue protocol, demonstrated a significant increase in peak anterior knee joint reaction forces from 0.181 to 0.239 BW or a 32% increase. It appears that instruction (with or without feedback) has no effect on peak anterior knee joint reaction forces; however there is some evidence that instruction combined with feedback and strength training may reduce the detrimental increases in anterior knee joint reaction forces that occur with fatigue. Further research would need to confirm this postulation.

Three studies analysed the effect of instruction (with or without feedback) on knee joint moments during landing (Herman et al., 2009; McGrath, 2009; Mizner et al., 2008). Two studies which examined peak internal knee extension moments (or peak external knee flexion moments) concluded that instruction (with or without feedback) significantly reduced peak knee extension moments during landing (McGrath, 2009; Mizner et al., 2008). Mizner et al. (2008) normalised their data to body mass (kg) and demonstrated a significant reduction in peak knee extension moment from 1.85 $Nmkg^{-1}$ to 1.73 $Nmkg^{-1}$. McGrath (2009) normalised their data to body mass multiplied by height and found that instruction on landing was able to overcome the deleterious effects of fatigue and significantly reduce the knee extension moment from 0.142 Nm/kgm to 0.135 Nm/kgm. From the limited studies, there is some evidence that instruction (with or without feedback) may reduce peak knee extension moments during landing. Herman et al. (2009) assessed knee extension moments at the point of peak anterior tibial shear force and this may have accounted for their non-significant findings.

### *2.6.6 Effect of instruction on ground reaction forces*

*Antero-posterior*

Two studies reported on the effect of instruction (with or without feedback) on peak antero-posterior ground reaction forces (APGRF) during landing and differed in their conclusions (Cowling et al., 2003; Cronin et al., 2008). APGRF, also known as horizontal braking forces, are the forces required to decelerate and arrest forward motion. Cowling et al. (2003), who examined a group of elite netball players running forwards to catch a pass to land predominantly on their dominant limb reported a significant reduction in peak APGRF from 1.7 to 1.52 BW or an 11% reduction following instruction. On the other hand, Cronin et al. (2008) concluded there were no significant differences in peak APGRF during double foot landing from a “spike” following instruction and feedback in a group of elite volleyball players. The effect of instruction (with or without feedback) on peak APGRF remains contentious and warrants further investigation.

*Vertical*

VGRF are the upward forces acting on the foot when it comes into contact with the support surface. All 12 studies in the review determined the effect of instruction (with or without feedback) on peak VGRF during landing. Six of the studies assessed peak VGRF after landing on both feet from a 29-31cm box (Gervais, 1997; McNair et al., 2000; Mizner et al., 2008; Prapavessis & McNair, 1999; Prapavessis et al., 2003; Walsh et al., 2007); three assessed landing on both feet after a run up approach (Cronin et al., 2008; Herman et al., 2009; Onate et al., 2005); one assessed landing on both feet after a maximal vertical jump (Onate et al., 2001) and two assessed a single foot land after a sporting action such as jumping a hurdle (McGrath, 2009) or catching a ball (Cowling et al., 2003). All the studies, with the exception of one (Gervais, 1997), reported a significant reduction in peak VGRF during landing following instruction (with or without feedback). The percentage reduction in VGRF following instruction, when combining the significant results from all studies, ranged from 7% to 36% with a pooled mean of 19%. Prior to instruction, peak VGRF ranged from 1.61 to 5.61 BW. Following instruction the magnitude of peak VGRF ranged from 1.26-4.80 BW. The majority of the studies reported on combined results for males and females (McGrath, 2009; McNair et al., 2000; Onate et al., 2005; Onate et al., 2001; Prapavessis & McNair, 1999; Prapavessis et al., 2003; Walsh et al., 2007). One study separated their results by gender and interestingly determined that there was no significant reduction in peak VGRF during landing for males following instruction alone, however females significantly reduced theirs (Walsh et al., 2007). In summary, research supports the tenet that instruction (with or without feedback) on landing technique reduces peak VGRF during landing.

### *2.6.7 Summary: effect of instruction on lower limb kinematics and kinetics*

From the systematic literature review, laboratory studies have found that instruction (with or without feedback) on landing technique increases peak knee flexion angles and reduces peak VGRF. There is some evidence that instruction (with or without feedback) on landing technique does not alter peak ankle dorsiflexion angles but does reduce peak internal knee extension moments and plays a role, in conjunction with strength training, on limiting significant increases in peak anterior knee joint reaction forces. Further research needs to determine the effects of instruction (with or without feedback) on the kinetics of the ankle joint and APGRF during landing.

## 2.7 Reliability and validity of outcome measures

### *2.7.1 Kinematics*

Seven studies in the review assessed joint motion and of these, five assessed three-dimensional (3-D) joint kinematics (Cowling et al., 2003; Herman et al., 2009; McGrath, 2009; Mizner et al., 2008; Onate et al., 2005), while the remaining two studies used video cameras to view two dimensional (Walsh et al., 2007) and one dimensional (Gervais, 1997) motion. In a review of the reliability of assessing sagittal knee joint motion (Piriyaprasarth & Morris, 2007) it was concluded that 3-D motion analysis was preferred over two dimensional motion analysis due to high reliability ($r > 0.90$) and low standard error of measurement ($< 3.5°$).

Several studies have evaluated the test-retest reliability of 3-D motion analysis while performing a landing manoeuvre (Earl, Monteiro, & Snyder, 2007; Ford, Myer, & Hewett, 2007; Milner, Westlake, & Tate, 2011; Ortiz, Olson, Libby, Kwon, & Trudelle-Jackson, 2007). For both a stop jump task and a drop vertical jump involving landing on both feet, peak knee flexion angles were shown to have excellent within session reliability (Ford et al., 2007; Milner et al., 2011) and between session reliability (Earl et al., 2007; Milner et al., 2011) with an intra-class correlation coefficient (ICC) > 0.84. Ford et al. (2007) reported only fair to good knee flexion reliability (ICC = 0.62) between sessions but reported excellent reliability for peak ankle dorsiflexion angle within and between sessions (ICC > 0.92) during double foot landing. Assessment of unilateral landing during a single leg drop vertical jump also established excellent reliability (ICC > 0.75) within a session for peak knee flexion but this was only obtained when an average of five trials was taken (Ortiz et al., 2007). Movement of surface markers (Piriyaprasarth & Morris, 2007) and natural human variability (James, Herman, Dufek, & Bates, 2007) are noted as causes of measurement error during 3-D motion analysis. For this reason studies recommend taking the average of several trials rather than a single trial (Hunter, Marshall, & McNair, 2004; James et al., 2007; Ortiz et al., 2007; Piriyaprasarth & Morris, 2007). Furthermore, reliability is enhanced when the motion analysis system is carefully calibrated prior to each testing session (Ford et al., 2007; Piriyaprasarth & Morris, 2007) and only one tester applies the surface markers (Ford et al., 2007).

### *2.7.2 Kinetics*

Eleven studies in the review assessed kinetic variables and used a single force plate (Cowling et al., 2003; Cronin et al., 2008; McGrath, 2009; McNair et al., 2000; Prapavessis & McNair, 1999; Prapavessis et al., 2003; Walsh et al., 2007) or two force plates (Herman et al., 2009; Mizner et al., 2008; Onate et al., 2005; Onate et al., 2001) of varying makes to collect the data. The main kinetic outcome variable reported in these studies was peak VGRF. The test-retest reliability of peak VGRF during landing has been investigated in several studies (Cordova & Armstrong, 1996; Harman, Rosenstein, Frykman, & Rosenstein, 1990; James et al., 2007; Milner et al., 2011; Ortiz et al., 2007; Prapavessis & McNair, 1999). For a double foot land, excellent within session reliability was reported (ICC > 0.82) (James et al., 2007; Prapavessis & McNair, 1999) (Chronbachs alpha 0.98) (Harman et al., 1990). Milner et al. (2011) reported only fair to good within session reliability (ICC = 0.63) but noted an excellent between session reliability (ICC = 0.96). For a single leg land, peak VGRF were reported to have excellent reliability (ICC > 0.86) (Cordova & Armstrong, 1996; Ortiz et al., 2007), however, Ortiz et al. (2007) reported excellent reliability only when three or more trials were measured.

The test-retest reliability of joint moments during landing has been discussed in two studies (Ford et al., 2007; Milner et al., 2011). Ford et al. (2007) and Milner et al. (2011) reported excellent within and between session reliability for peak knee extension moments (ICC > 0.84). Furthermore, Ford et al. (2007) reported excellent (ICC > 0.83) peak ankle plantar flexion moment reliability within and between sessions.

### *2.7.3 Summary: the reliability and validity of outcome measures*

The research suggests excellent test–retest reliability for 3-D motion analysis during landing for particular biomechanical outcome measures (Cordova & Armstrong, 1996; Earl et al., 2007; Ford et al., 2007; Harman et al., 1990; James et al., 2007; Milner et al., 2011; Ortiz et al., 2007; Prapavessis & McNair, 1999). These include peak knee flexion angles, peak VGRF and peak knee extension moments. Although initial reports of peak ankle dorsiflexion angles and peak plantar flexion moments indicate that these may also be reliable measures; evidence is lacking to draw firm conclusions. No studies appeared to assess the validity of 3-D motion analysis during landing tasks however the construct and face validity appear to be good.

### 2.8 Biomechanics of netball players

The following sections discuss landing biomechanics specific to netball players. Although all identified studies were conducted in a laboratory (Cowling et al., 2003; Neal & Sydney-Smith, 1992; Otago, 2004; Steele & Milburn, 1987a, 1987b, 1988a, 1988b, 1989), all used a running approach to assess landing mechanics as opposed to a drop vertical jump or drop land from a box which are accepted forms of assessing landing mechanics in many other biomechanical studies (Carson & Ford, 2011). The majority of the literature on landing biomechanics of netball players has focused on 1-2 foot landing and few studies have investigated the double foot land.

#### *2.8.1 Joint kinematics in netball players*

Ankle and knee kinematics of netball players have not been widely researched. One study established the average sagittal ankle angle at initial contact of a 1-2 foot land in 21 netball players wearing footwear was 123° (SD = 8°) where angles greater than 90° represented ankle plantar flexion (Steele & Milburn, 1987b). The authors conceded a wide range of values were noted in this study and felt there was no consistent pattern demonstrated at the initial contact of landing.

One study reported the average sagittal knee angle at initial contact during landing was 15° (SD = 4°) of flexion (Steele & Milburn, 1987b). A further study noted the average sagittal knee angle at initial contact during landing in 24 netball players was 9° (SD = 4°) of flexion and the sagittal knee angle at peak force during landing was 14° (SD = 4°) of flexion (Cowling et al., 2003). Although both of these studies analysed a unilateral landing style, the two studies differed in the approach to landing and the motion analysis system used to collect the data. Participants in the first study had to run forwards and break away from a defender to catch a ball and were analysed using two video cameras while participants in the second study ran forward three paces to catch ball and were analysed by 3-D motion analysis.

#### *2.8.2 Joint kinetics in netball players*

To date, there appears to be limited research on the joint reaction forces and the joint moments of the ankle and knee in netball players. One study identified 22 participants, not specifically netball players, with an average age of 30 years, predominantly male, completing a netball manoeuvre where they ran forwards three paces to catch a netball landing 1-2 foot (Steele & Brown, 1999). These participants were a mixture of controls and ACL deficient participants who experienced knee instability, defined by a Lysholm knee score < 84, in their normal daily activities. The average normalised tibiofemoral joint forces (anterior knee joint reaction forces) for the dominant and non-dominant limbs of the healthy 11 controls during landing were 0.43 (SD = 0.68) and 0.27 (SD = 0.33) BW at initial contact, 2.17 (SD = 0.54) and 2.39 (SD = 0.49) BW at peak force and at their peak during landing these were 3.40 (SD = 1.12) and 3.97 (SD =1.37) BW.

### *2.8.3 Ground reaction forces in netball players*

The APGRF of netball players during landing, due to abrupt deceleration, are much higher than those produced during running and are considered a potential causative factor for the high incidence of ankle and knee injuries in netball (Steele & Milburn, 1987a). Greater approach speed (Neal & Sydney-Smith, 1992) and landing on the non-dominant limb (Steele & Milburn, 1987a) were found to correlate with increased APGRF during landing in netball players. One study reported that APGRF were increased when landing from catching a chest pass rather than a high pass (Steele & Milburn, 1989). A later study found that a chest pass correlated with an increased approach speed and was the reason for greater APGRF rather than the type of pass (Neal & Sydney-Smith, 1992). The average peak APGRF for players landing primarily on one limb vary widely from 1.4 to 4.6 BW (Cowling et al., 2003; Neal & Sydney-Smith, 1992; Otago, 2004; Steele & Milburn, 1987a, 1989). The variation in average APGRF in studies investigating netball players may be attributed to methodological differences such as the type of netball manoeuvre being compared, the experience of netball players and the approach speed. One study reported average peak APGRF of 1.75 BW in netball players landing double foot (Otago, 2004).

Studies have found the VGRF of netball players during landing are much higher than those of runners (Steele, 1990; Steele & Milburn, 1987a). Factors that increase the VGRF of netball players during landing are a faster approach speed (Neal & Sydney-Smith, 1992), a chest pass compared to a high pass (Steele & Milburn, 1989), initial contact of the heel compared to the forefoot (Neal & Sydney-Smith, 1992; Steele & Milburn, 1989) and reduced ankle range of motion (Steele & Milburn, 1988b). Steele and Milburn (1987a) reported that there were no significant differences in VGRF between the dominant and non-dominant limb in a unilateral landing style. The average peak VGRF of netball players landing primarily on one limb range from 3.4 to 4.7 BW (Cowling et al., 2003; Neal & Sydney-Smith, 1992; Otago, 2004; Steele & Milburn, 1987a, 1988a). Average peak VGRF range from 4.5 to 5.4 BW when initial foot contact is made with the heel (Neal & Sydney-Smith, 1992; Steele & Milburn, 1989) whereas initial contact with the forefoot has an average peak VGRF range of 3.3 to 4.0 BW (Neal & Sydney-Smith, 1992; Steele & Milburn, 1989). One study reported average peak VGRF of 5.7 BW for netball players landing double foot (Otago, 2004).

### *2.8.4 Approach velocity*

A netball player is likely to have a different approach velocity when landing in a laboratory setting compared to a netball court. As approach velocity has a significant effect on ground reaction forces in netball players, two studies have reported the approach velocity of netball participants in a laboratory setting (Neal & Sydney-Smith, 1992; Otago, 2004). Netball players landing primarily on one limb have an average approach velocity ranging from 3.3 to 4.3 $ms^{-1}$, where a chest pass or run on landing produces greater velocities (Neal & Sydney-Smith, 1992; Otago, 2004). One study reported the average approach velocity of a double foot land is 3.3 $ms^{-1}$ (Otago, 2004).

### *2.8.5 Summary: biomechanics of netball players*

Netball players have been found to land with average peak APGRF ranging from 1 to 5 BW where approach speed and landing on the non-dominant limb may influence the magnitude of these forces. Furthermore, average peak VGRF range between 3 to 6 BW for double and 1-2 foot landing styles where approach velocity, the type of pass, footfall pattern and ankle range of motion during landing influence the magnitude of these forces. Research in a real time netball situation is difficult to undertake but laboratory research indicates that the approach velocity of netball players ranges between 3 to 5 $ms^{-1}$.

Little is known about peak ankle and knee joint sagittal angles of netball players during landing or peak ankle and knee joint reaction forces or moments during landing. Furthermore, although landing guidelines exist, the effects of instruction and feedback using the key principles from these guidelines to influence landing kinematics and kinetics of netball players is not known. One study has investigated the effect of instruction on biomechanical factors associated with landing in netball players, however, this was a small group of elite players with no control group to make comparisons (Cowling et al., 2003). There are no studies that determine the effects of instruction and feedback on the kinematics and kinetics of the ankle and knee as well as ground reaction forces during landing in young netball players. This forms the basis of the present study.

## 2.9 Study aim, objective and hypothesis

### *2.9.1 Study aim*

The aim of this preliminary study was to determine the effect of instruction and feedback (based on NetballSmart Netball New Zealand guidelines) on sagittal ankle and knee joint kinematics and kinetics during landing in female novice netball players.

### *2.9.2 Study objective*

The objective of this study was to carry out a laboratory based experiment using 3-D motion analysis and force platforms to measure sagittal ankle and knee joint motion, ankle and knee joint forces and moments as well as ground reaction forces for two common netball landing styles (double foot and 1-2 foot) at two time points (pre and post instruction). The results of the study will contribute to the existing literature examining the effects of instruction (with or without feedback) on landing technique and will provide data on the landing biomechanics of novice female netball players; a demographic which has been given little attention in the literature

### *2.9.3 Hypothesis*

The study hypothesis was based on biomechanical outcome variables linked to lower limb injury during landing, namely peak ankle and knee joint sagittal kinematics and peak VGRF. In addition, peak anterior and vertical joint reaction forces, peak sagittal plane moments at the knee and ankle and peak APGRF ground reaction forces were investigated due to little or conflicting evidence in the literature on the effect of instruction (with or without feedback) on landing technique relating to these kinetic variables.

The study hypothesised that instruction and feedback would alter lower limb kinematic and kinetic variables during landing in a group of female novice netball players.

# Chapter Three

## Research Design

### 3.1 Introduction

This section describes the processes that were used to answer the study hypothesis. Firstly, the study design is outlined followed by an explanation of the study participants. Secondly, the experimental procedures are explained, the methods used to collect and process the data and the biomechanical model are described in detail. Lastly, the outcome variables and statistical methods employed in the study are stated.

### 3.2 Methods

#### *3.2.1 Study design*

A repeated measures, experimental control study was used to investigate the effect of instruction and feedback on lower limb kinematics and kinetics during landing in female novice netball players. Participants were allocated to an instruction or control group. The instruction group received instruction and feedback, based on the key principles of the NetballSmart landing guidelines, on landing technique while the control group were guided by simple prompts to practice their normal landing. Motion analysis was evaluated at two time points; at baseline and again following instruction or landing practice. Two netball landing styles were evaluated; double foot landing and 1-2 foot landing.

The study was approved by the Auckland University of Technology Ethics Committee (AUTEC) (Refer to Appendix B for ethical approval letter). All participants gave informed, written and verbal assent to take part in the study and their parent or guardian provided informed, written and verbal consent for their child to participate.

#### *3.2.2 Study participants*

*Population*

The sample population was defined as: "Novice netball players". The term "novice" was defined as players aged 10-13 who were in their first two years of formal netball participation, following on from both the explorative (fun ferns) and learning (future ferns) categories of Netball New Zealand's player development guidelines (Netball New Zealand, 2012). They all attended a Ministry of Education registered intermediate school (age 10-13) on the North Shore, Auckland and within a seven kilometre radius of

AUT University, Akoranga campus. A priori power analysis with an alpha level of 0.05 and power of 0.8, which was based on two studies that examined the effect of instruction on VGRF in youth (Prapavessis & McNair, 1999; Prapavessis et al., 2003), determined that a sample size of nine or 24 participants would be required to detect a significant change. Taking into account the effect sizes amongst the remaining variables; a sample size of 20 for both the instruction and control groups was deemed appropriate for this study.

Nine intermediate schools, with a sample population of 603 novice netball players, were initially selected based on the defined population. Netball North Harbour was contacted to determine which of these schools would be appropriate to participate in the study, based on the following inclusion and exclusion criteria. In particular, schools that had received prior coaching on landing technique were not considered. As a result, four schools were approached to be part of the study.

Inclusion criteria:

- Healthy, female netball player aged 10-13 years.
- Able to comprehend and speak English.

Exclusion criteria:

- Previous knowledge or coaching on landing technique in netball.
- Visual, auditory, cognitive or balance deficits.
- Unable to play a game of netball in the last 6 months due to injury or illness including but not limited to: musculoskeletal injury to the foot, ankle, knee, hip, shoulder, elbow, wrist; cardiovascular or respiratory illness or surgery.

#### *Recruitment*

The netball co-ordinator at each school was contacted and a meeting arranged to discuss the study aims and objectives, as well as the procedures involved. Co-ordinators were provided with an advertisement and information sheets about the study (refer to Appendix C for school advertisement poster). Upon agreement to participate, a further meeting was held with netball players at each school to explain the purpose and procedures of the study. Interested participants were provided with an information sheet for themselves and their parent or guardian to take home and read (refer to Appendix D and E for the participant information sheet and parent/guardian information sheet). Parents or guardians were contacted by telephone to discuss the study and answer any questions. Upon verbal consent from the parent or guardian for their child to participate, a screening questionnaire was completed over the telephone to determine the eligibility of a participant to be part of the study (refer to Appendix F for participant screening questionnaire).

Once an appointment was made, an appointment confirmation sheet with further details of what they were required to bring to the laboratory was emailed or posted to prospective participants (refer to Appendix G for participant appointment details sheet). A further reminder text message or phone call was made on the day prior to their appointment to confirm their attendance.

Of the 71 participants who volunteered, 39 completed the motion analysis session. Participants were screened (see Appendix F: participant screening questionnaire) and participant assent and parental or guardian consent was obtained in written and verbal form prior to data collection (Refer to Appendix H and I for participant assent form and parent/guardian consent form). A summary of the process of accepting volunteers in the study and group allocation is shown in Figure 3.1.

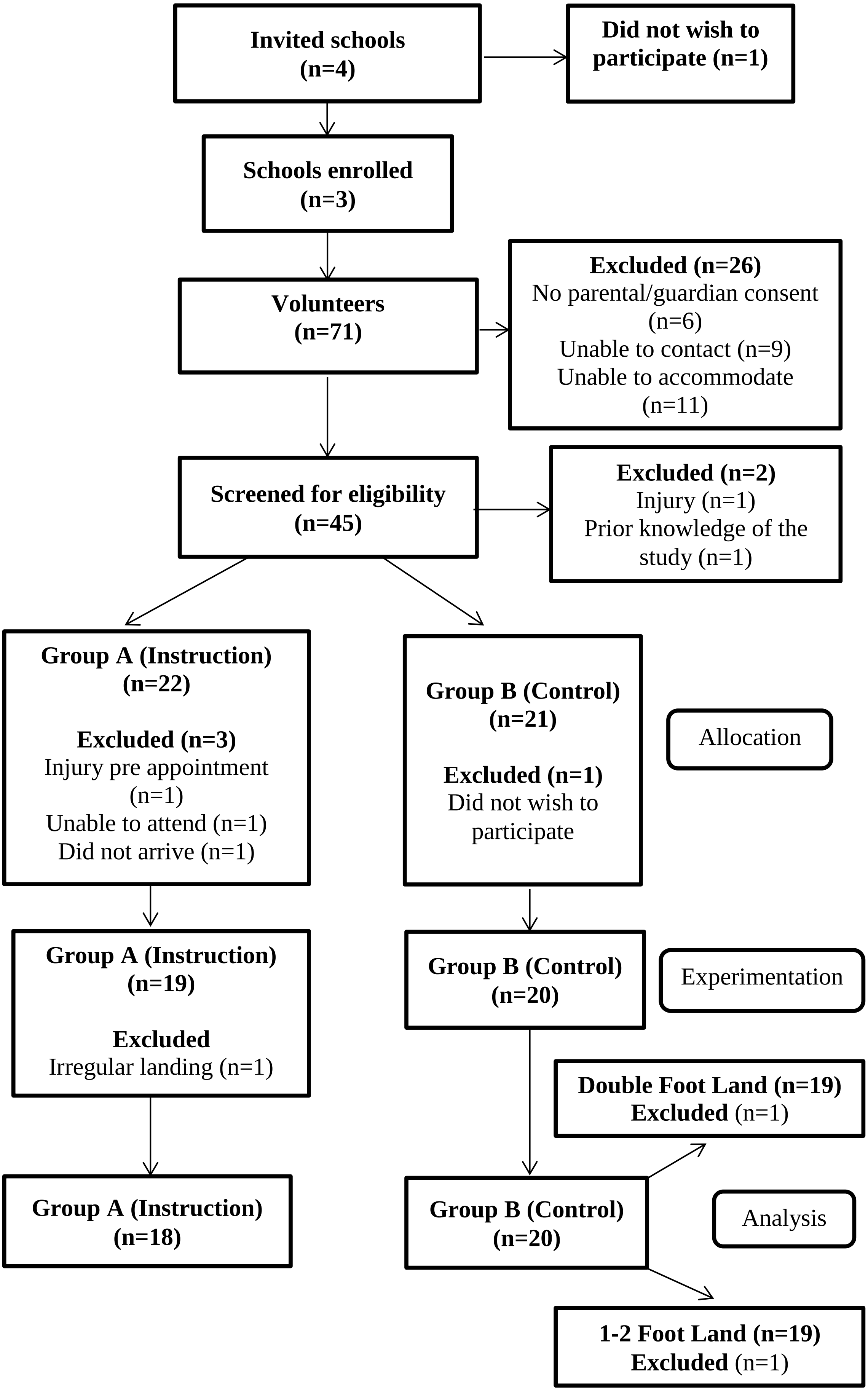



*Figure 3.1:* Flow diagram of participants through the study.

### *3.2.3 Experimental procedures*

Participants were allocated to an instruction or control group, according to the school they attended. Allocation of participants based on school, rather than randomisation was used due to the possibility of participants discussing the study which could potentially influence the results. Participants attended a 1.5 hour laboratory session which examined two landing styles; double foot and 1-2 foot, as they ran forwards to catch a netball at chest height. They wore their normal netball footwear throughout the laboratory session, or were provided with a pair of training shoes if they had forgotten their own. Data was collected at baseline and again following either instruction and feedback (instruction group) or landing practice (control group). The instruction group received verbal instructions on landing technique, followed by demonstration of good and bad examples of landing and the repetition of key words. Subsequently, verbal and visual feedback was also provided. The instructions and feedback were key principles based on a selection of recommendations outlined in the NetballSmart for Coaches handbook (NetballSmart, 2007).

*Preparation*

Preparation of each participant took approximately 45 minutes and consisted of a warm-up session, the placement of 42 light-weight, retro-reflective markers on specific anatomical landmarks and a static motion capture.

Each participant completed a 10 minute warm-up on a cycle ergometer set on a light resistance of 60-90 W and they were required to cycle at 60 revolutions per minute. They then completed a series of 10 dynamic stretches for each of the major muscle groups of the trunk, lower limbs and upper limbs, following demonstration from the researcher.

Participants were measured for height in bare feet and their shoe type was recorded. Markers were attached to the skin with double-sided tape and were secured with strips of fixamull® and rigid 38mm strapping tape to minimise marker movement. During the placement of markers, any reflective areas of footwear or clothing were covered, loose areas of clothing taped securely and hair tied back to ensure all markers were clearly visible to motion analysis cameras.

Prior to performing landing tasks, a six second "static" capture was completed which identified all 42 markers on each participant. This involved participants stepping forward onto a force plate with their arms out to the side and standing still until instructed to move. The medial femoral condyle and medial malleoli markers were then removed so as not to interfere with the dynamic landing tasks.

*Task familiarisation*

According to a standardised script (refer to Appendix J for research testing: baseline script) the researcher discussed and demonstrated the double foot and 1-2 foot landing styles with each participant, as well as the landing task of running forwards to catch a netball. Participants were able to familiarise themselves with the landing styles and landing task in the laboratory environment prior to data collection. A double foot landing involved contacting the floor with both feet at the same time and a 1-2 foot landing involved landing on one foot then bringing the other foot down to meet it.

The landing task involved running forwards from a marked area which was three metres behind the landing zone and catching a netball which was passed to the participant’s chest height by the researcher standing two metres in front of the landing zone. The researcher was an experienced netball player of 20 years who was able to deliver a pass to the sternal area of the participant. Participants were guided to land on two adjacent force plates in the landing zone with their feet on separate force plates, that is, the left foot on force plate one and their right foot on force plate two. White taped lines marked the anterior aspect of the plates and the median aspect between the plates. The white line at the anterior aspect of the plates was described to participants as a “transverse line”. A transverse line is the term used in netball to describe the lines which separate the three sections of a netball court and is used to define the areas where a player, according to their position, may move (International Federation of Netball, 2008). Participants were asked to run forwards to catch a netball and land in front of the transverse line, as if in a netball game, and make sure they did not go into an “offside” area. This sought to replicate a functional netball task ensuring that participants landed on the force plates embedded into the ground without being aware or distracted by their presence. This was an important aspect of the study in order to simulate the natural landing style of each participant despite being in the unfamiliar laboratory environment.

Participants practiced the double foot landing first, followed by the 1-2 foot landing. Both the researcher and research assistant observed the participant for their dominant take off leg prior to landing. In most instances, a participant would self-select a dominant take-off limb. In the case where they took off from either leg with no discernible dominant limb, the participant was asked to make sure they stepped forward off the same leg each time they started their run-up. If a participant could not consistently land squarely on the force plates, or if they appeared to alter their step length as they approached the landing zone, they were asked to start their run-up either slightly forward or backwards from the three metre mark, ensuring they were within 2.5-3.5 m with their run-up. Data collection commenced once participants felt comfortable to proceed. The research assistant recorded the number of practice lands for each type of landing.

*Baseline measures*

Participants were asked to run forwards quickly as if on a netball court and catch a ball being passed in front of them, landing either double or 1-2 foot. The order of landing was randomised with a coin toss where heads represented a double foot land and tails represented a 1-2 foot land. The researcher advised the participant when to start their run-up and the research assistant commenced capturing the land, over eight seconds, by pressing an external trigger. Following landing, the participant was asked to stand with their arms forward and remain stationary once in the upright position to ensure that no markers were obscured by the ball. Once the land was captured, they were asked to walk back to the start, in preparation for further lands. Four lands which met the criteria for an appropriate land (see below) were recorded for each landing style. The number of landing attempts for each landing style was recorded.

The criteria for an appropriate land were:

- The correct type of landing was demonstrated. During a double foot land there were four frames or less difference between each foot touching the corresponding force plate (equivalent to $<$ 0.033 s difference). A 1-2 foot land was greater than four frames difference between each foot.
- Each foot was contained within the corresponding force plate. If a shoe was touching the force plate border, the capture was not accepted.
- The landing and catching of the netball was controlled such that the participant did not over balance, fall or drop the ball.
- The take-off limb was consistent with the established dominant take-off limb during task familiarisation.

*Intervention*

Participants were blinded to whether they received landing instruction or not. The instruction group, according to a script (refer to Appendix K for intervention script group A), received three simple verbal instructions to incorporate during landing. These included “bend at your hips and knees as if sitting on a chair”, “knees in line with toes but not in front of toes” and “land softly”. The NetballSmart guidelines on landing include eight or nine instructions for both the double foot and 1-2 foot landing styles respectively. The instructions used in the study were derived from the NetballSmart guidelines but modified and simplified to incorporate only three key components that have previously been identified from coaches (Gianotti, Hume, & Tunstall, 2010). Prior to participants practicing landing, the researcher demonstrated good and bad examples of landing and repeated keywords from the previous verbal instructions. After a single instruction, participants were able to practice the particular component of landing until they felt comfortable to receive the next instruction. Following the third instruction they were able to practice all three components together as they landed. The researcher provided feedback throughout the instruction period by affirming when they had incorporated the instruction well using words such as “Good”, “Great”, “Excellent”, “Perfect”, “Spot on” and “Nice”. If the participant did not appear to be incorporating the instruction, the researcher repeated the necessary key words, that is, “Bend at your hips”, “Bend at your knees”, “Knees in line with toes not in front of toes” or “Softly”. The instruction period was approximately 20 minutes in duration. Again, the order of landing was randomised and the total number of practice landings was recorded for each instruction and each landing style.

The control group (refer to Appendix L for intervention script group B) were advised that they would have an opportunity to practice both types of landing for 20 landings each over 20 minutes. They were effectively practicing normal landings without any instruction and no verbal or visual feedback was provided on landing technique. The order of landing was again randomised. Participants were given positive words of affirmation when they completed an appropriate land as identified in baseline testing. Words included “Awesome”, “Cool”, “Lovely”, “Fine”, “Looking natural”, “Perfect”, “Nice”, “Great”, “Beautiful”.

*Post instruction measures*

Participants were asked to incorporate the movements they had practiced and the same testing procedures as the baseline measures were adopted, that is, four appropriate eight second captures were recorded for each type of landing. In order to fit with a coaching scenario, those in the instruction group were given specific feedback, using the key words previously identified, after each landing. The control group, however, received no specific feedback except for positive words of affirmation when an appropriate land was completed.

### *3.2.4 Data collection methods*

The experiment was conducted in the motion analysis laboratory at the Health and Rehabilitation Research Institute (HRRI) AUT University. Nine motion analysis cameras (Qualysis Medical AB Sweden, MCU 1000 ProReflex TM) positioned concentrically around the room were used to detect movement (refer to Figure 3.2 for a coronal view of the motion analysis laboratory). Two Advanced Medical Technology Incorporated (AMTI) force plates embedded into the wooden floor of the laboratory were used to measure 3-D ground reaction forces. Movement and force data were synchronised and integrated to assess 3-D kinematics and kinetics using Qualysis track manager software (Qualysis Medical, AB Sweden).

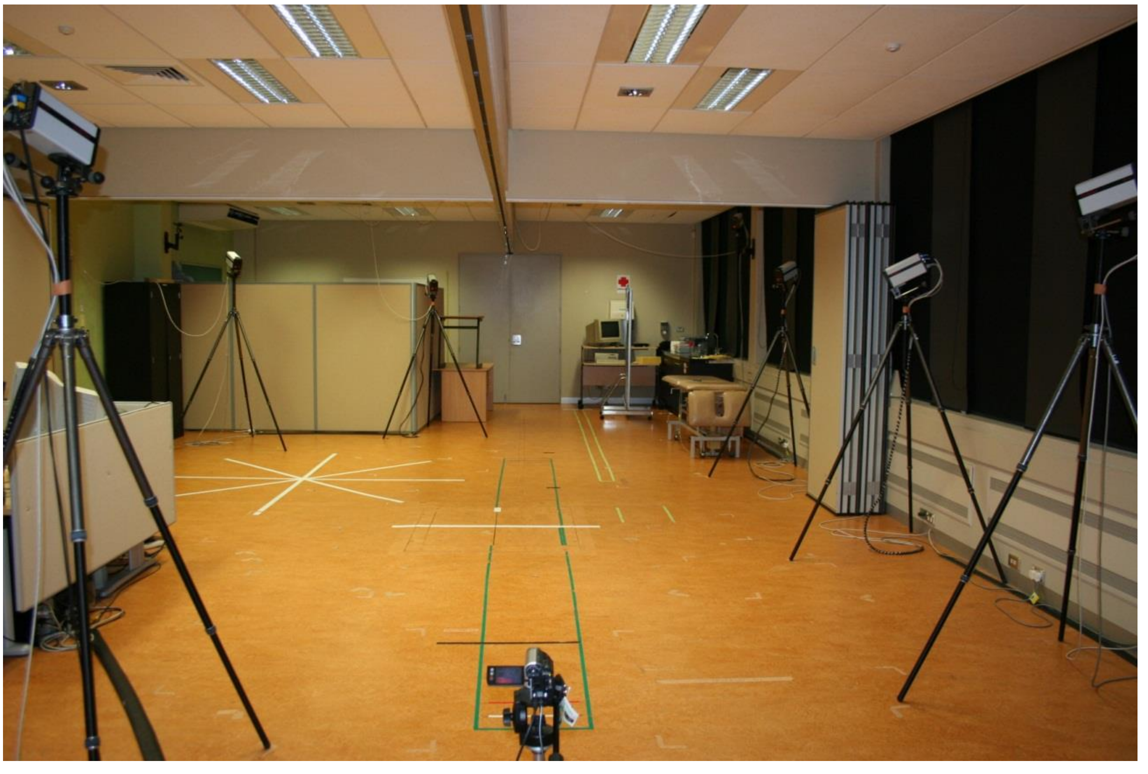


*Figure 3.2:* Coronal view of the HRRI Motion Analysis Laboratory.

*Kinematics*

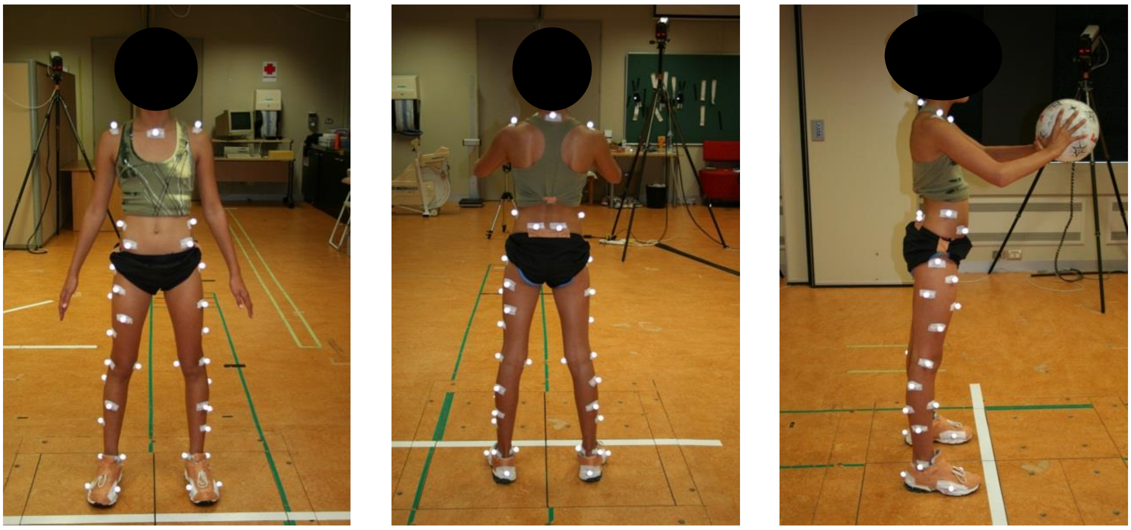
The motion analysis system was calibrated at the start of each testing session according to the manufacturer's recommendations. This included a 30 second calibration using a dynamic calibration wand which was rotated above a stationary calibration frame placed on the floor in the landing zone, which defined the X and Y axes of the laboratory. The average resolution of each of the nine motion analysis cameras which were orientated towards the landing zone was calculated and residuals of less than 0.6 mm were deemed acceptable. If any camera had a residual greater than 0.6 mm a repeat calibration was performed. The calibrated capture volume area approximated 2 $m^3$ and was concentrated on the landing zone to ensure that participants could clearly be seen during take-off and landing. Prior to commencing motion analysis, the researcher, a trained physiotherapist with experience in musculoskeletal palpation, attached 42 light-weight, 19 mm diameter retro-reflective markers with adhesive tape to the apex of specific bony landmarks and the thighs and shanks of each participant (refer to Table 3.1 and Figures 3.3a, 3.3b and 3.3c for the location of markers). The markers overlying a bony landmark provided the proximal and distal references for bony segments. The cluster markers or reference markers were positioned according to recommendations by Cappozzo, Cappello, Della Croce and Pensalfini (1997) who suggest a minimum of four markers are positioned away from bony landmarks and areas of strong muscle contraction. The 3-D co-ordinates of each of the markers were detected by motion analysis cameras sampling at a frequency of 120 Hz. Two Sony 40x optical zoom video cameras were positioned in the sagittal and coronal planes facing the landing zone. These images were used as a visual check to ensure participants had landed on the force plates.

Table 3.1

*Anatomical Landmarks of Retro-reflective Markers*

| **Trunk** | **Pelvis** | **Thigh** | **Shank** | **Foot** |
|---|---|---|---|---|
| -Acromion (2)<br>-Spinous process 7th cervical vertebrae<br>-Suprasternal notch | -Iliac crests (2)<br>-Posterior superior iliac spines (2)<br>-Anterior superior iliac spines (2) | -Greater trochanters (2)<br>-Medial femoral condyles (2)<br>-Lateral femoral condyles (2)<br>-4x cluster markers (2) | -Medial malleoli (2)<br>-Lateral malleoli (2)<br>-4x cluster markers (2) | -Calcaneum (2)<br>-Head of 1st metatarsal (2)<br>-Head of 5th metatarsal (2) |

*Note.* Number in brackets (2) refers to the marker or cluster marker set being used on the left and right side of body.



a) b) c)

*Figures 3.3:* a) Anterior, b) Posterior and c) Sagittal views of marker placement.

*Kinetics*

Two 45x50 cm AMTI force plates collecting at 1200 Hz were orientated such that force plate one and force plate two were adjacent and perpendicular to the run up of a participant (refer to Figure 3.4). The force plates were identified within the global reference system of the motion cameras using four stationary retro-reflective markers placed on the corners of each force plate. The force plates were zeroed prior to each calibration.

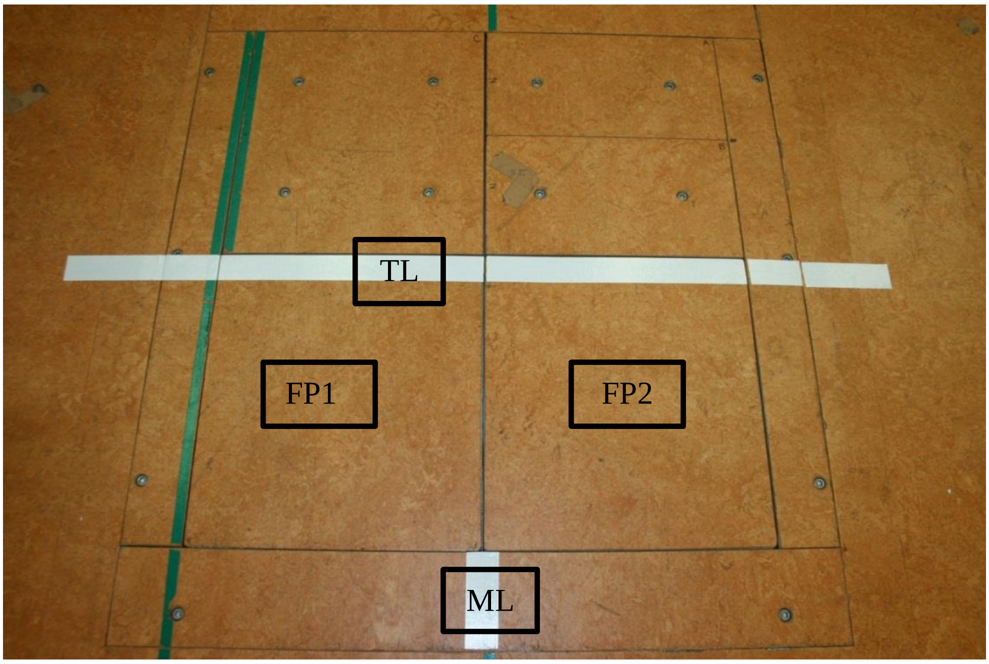



*Figure 3.4:* Force plate orientation in the laboratory. The white lines are the horizontal line representing the "transverse" line (TL) and the median line (ML) guiding the landing position of participants. The left square plate represents force plate one (FP1) and the right square plate represents force plate two (FP2).

#### *3.2.5 Data processing*

*Overview*

Raw motion data was tracked using Qualysis track manager software and exported in a format (C3D) to enable its recognition in Visual 3D, a commercial biomechanical analysis software programme (Visual 3D, C-Motion Inc, USA). In Visual 3D the C3D files were loaded, event marked, smoothed and outcome variables calculated. The outcome variables were exported as American Standard Code for Information Interchange (ASCII) text files to enable their recognition in Microsoft Excel. Within Excel, the participants' results were collated by region and the outcome variables of interest. Mean and standard deviation values for three landings were calculated for both the double foot and 1-2 foot landing styles for each participant at baseline and following landing instruction and feedback (instruction group) or practice (control group).

*Qualysis track manager*

All captured landings were assessed to ensure they met the criteria for an appropriate land, as described previously, and the mass of each participant was determined from their static trial while standing on a single force plate. Each appropriate landing was assessed for peak anterior velocity of the right anterior superior iliac spine marker ($mmsec^{-1}$) at take-off. Three landings that had a take-off velocity within 10% of each other were selected for data tracking for both the double foot and 1-2 foot landing styles.

The 42 markers were individually identified from the six second static capture and labelled according to the appropriate bony landmark or reference marker they represented to create an automatic identification of markers (AIM) or "static AIM model". The static AIM model was then applied to a dynamic landing capture and in the instance that a marker was not identified throughout the landing; the appropriate corresponding marker was selected and applied. If a marker was less than 100% identified during a landing, the marker trajectory gap was filled by applying the predicted line of best fit. A "dynamic AIM model" was then generated and applied to each of the subsequent landings and markers were identified accordingly. This was repeated for all the double foot and 1-2 foot landings, at baseline and following instruction or landing practice. Each file, with all markers identified and labelled, was saved and exported as a C3D file.

*Visual 3D*

All C3D files and the relevant static AIM model assigned to it were loaded into Visual 3D. The mass and height of each participant was recorded and the events of interest within a land were defined. The events for each participant included the take-off, landing on force plate one, landing on force plate two and the completion of the land, each corresponding to a single frame. Data was smoothed using a second-order Butterworth bidirectional low-pass filter to reduce noise (e.g., movement and vibration artefacts). The kinematic data was smoothed at 6 Hz and the kinetic data at 15 Hz. A pipeline was applied which provided the data for the outcome variables of interest and the output files were exported to Excel as ASCII files for subsequent statistical analysis.

### *3.2.6 Biomechanical modelling*

The static AIM model which identified all 42 markers, including four cluster marker sets on each thigh and shank, provided the reference marker set to create a biomechanical skeletal model for each participant in Visual 3D. Cluster marker sets were used to provide a reference system for the local joint co-ordinates and enhance the predicted position of each joint, with its six degrees of freedom, at a particular point in time (Cappozzo et al., 1997). Due to the markers of the foot being adhered to the shoes of participants overlying the bony landmarks and not precisely on the skin, a virtual marker set was created for each foot. The virtual marker set aimed to negate the movement artefacts created by motion of the shoe during landing and model the foot as a rigid segment (Okita, Meyers, Challis, & Sharkey, 2009). The link segment model described by Winter (2009) and the modelling approach used by Hanavan (1964) provided the basis for the creation of an eight segment geometric skeletal model of the trunk, pelvis, thighs, shanks and feet (refer to Figure 3.5). The model was scaled according to the anthropometry of each participant using their height and mass. Dempster's (1955) data were used to estimate mass, centre of mass (COM) and moment of inertia of each segment. Proximal and distal markers defined each segment and the joint centres for the ankle and knee were determined by the midpoint of these markers (refer to Table 3.2). For this study, although the trunk and pelvis were modelled, kinematic and kinetic data was restricted to the thigh, shank and foot segments. The kinematics and kinetics for each participant were calculated using inverse dynamics in Visual 3D. (Refer to Figures 3.6a and 3.6b for the double foot land and corresponding biomechanical model in Visual 3D and Figures 3.7a and 3.7b for a 1-2 foot land).

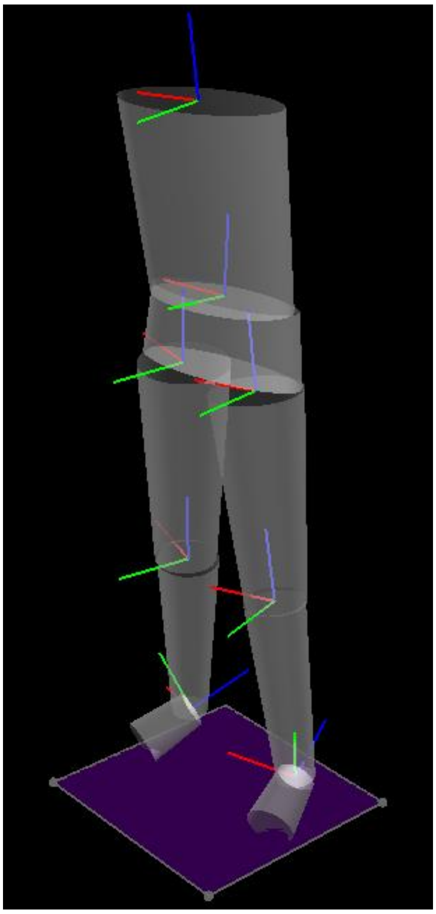


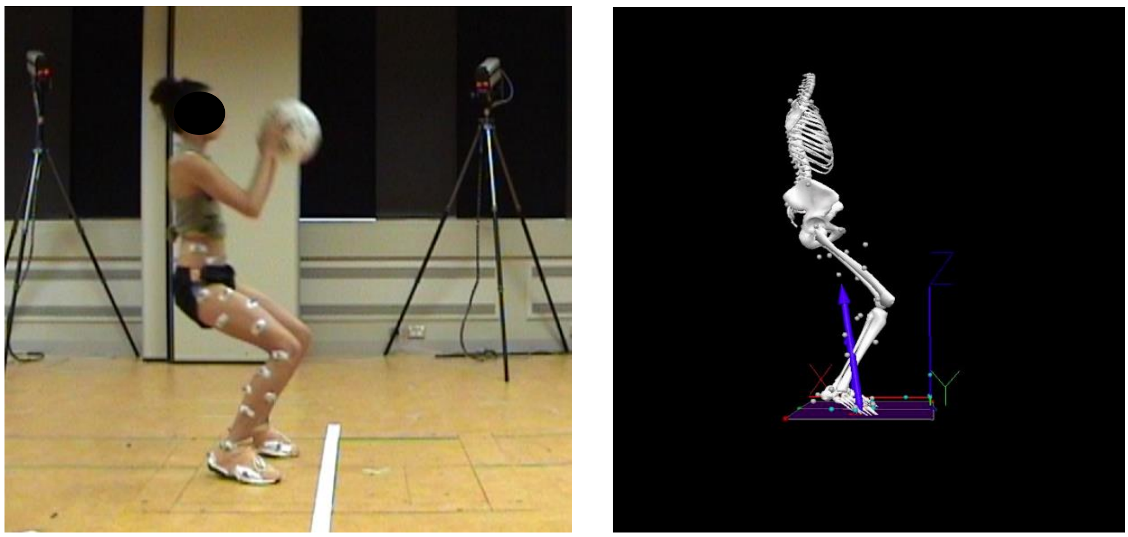
*Figure 3.5:* Diagram of the eight segment geometric skeletal model in Visual 3D.

Table 3.2

*Description of Markers Defining Geometric Segments*

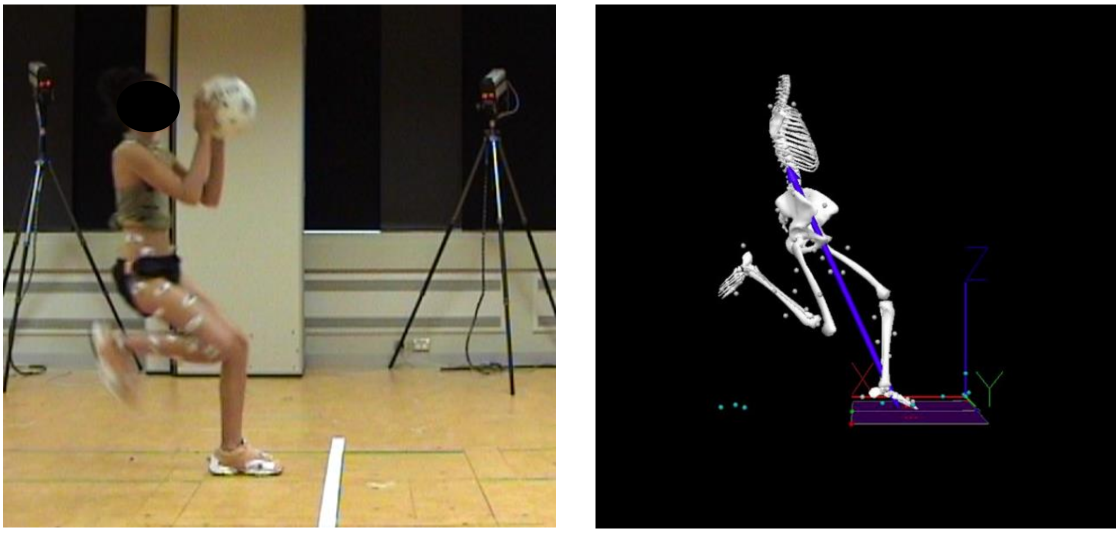
| **Segment** | **Thigh** | **Shank** | **Foot** |
|---|---|---|---|
| **Proximal markers** | Greater trochanters | Medial and lateral femoral condyles knee | Medial and lateral malleoli ankle |
| **Distal markers** | Medial and lateral femoral condyles knee | Medial and lateral malleoli ankle | Calcanei, first and fifth metatarsal heads |
| **Proximal joint centre** | ¼ distance of hip width from greater trochanter | Mid-point of medial and lateral femoral condyles knee | Mid-point of medial and lateral malleoli ankle |
| **Distal joint centre** | Mid-point of medial and lateral femoral condyles knee | Mid-point of medial and lateral malleoli ankle | N/A |

*Note.* N/A = not applicable



a) b)

*Figures 3.6.* Double Foot Land a) Laboratory b) Visual 3D model




a) b)

*Figures 3.7.* 1-2 Foot Land a) Laboratory b) Visual 3D model

***3.2.7 Axis orientation***

*Global movement co-ordinate system*

Laboratory and force plate axes were orientated to align with the global movement co-ordinate system in Visual 3D. The global movement co-ordinate system was defined by three dimensional co-ordinates and was represented by three orthogonal axes: the anterior-posterior axis (X), the medial-lateral axis (Y) and the vertical axis (Z). The positive anterior axis (X) was in the opposite direction to the participant's run-up, the positive lateral axis (Y) was directed to the right of the participant and the positive vertical axis (Z) was directed upwards.

*Local movement co-ordinate system*

Localised joint co-ordinate systems were for the ankle and knee in Visual 3D and aligned to the recommendations of the International Society of Biomechanics Joint Co-ordinate System (Wu et al., 2002). The local co-ordinate axes were located at the proximal end of each segment and were defined by three orthogonal axes: the anterior-posterior axis (X), the vertical axis (Y) and the medial-lateral axis (Z). The positive anterior axis (X) was directed forward of the participant, the positive vertical axis (Y) was directed upwards and the positive lateral axis (Z) was directed to the right of the participant.

### *3.2.8 Outcome variables*

Twelve outcome variables were investigated in the study. These were based on known biomechanical factors linked to lower limb injury during landing as well as a selection of biomechanical factors with little or conflicting evidence in the literature on the effect of instruction (with or without feedback) on landing technique relating to these variables. Measures of joint reaction forces and muscle moments served as an indication of whether any changes in kinematics could be viewed as detrimental by increasing potentially hazardous loading to the joints. The elected outcome variables were considered an appropriate number based on the study aims and objectives of this preliminary study.

Event markers associated with landing were defined in Visual 3D in order to obtain points of reference to calculate the values for the outcome measures of interest. In order of occurrence, take-off (TOFF) represented the frame where the fifth metatarsal head of the take-off leg left the ground, left on (LON) represented the frame where the left leg initially contacted force plate one (defined by the onset of the vertical force vector), right on (RON) represented the frame where the right leg initially contacted force plate two (defined by the onset of the vertical force vector) and STAND represented the end of the land where the participant was upright and the anterior force vector approached zero. All outcome variables were calculated for each of the three double and 1-2 foot lands at baseline and following instruction or landing practice. Measurements for analysis were derived from the dominant landing limb; that is the limb that landed first for a 1-2 foot land which corresponded to the opposite limb from the take-off limb of each participant.

*Kinematics*

The kinematic outcome variables of interest were peak ankle angle during landing (dorsiflexion) in the sagittal plane (Z) and peak knee angle during landing (flexion) in the sagittal plane (Z). The peak angle between LON or RON (depending on the dominant leg of the participant) and STAND was calculated. For both of these angles the relative angle was measured by the motion of the distal segment with respect to the proximal segment and angles were determined by the Z axis of the local co-ordinate system.

*Kinetics*

The kinetic variables of interest were anterior and vertical ankle and knee joint reaction forces, the net internal ankle plantar flexion and knee extension joint moments in the sagittal plane and the APGRF and VGRF. Joint forces and moments were derived from axes of the local co-ordinate system while ground reaction forces were derived from the axes of the global co-ordinate system.

Peak anterior ankle and knee joint reaction forces were calculated as the maximum joint force in the anterior plane (X) between LON or RON (depending on the dominant leg of the participant) and STAND. Peak vertical ankle and knee joint reaction forces were calculated as the peak negative force in the vertical plane (Y) between LON or RON (depending on the dominant leg of the participant) and STAND.

Peak plantar flexion moment for the ankle was calculated as the peak negative moment in the sagittal plane (Z) between LON or RON (depending on the dominant leg of the participant), and STAND. Peak knee extension moment was calculated as the maximum moment in the sagittal plane (Z) between LON or RON (depending on the dominant leg of the participant) and STAND.

Peak APGRF were calculated as the maximum force in the anterior (X) plane between LON or RON (depending on the dominant leg of the participant) and STAND. Peak VGRF were calculated as the maximum force in the vertical (Z) plane between LON or RON (depending on the dominant leg of the participant) and STAND.

*Model centre of mass*

Peak approach velocity was calculated by determining the maximum horizontal velocity (X) of the model's COM between TOFF and STAND for each land. Peak vertical position was calculated by determining the maximum position of the model's COM in the vertical plane (Z) between TOFF and STAND.

### ***3.2.9 Statistical analysis***

All statistical analyses were undertaken using the statistical package for the social sciences (SPSS) (IBM SPSS Inc, Chicago) Version 19. An alpha level of $p$ less than or equal to 0.05 was set. The two within-subject independent variables were time and landing style. For time, baseline measures were denoted as "pre" and measures following instruction and feedback or landing practice were denoted as "post". For landing style, a double foot landing was denoted as a "2" and a 1-2 foot landing was denoted as a "1". The between-subjects independent variable was the assigned group, either instruction or control. The instruction group were denoted as group "A" and the control group were denoted as group "B". The dependent variables for this study have been outlined in the outcome measures previously described.

*Baseline demographics*

To compare the homogeneity of the instruction group and control group at baseline, descriptive statistics and independent sample t-tests were calculated for age, height, mass, body mass index and years playing netball.

*Dependent variables*

All dependent variables were assessed for normality using the Shapiro-Wilk test. Box and whisker plots were created to assess the data distribution and detect any outliers. In the instance of an outlier, raw data values from the three landings were scrutinised and any value that was not within 10% of the other two values was excluded. Outliers were assessed for significance using Grubbs' test.

A mixed model analysis of variance (ANOVA) was used to compare the two within subject factors of "land" and "time" and the between subjects factor "group". Initial analysis revealed a significant main effect for "land" for all dependent variables therefore it was decided to analyse landing styles independently using a 2x2 repeated measures ANOVA where the within subjects factor was "time" (pre and post) and the between subjects factor was "group" (instruction and control).

*Additional factors*

Peak approach velocity and peak vertical position of the model's COM were identified as potential factors that could influence the biomechanical outcome variables in the study. Paired sample t-tests were performed to determine the consistency of peak approach velocity and peak vertical position of the model's COM before landing for each participant prior to and following either instruction and feedback (instruction group) or landing practice (control group).

## Chapter Four

## Results

### 4.1 Overview

The results section is divided into three subsections. Firstly, the study participants for final analyses are described. Secondly, the results of statistical tests to determine the effect of instruction and feedback on lower limb kinematics and kinetics are reported. Lastly, additional factors that may influence the kinematic and kinetic results are highlighted.

### 4.2 Study participants

#### *4.2.1 Final analyses*

In total 38 participants (18 instruction group and 20 control group) completed the movement testing session and were included in the final analyses. One participant in the intervention group, who met the inclusion criteria for the study, had not played netball before. Although the full experimental procedure was undertaken with this participant, her results were excluded from the final analysis due to her data consistently presenting as significant outliers with box and whisker and Grubbs' statistical tests. As her landing mechanics were not comparable to the other participants, she was excluded from the final analysis.

For each landing style, 37 participants (18 intervention group and 19 control group) were included in the final analyses for the study. One participant in the control group was analysed for her double foot land only as she was unable to co-ordinate a 1-2 foot land in the laboratory. A further control group participant was analysed for her 1-2 foot land only as her double foot lands, by definition of more than four frames difference between landing legs, did not meet the criteria for an appropriate double foot land.

#### *4.2.2 Baseline demographics*

A comparison of baseline demographics revealed no significant differences between the instruction and control groups for age, height, mass, body mass index (BMI) or years of netball experience ($p > 0.05$). Table 4.1 summarises mean baseline demographics for the instruction and control groups.

Table 4.1

*Mean Baseline Demographics for Participants in the Study*

| **Group** | Instruction | Control | **Total** |
|---|---|---|---|
| Number | 18 | 20 | 38 |
| Age (years) | 11.89 (0.55) | 11.93 (0.58) | 11.91 (0.57) |
| Height (m) | 1.57 (0.06) | 1.54 (0.09) | 1.56 (0.07) |
| Mass (kg) | 49.1 (7.31) | 45.3 (10.79) | 47.2 (9.05) |
| BMI (kgm$^{2)}$ | 19.9 (2.54) | 18.9 (2.76) | 19.4 (2.65) |
| Experience (years) | 3.5 (1.42) | 4.05 (1.61) | 3.78 (1.51) |

*Note.* Standard deviations are in parentheses.

## 4.3 Effect of instruction and feedback on landing technique

### *4.3.1 Joint kinematics*

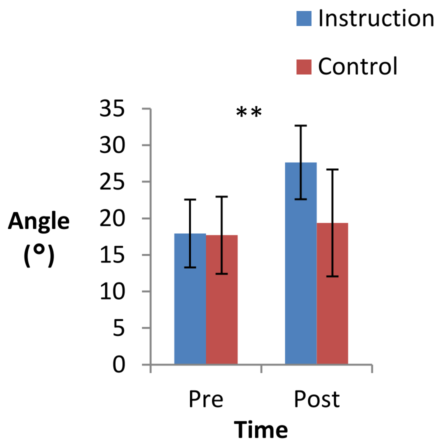
Kinematic results for the ankle and knee are summarised in a table, for each landing style, in Appendix M.

*Peak ankle dorsiflexion*

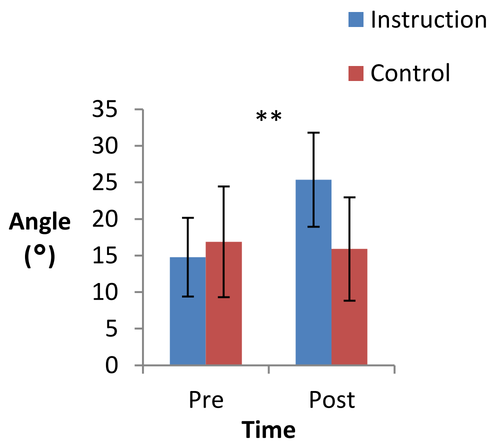
Instruction and feedback on landing technique significantly increased peak ankle dorsiflexion angle during landing for the double foot land and the 1-2 foot land (refer to Figures 4.1a and 4.1b). For the double foot land, the instruction group increased dorsiflexion by 10° (SD = 6) or 54% while the control group increased dorsiflexion by 2° (SD = 5). Significant main effects were found for group ($p = 0.014$) and time ($p < 0.001$) and a significant group x time interaction ($p < 0.001$) confirmed that the instruction and control groups responded differently following instruction and feedback or landing practice; the instruction group significantly increased their peak ankle dorsiflexion angle while the control group did not.

For the 1-2 foot land, the instruction group increased their dorsiflexion angle by 11° (SD = 7) or 72% while the control group reduced their dorsiflexion angle by 1° (SD =

5). Whilst there was a trend towards a significant main effect for group ($p = 0.064$), this was not statistically significant. There was, however, a significant main effect for time ($p < 0.001$) and a significant interaction for group x time ($p < 0.001$) indicating that the instruction and control groups responded differently following instruction and feedback or landing practice; the instruction group significantly increased their peak ankle dorsiflexion angle while the control group did not.




a)



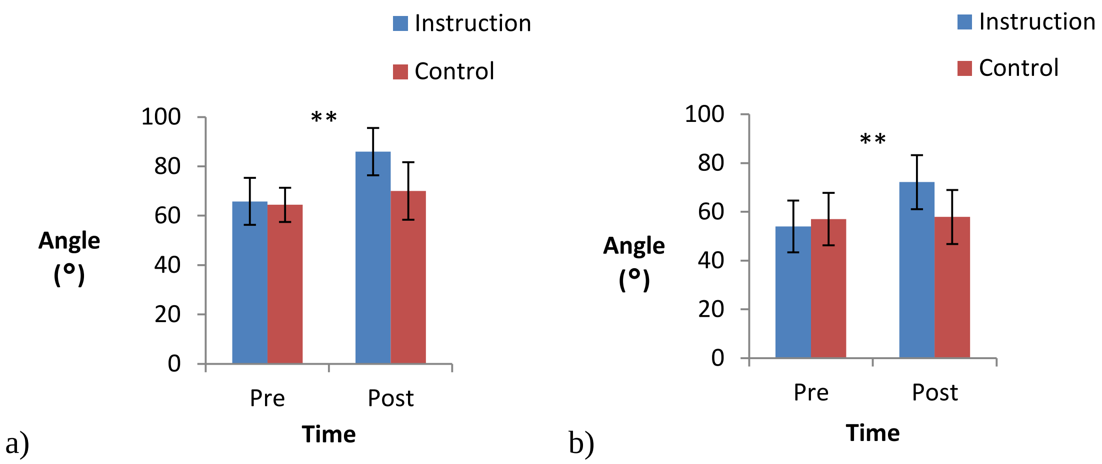

b)

*Figures 4.1.* Peak ankle dorsiflexion a) double foot land b) 1-2 foot land. The double asterisk (**) represents a signficant interaction $p < 0.001$. Error bars indicate SD.

*Peak knee flexion*

Instruction and feedback on landing technique significantly increased peak knee flexion angle during landing for the double foot land and the 1-2 foot land (refer to Figures 4.2a and 4.2b). For the double foot land, the instruction group increased knee flexion by 20° (SD = 9) or 31% while the control group increased knee flexion by 6° (SD = 6). Significant main effects were found for group ($p = 0.05$) and time ($p < 0.001$) and a significant group x time interaction ($p < 0.001$) verified that the instruction and control groups responded differently following instruction and feedback or landing practice; the instruction group significantly increased their peak knee flexion angle while the control group did not.

For the 1-2 foot land, the instruction group increased their knee flexion angle by 18° (SD = 14) or 34% while the control group increased their knee flexion angle by 1° (SD = 10). Whilst there was a trend towards a significant main effect for group ($p = 0.062$), this was not statistically significant. There was, however, a significant main effect for time ($p < 0.001$) and a significant interaction for group x time ($p < 0.001$) showing that the instruction and control groups responded differently following instruction and feedback or landing practice; the instruction group increased their peak knee flexion angle while the control group did not.




*Figures 4.2.* Peak knee flexion a) double foot land b) 1-2 foot land. The double asterisk (**) represents a signficant interaction $p < 0.001$. Error bars indicate SD.

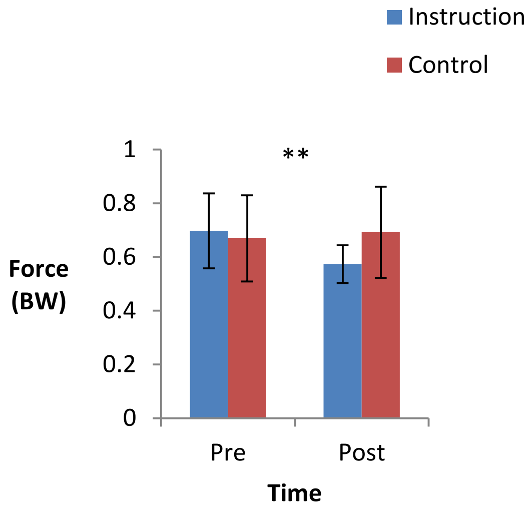
#### *4.3.2 Joint kinetics –reaction forces*

Results of joint reaction forces at the ankle and knee are summarised in a table for each landing style in Appendix N.

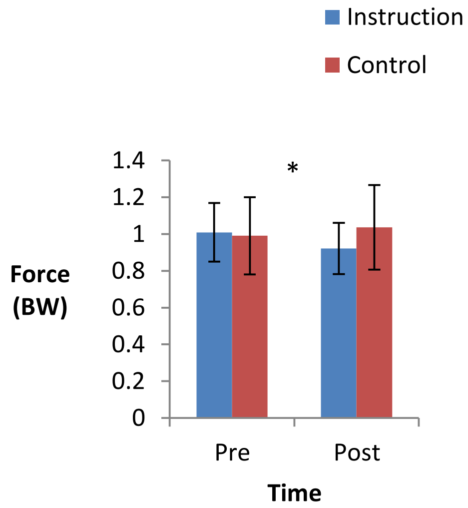
##### *Peak anterior ankle joint reaction forces*

Instruction and feedback on landing technique significantly reduced peak anterior ankle joint reaction forces during landing for the double foot land and the 1-2 foot land (refer to Figures 4.3a and 4.3b). For the double foot land, the instruction group reduced their anterior ankle joint reaction forces by 0.12 BW (SD = 0.11) or 17% while the control group increased theirs by 0.02 BW (SD = 0.1) or 3%. There was no significant main effect for group ($p = 0.29$), however, there was a significant main effect for time ($p = 0.006$) and a significant interaction for group x time ($p < 0.001$) demonstrating that the instruction and control groups responded differently following instruction and feedback or landing practice; the instruction group significantly reduced their peak anterior ankle joint reaction forces while the control group did not.

For the 1-2 foot land, the instruction group reduced their anterior ankle joint reaction forces by 0.09 BW (SD = 0.13) or 9% while the control group increased their anterior ankle joint reaction forces by 0.05 BW (SD = 0.24) or 5%. There were no significant main effects for group ($p = 0.41$) or time ($p = 0.35$) however, there was a significant interaction for group x time ($p = 0.005$) suggesting that following instruction and feedback or landing practice the two groups responded differently; the instruction group reduced their peak anterior ankle joint reaction forces while the control group did not.




a)



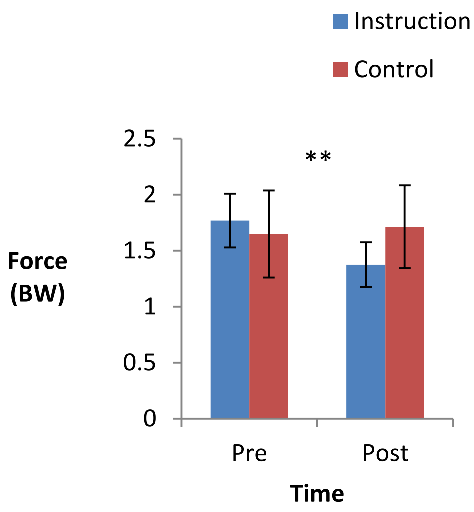

b)

*Figures 4.3:* Peak anterior ankle joint reaction forces a) double foot land b) 1-2 foot land. The double asterisk (**) represents a signficant interaction $p < 0.001$ and the single asterisk (*) represents a significant interaction $p < 0.05$. Error bars indicate SD.

*Peak vertical ankle joint reaction forces*

Instruction and feedback on landing technique significantly reduced peak vertical ankle joint reaction forces during landing for the double foot land and the 1-2 foot land (refer to Figures 4.4a and 4.4b). For the double foot land, the instruction group reduced their vertical ankle joint reaction forces by 0.4 BW (SD = 0.19) or 23% while the control group increased their vertical ankle joint reaction forces by 0.06 BW (SD = 0.23) or 4%. There was no significant main effect for group ($p = 0.27$), however, there was a significant main effect for time ($p < 0.001$) and a significant interaction for group x time ($p < 0.001$) indicating that the instruction and control groups responded differently following instruction and feedback or landing practice; the instruction group significantly reduced their peak vertical ankle joint reaction forces while the control group increased theirs.

For the 1-2 foot land, the instruction group reduced their vertical ankle joint reaction forces by 0.31 BW (SD = 0.41) or 12% and the control group increased their vertical ankle joint reaction forces by 0.15 BW (SD = 0.24) or 7%. There were no significant main effects for group ($p = 0.53$) or time ($p = 0.17$), however, there was a significant interaction for group x time ($p < 0.001$) implying that following instruction and feedback or landing practice the two groups responded differently; the instruction group significantly reduced their peak vertical ankle joint forces while the control group increased theirs.

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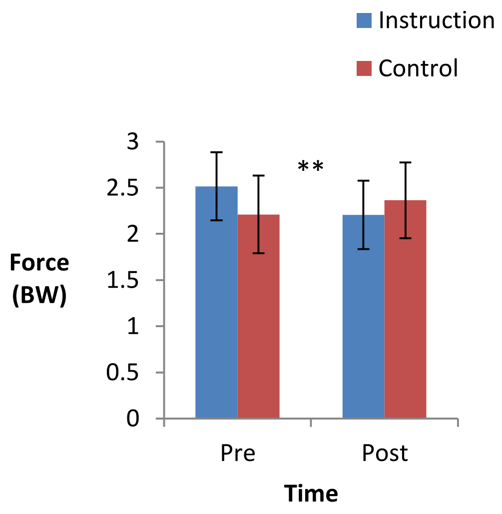


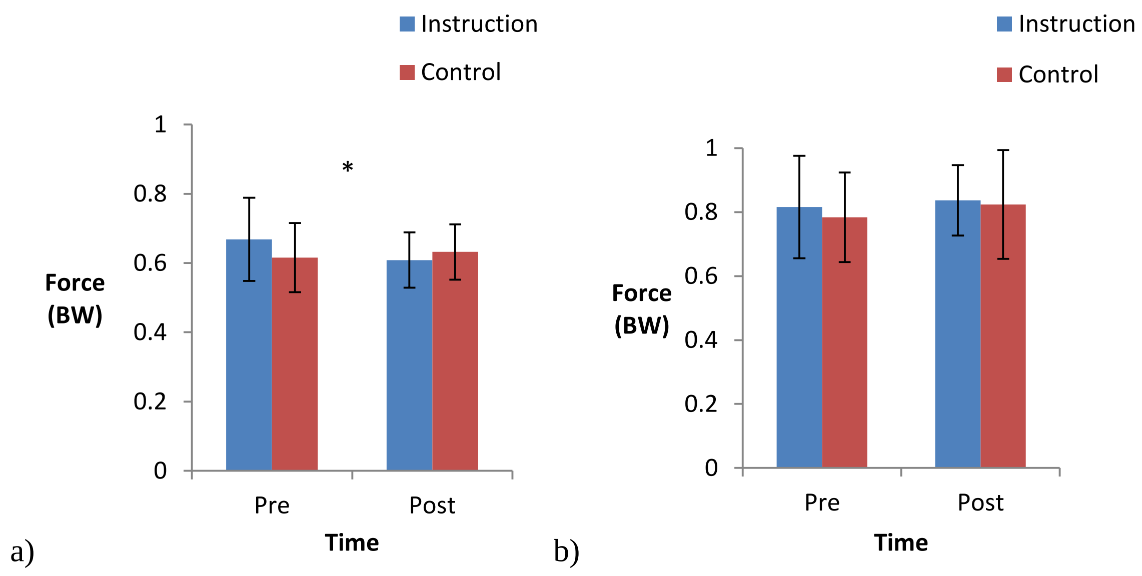

b)

*Figures 4.4.* Peak vertical ankle joint reaction forces a) double foot land b) 1-2 foot land. The double asterisk (**) represents a significant interaction $p < 0.001$. Error bars indicate SD.

*Peak anterior knee joint reaction forces*

Instruction and feedback on landing technique significantly reduced peak anterior knee joint reaction forces during landing for the double foot land; however there were no significant differences for the 1-2 foot land (refer to Figures 4.5a and 4.5b). For the double foot land, the instruction group reduced their anterior knee joint reaction forces by 0.06 BW (SD = 0.11) or 9% while the control group increased theirs by 0.02 BW (SD = 0.08) or 3%. There were no significant main effects for group ($p = 0.599$) or time ($p = 0.172$) however, there was a significant interaction for group x time ($p = 0.02$) suggesting that following instruction and feedback or landing practice the two groups responded differently; the instruction group significantly reduced their peak anterior knee joint reaction forces while the control group showed an increase.

For the 1-2 foot land there were no significant main effects for group ($p = 0.61$) or time ($p = 0.15$) and there was no significant interaction for group x time ($p = 0.64$). The instruction and control groups did not differ in peak anterior knee joint reaction forces for the 1-2 foot land following instruction and feedback or landing practice.

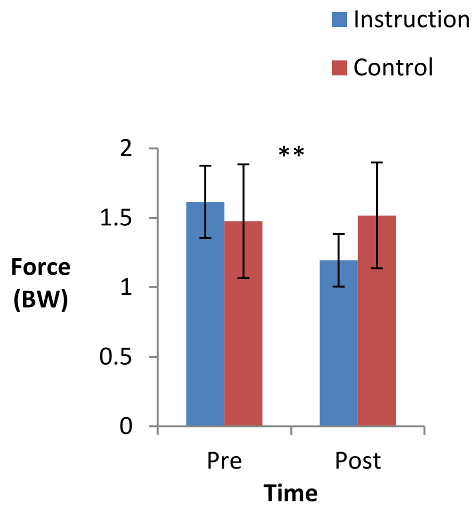



*Figures 4.5.* Peak anterior knee joint reaction forces a) double foot land b) 1-2 foot land. The single asterisk (*) represents a significant interaction $p < 0.05$. Error bars indicate SD.

*Peak vertical knee joint reaction forces*

Instruction and feedback on landing technique significantly reduced peak vertical knee joint reaction forces during landing for the double foot land and the 1-2 foot land (refer to Figures 4.6a and 4.6b). For the double foot land, the instruction group reduced their vertical knee joint reaction forces by 0.42 BW (SD = 0.19) or 26% while the control group increased their vertical knee joint forces by 0.04 BW (SD = 0.25) or 3%. There was no significant main effect for group ($p = 0.37$), however, there was a significant main effect for time ($p < 0.001$) and a significant interaction for group x time ($p < 0.001$) showing that the instruction and control groups responded differently following instruction and feedback or landing practice; the instruction group significantly reduced their peak vertical knee joint reaction forces while the control group increased theirs.

For the 1-2 foot land, the instruction group reduced their vertical knee joint reaction forces by 0.33 BW (SD = 0.41) or 13% while the control group increased theirs by 0.15 BW (SD = 0.24) or 7%. There were no significant main effects for group ($p = 0.57$) or time ($p = 0.11$), however, there was a significant interaction for group x time ($p < 0.001$) suggesting that the two groups responded differently following instruction and feedback or landing practice; the instruction group significantly reduced their peak vertical knee joint reaction forces while the control group increased theirs.

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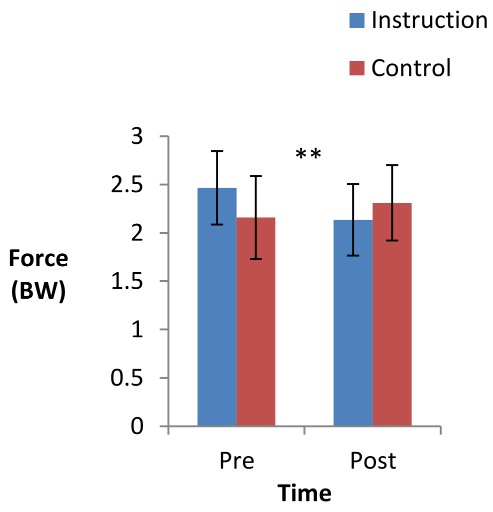



b)

*Figures 4.6.* Peak vertical knee joint reaction forces a) double foot land b) 1-2 foot land. The double asterisk (**) represents a significant interaction *p* < 0.001. Error bars indicate SD.

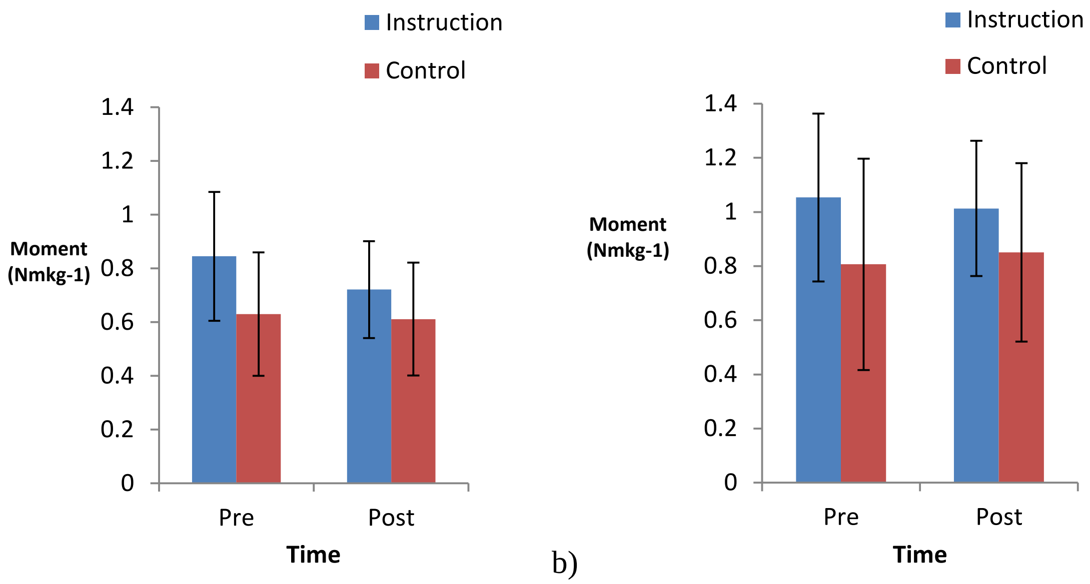
### *4.3.3 Joint kinetics – moments*

Results of net internal joint moments at the ankle and knee are summarised in a table for each landing style in Appendix O.

*Peak ankle plantar flexion moments*

Instruction and feedback on landing technique did not significantly alter peak ankle plantar flexion moments during landing for the double foot land or the 1-2 foot land (refer to Figures 4.7a and 4.7b). For the double foot land, although the instruction group reduced their plantar flexion moment by 0.12 $Nmkg^{-1}$ (SD = 0.19) or 22% while the control group reduced theirs by 0.02 $Nmkg^{-1}$ (SD = 0.14) or 3%, the results did not reach statistical significance. There was a trend towards a significant interaction for group x time (*p* = 0.064) suggesting that the instruction and control groups responded differently following instruction and feedback or landing practice, however this was not significant. Significant main effects were found for group (*p* = 0.019) and time (*p* = 0.014) however these were indicative of differences at baseline and not following instruction.

For the 1-2 foot land, although there was a significant main effect for group (*p* = 0.048), this was indicative of differences at baseline and not following instruction. There was no significant main effect for time (*p* = 0.96) nor was there a significant group x time interaction (*p* = 0.29). The instruction and control groups did not differ in peak ankle plantar flexion moments for the 1-2 foot land following instruction and feedback or landing practice.

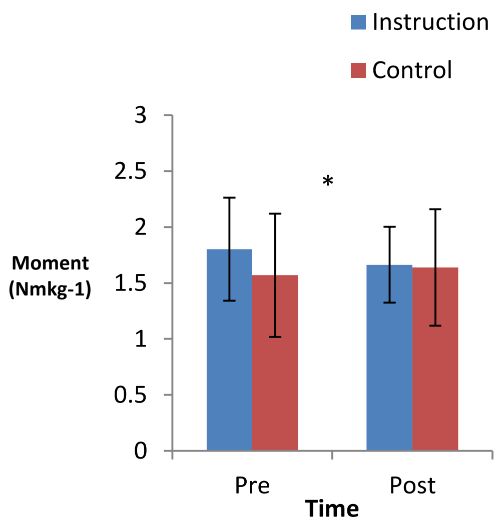



*Figures 4.7.* Peak ankle plantar flexion moments a) double foot land b) 1-2 foot land. Error bars indicate SD.

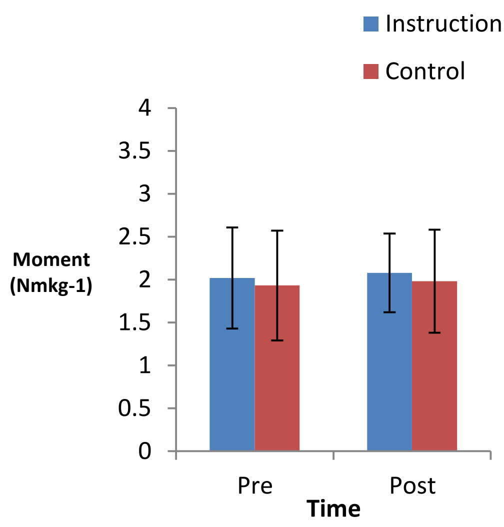
*Peak knee extension moments*

Instruction and feedback on landing technique significantly reduced peak knee extension moments during landing for the double foot land; however, there were no significant differences for the 1-2 foot land (refer to Figures 4.8a and 4.8b). For the double foot land, the instruction group reduced their knee extension moment by 0.14 $Nmkg^{-1}$ (SD = 0.25) or 8% while the control group increased theirs by 0.07 $Nmkg^{-1}$ (SD = 0.20) or 5%. There were no significant main effects for group ($p = 0.41$) or time ($p = 0.37$), however, there was a significant interaction for group x time ($p = 0.008$) implying that the two groups responded differently following instruction and feedback or landing practice; the instruction group significantly reduced their peak knee extension moment while the control group increased theirs.

For the 1-2 foot land, there were no significant main effects for group ($p = 0.62$) or time ($p = 0.15$) and there was no significant interaction for group x time ($p = 0.91$). The instruction and control groups did not differ in peak knee extension moments for the 1-2 foot land following instruction and feedback or landing practice.



a)



b)

*Figures 4.8.* Peak knee extension moments a) double foot land b) 1-2 foot land. The single asterisk (*) represents a significant interaction $p < 0.05$). Error bars indicate SD.

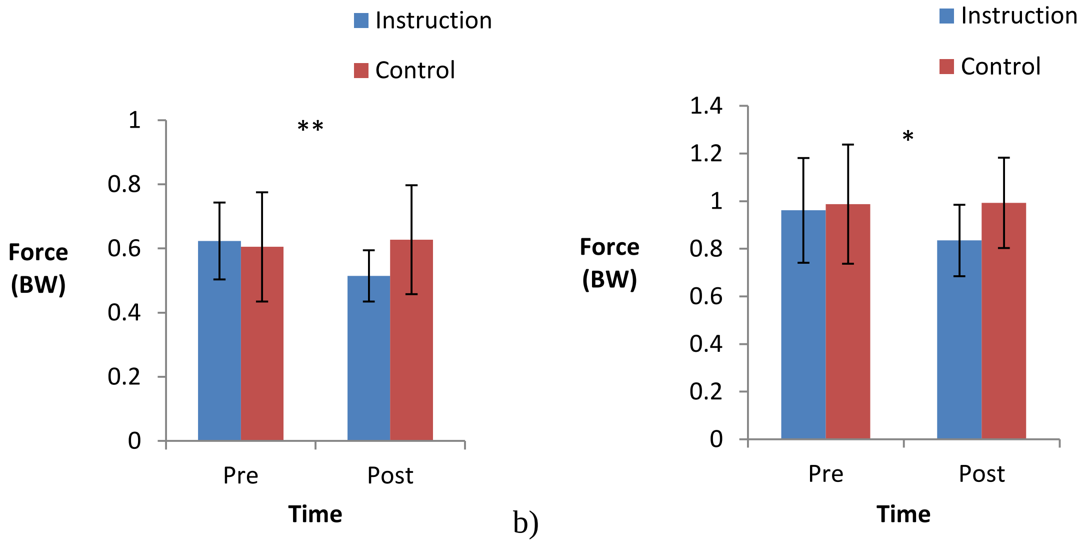
### *4.3.4 Ground reaction forces*

Ground reaction force results for each landing style are summarised in tables in Appendix P

*Peak antero-posterior ground reaction forces (APGRF)*

Instruction and feedback on landing technique significantly reduced peak APGRF during landing for the double foot land and the 1-2 foot land (refer to Figures 4.9a and 4.9b). For the double foot land, the instruction group reduced their APGRF by 0.11 BW (SD = 0.11) or 18% while the control group increased theirs by 0.02 BW (SD = 0.1) or 4%. There was no significant main effect for group ($p = 0.28$), however, there was a significant main effect for time ($p = 0.016$) and a significant interaction for group x time ($p < 0.001$) demonstrating that the instruction and control groups responded differently following instruction and feedback or landing practice; the instruction group significantly reduced their peak APGRF while the control group increased theirs.

For the 1-2 foot land, the instruction group reduced their APGRF by 0.13 BW (SD = 0.13) or 14% while the control group showed no change. There was no significant main effect for group ($p = 0.153$), however, there was a significant main effect for time ($p = 0.017$) and a significant interaction for group x time ($p = 0.01$) indicating that the instruction and control groups responded differently following instruction and feedback or landing practice; the instruction group significantly reduced their peak APGRF while the control group remained unchanged.

a) 

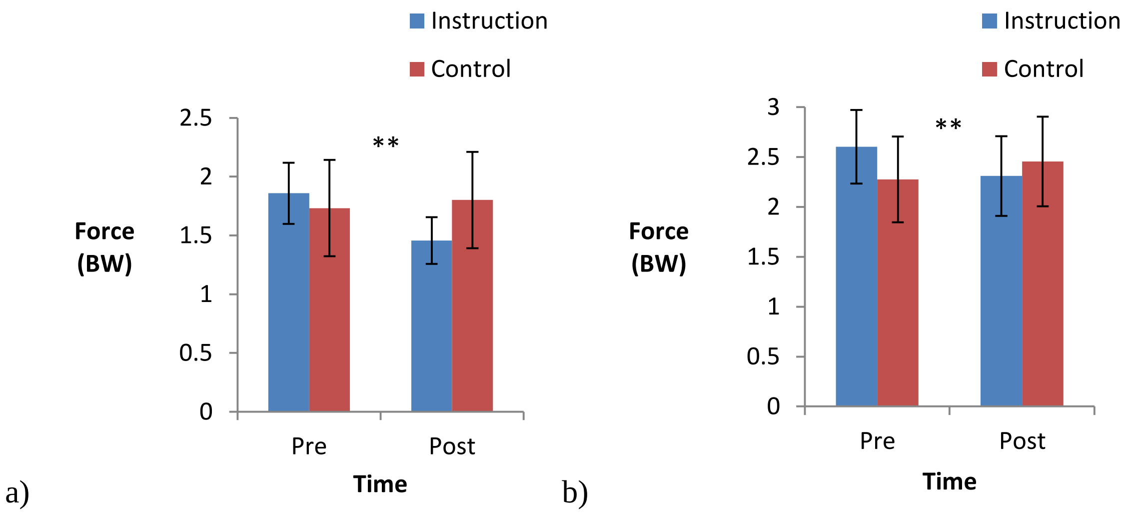

b)


*Figures 4.9.* Peak APGRF a) double foot land b) 1-2 foot land. The double asterisk (**) represents a significant interaction $p < 0.001$ and the single asterisk (*) represents a significant interaction $p < 0.05$. Error bars indicate SD.

*Peak vertical ground reaction forces (VGRF)*

Instruction on landing technique significantly reduced peak VGRF during landing for the double foot land and the 1-2 foot land (refer to Figures 4.10a and 4.10b). For the double foot land, the instruction group reduced their VGRF by 0.4 BW (SD = 0.2) or 22% while the control group increased theirs by 0.07 BW (SD = 0.26) or 4%. There was no significant main effect for group ($p = 0.30$), however, there was a significant main effect for time ($p < 0.001$) and a significant interaction for group x time ($p < 0.001$) showing that the instruction and control groups responded differently following instruction and feedback or landing practice; the instruction group significantly reduced their peak VGRF while the control group showed an increase.

For the 1-2 foot land, the instruction group reduced their peak VGRF by 0.29 BW (SD = 0.43) or 11% while the control group increased theirs by 0.18 BW (SD = 0.28) or 8%. There were no significant main effects for group ($p = 0.46$) or time ($p = 0.35$), however, there was a significant interaction for group x time ($p < 0.001$) suggesting that the two groups responded differently following instruction and feedback or landing practice; the instruction group significantly reduced their peak VGRF while the control group increased theirs.




*Figures 4.10.* Peak VGRF a) double foot land b) 1-2 foot land. The double asterisk (**) represents a significant interaction $p < 0.001$. Error bars indicate SD.

## 4.4 Additional factors

### *4.4.1 Approach velocity*

Peak approach velocity of the model COM is summarised in Table 4.2 for both the instruction and control groups for double foot and 1-2 foot landing.

Table 4.2

*Peak Approach Velocity*

| **Velocity ($ms^{-1}$)** | **Pre Instruction Mean (SD)** | **Confidence Interval** | **Post Instruction Mean (SD)** | **Confidence Interval** | **Significance (*p* value)** |
|---|---|---|---|---|---|
| Double Foot Land (Instruction) | 1.95 (0.29) | 1.80-2.09 | 1.86 (0.22) | 1.75-1.97 | 0.051 |
| Double Foot Land (Control) | 1.96 (0.36) | 1.78-2.13 | 2.03 (0.33) | 1.87-2.19 | 0.212 |
| 1-2 Foot Land (Instruction) | 2.02 (0.29) | 1.88-2.16 | 1.96 (0.23) | 1.84-2.07 | 0.102 |
| 1-2 Foot Land (Control) | 2.15 (0.35) | 1.99-2.32 | 2.16 (0.31) | 2.01-2.31 | 0.909 |

Instruction and feedback did not significantly alter peak approach velocity during landing for the double foot land and the 1-2 foot land. For the double foot land, although there was a trend towards the instruction group reducing their approach velocity following instruction and feedback ($p$ = 0.051), this was not statistically significant. The control group did not significantly alter their approach velocity ($p$ = 0.21) following landing practice. For the 1-2 foot land, there were no significant differences in approach velocity for the instruction or control groups.

### *4.4.2 Centre of mass (COM) vertical position*

Peak vertical position of the model COM prior to landing is summarised in Table 4.3 for both the instruction and control groups for the double foot and 1-2 foot land.

Table 4.3

*Peak Vertical Position*

| **COM Maximum Position (m)** | **Pre Instruction Mean (SD)** | **Confidence Interval** | **Post Instruction Mean (SD)** | **Confidence Interval** | **Significance (*p* value)** |
|---|---|---|---|---|---|
| Double Foot Land (Instruction) | 0.97 (0.06) | 0.95-1.00 | 0.99 (0.04) | 0.97-1.01 | 0.028 |
| Double Foot Land (Control) | 0.93 (0.08) | 0.89-0.97 | 0.96 (0.07) | 0.93-0.99 | 0.009 |
| 1-2 Foot Land (Instruction) | 0.91 (0.06) | 0.89-0.94 | 0.93 (0.05) | 0.91-0.96 | 0.083 |
| 1-2 Foot Land (Control) | 0.85 (0.09) | 0.81-0.89 | 0.88 (0.09) | 0.84-0.92 | 0.004 |

*Note.* COM = centre of mass.

For the double foot land, both the instruction and control groups significantly increased the maximum vertical position of their model COM following instruction and feedback or landing practice. The instruction group increased their maximum vertical position by 0.02 m (SD = 0.04) and the control group increased their maximum vertical position by 0.03 m (SD = 0.04).

For the 1-2 foot land, the instruction group increased their maximum vertical position by 0.02 m (SD = 0.04), although this was not statistically significant ($p = 0.08$). The control group significantly ($p = 0.004$) increased their maximum vertical position by 0.03 m (SD = 0.04).

# Chapter Five

## Discussion

### 5.1 Overview

The discussion is divided into five subsections. Firstly, the results of the study will be discussed and compared to previous biomechanical netball research and research examining the effects of instruction (with or without feedback) on landing. Secondly, the instruction and feedback intervention as well as the clinical implications of the study will be examined. Considerations and potential limitations associated with the study will be highlighted and lastly directions for further research will be considered.

### 5.2 Study findings

#### *5.2.1 Joint kinematics*

Instruction and feedback on landing technique significantly increased peak ankle dorsiflexion and peak knee flexion angles during landing for the two common netball landing styles; double foot landing and 1-2 foot landing. In support of the finding that instruction increased knee flexion, Cowling and Steele (2001) found instruction on landing technique in elite netball players significantly increased knee flexion at initial contact and the time of peak force during 1-2 foot landing. The knee flexion angles, however, were not peak knee flexion angles during landing and the values obtained both pre and post instructions were much less (< 20°) than the peak knee flexion angles in this study.

*Peak ankle dorsiflexion*

With respect to the effect of instruction and feedback on ankle kinematics in alternative athletic populations, this study contrasts with the findings of two studies who investigated peak ankle dorsiflexion during double foot landing (Gervais, 1997; Mizner et al., 2008) but agrees with the findings from a recent study that investigated a combination of double and 1-2 foot landing styles during landing from a volleyball spike (Parsons & Alexander, 2012). Mizner et al. (2008) and Gervais (1997) concluded that instruction and feedback had no effect on peak ankle dorsiflexion during double foot landing. Conversely, similar to this study, Parsons and Alexander (2012) reported significant increases in both right and left peak ankle dorsiflexion angle following instruction and feedback with an 8°increase for the right ankle from 13° pre instruction to 21° post instruction and 10° for the left ankle from 14° to 24°. Although Parsons and Alexander (2012) examined both the double foot and 1-2 foot landing styles congruently and motion analysis was performed two dimensionally with four video cameras, their study had many similarities to this study in that they assessed a functional sporting motion (landing from a volleyball spike) and had a similar demographic of participants (12-14 year old females). The reason for the conflicting conclusions between the four studies examining peak ankle dorsiflexion during landing may be due to methodological differences. In particular, participants landed from a 31 cm drop box or 29 cm gymnastics horse box in the studies who found no significant effect from instruction while the participants from this study and Parsons and Alexander (2012) were running forwards and stopping to land.

*Peak knee flexion*

The results of the current study agree with the findings from three other studies that instruction (with or without feedback) on landing technique increases peak knee flexion angle during double foot landing (Milner, Fairbrother, Srivatsan, & Zhang, 2012; Mizner et al., 2008; Onate et al., 2005) and one study that investigated the combination of double foot and 1-2 foot landing styles during landing from a volleyball spike (Parsons & Alexander, 2012). Milner et al. (2012) reported a significant average increase of 9° knee flexion from 87° to 96° after using three simple verbal instructions alone. Similarly, Mizner et al. (2008) reported a significant increase of 12° knee flexion from 86° to 98° following instruction and feedback and Onate et al. (2005) reported a significant average increase of 33° knee flexion across three feedback models from 58° to 91° following instruction and feedback. Parsons and Alexander (2012) reported a significant increase in right knee flexion of 18° from 67° to 85° for 10 right handed youth volleyball players landing either double foot or 1-2 foot. Although the significant increase in knee flexion for this study is greater than three of the aforementioned studies (Milner et al., 2012; Mizner et al., 2008; Parsons & Alexander, 2012) but much less than what was reported by Onate et al. (2005), it does add further support that instruction (with or without feedback) on landing technique increases peak knee flexion angles.

### *5.2.2 Joint kinetics – reaction forces*

Instruction and feedback on landing technique significantly reduced peak anterior and peak vertical joint reaction forces at the ankle for the two common netball landing styles;

double foot landing and 1-2 foot landing. For the knee, instruction and feedback on landing technique significantly reduced peak anterior and peak vertical joint reaction forces for the double foot land, however, only vertical joint forces were significantly reduced for the 1-2 foot land. No other studies have been identified in the literature that report on peak anterior and peak vertical joint reaction forces in netball players. This study serves as a preliminary guide and supports the tenet that instruction and feedback significantly reduces peak ankle and knee joint forces during double and 1-2 foot landing.

*Peak anterior knee joint reaction forces*

With respect to the effect of instruction (with or without feedback) on ankle and knee joint reaction forces in alternative athletic populations, this study contrasts with the findings from two studies that examined peak anterior knee joint reaction forces during double foot landing (Herman et al., 2009; Onate et al., 2005) but agrees with the findings from a further study that examined 1-2 foot landing (McGrath, 2009). Herman et al. (2009) and Onate et al. (2005) found that instruction and feedback had no significant effect on peak anterior knee joint reaction forces during double foot landing in their studies on recreational athletes. Conversely, the current study found that instruction and feedback significantly reduced peak anterior knee joint reaction forces by 0.06 BW or 9% for the double foot land. For the 1-2 foot land this study was in accordance with the findings of a study by McGrath (2009) who found that instruction on landing technique had no significant effect on peak anterior knee joint reaction forces.

### *5.2.3 Joint kinetics – moments*

The results from the current study suggest that instruction and feedback on landing technique reduces peak knee extension moments for the double foot land but there were no significant effects for peak ankle plantar flexion moments for both landing styles or peak knee extension moments for the 1-2 foot land. In this study, the instruction and control groups were dissimilar at baseline for joint moments and the data showed large variation, making comparisons and therefore firm conclusions difficult.

*Peak plantar flexion moments*

With respect to the effect of instruction and feedback on peak ankle joint moments during landing, Mizner et al. (2008) reported on peak external dorsiflexion moments (or peak internal plantar flexion moments) for a double foot land. Mizner et al. (2008)

reported a significant reduction in peak external dorsiflexion moment of 0.12 $Nmkg^{-1}$ from 1.50 $Nmkg^{-1}$ to 1.38 $Nmkg^{-1}$, a similar reduction to what was found in this study, however, the magnitude of the moments were almost double those of this study. Although this study noted a trend towards instruction and feedback reducing peak plantar flexion moments during landing, the results contrast with Mizner et al. (2008) as a statistically significant result was not achieved. The larger moments may have been found in their study due to methodological differences, in particular they examined older collegiate athletes and participants landed from a 31cm drop box rather than running forwards to land, as was performed in this study.

*Peak knee extension moments*

Two studies have reported on the effect of instruction (with or without feedback) on peak internal knee extension moments (or peak external knee flexion moments); one for a double foot land (Mizner et al., 2008) and one for the 1-2 foot land (McGrath, 2009). For the double foot land, Mizner et al. (2008) reported a significant reduction in peak external knee flexion moment of 0.12 $Nmkg^{-1}$ from 1.85 $Nmkg^{-1}$ to 1.73 $Nmkg^{-1}$ following instruction and feedback, a similar reduction to what was found in this study with similar moments reported and in support of the conclusions from this study. McGrath (2009) normalised moment data by mass and height making comparisons to this study difficult, however, they concluded for the 1-2 foot land that instruction significantly reduced peak knee extension moments, a contrasting finding to this study. Due to the conflicting findings of this study and McGrath (2009), the effect of instruction (with or without feedback) on peak knee extension moments for the 1-2 foot land remains inconclusive. Of note, McGrath (2009) examined competitive university aged athletes and in comparison, this study investigated novice athletes. At an elite level, netball players land commonly in both double foot and 1-2 foot landing styles (Ferdinand et al., 2008); however the landing style selected by younger, novice netball players has not been determined. During this laboratory study, it was evident the participants were more comfortable with a double foot landing style as opposed to a 1-2 foot landing style. Therefore, the conflicting findings regarding peak knee extension moments for a 1-2 foot land may be related to age and experience of athletes.

### *5.2.4 Ground reaction forces*

Instruction and feedback on landing technique significantly reduced peak APGRF and peak VGRF during landing for the two common netball landing styles; double foot landing and 1-2 foot landing. Otago (2004) reported peak APGRF (or braking forces) of 1.75 BW for netball players during a double foot land. In this study the average peak APGRF for a double foot land were 0.6 BW, approximately one third of the value previously reported. For a 1-2 foot land, peak APGRF reported in the literature vary greatly from 1.4 – 4.6 BW (Cowling et al., 2003; Neal & Sydney-Smith, 1992; Otago, 2004; Steele & Milburn, 1987a, 1989). This study found the average peak APGRF for a 1-2 foot land was 1.0 BW. The large difference may be attributed to the methodological differences of each study, particularly the fact that participants in this study were younger and had a slower approach velocity.

With regards to peak VGRF in netball players landing double foot, Otago (2004) reported the average force to be 5.7 BW. This study found average peak VGRF of 1.8 BW, again, approximately one third of the value previously reported. For a 1-2 foot land, the peak VGRF reported in the literature vary between 3.4 – 4.7 BW. This study found average peak VGRF of 2.4 BW, much lower than the range previously reported. Again, the large difference may be attributed to the methodological differences of each study, particularly the fact that participants in this study were younger and had a slower approach velocity.

This study agrees with the findings of one study that examined the effect of instruction on peak APGRF and peak VGRF in netball players during a 1-2 foot land (Cowling et al., 2003). Cowling et al. (2003) reported a significant 11% reduction in peak APGRF of 0.19 BW from 1.71 BW to 1.52 BW and a significant 9% reduction in peak VGRF of 0.29 BW from 3.39 to 3.10 BW. The findings from this study and Cowling et al. (2003) indicate that instruction (with or without feedback) on landing technique reduces peak APGRF and peak VGRF during 1-2 foot landing in netball players.

With respect to studies that examined the effect of instruction (with or without feedback) in alternative populations, this study contrasts with the conclusions from one study that reported instruction and feedback had no effect on peak APGRF during double foot landing (Cronin et al., 2008). This study does, however, support the conclusions from numerous studies that instruction (with or without feedback) on landing technique reduces peak VGRF for both the double foot land (Cronin et al., 2008; Herman et al., 2009; McNair et al., 2000; Mizner et al., 2008; Onate et al., 2005; Onate et al., 2001; Prapavessis & McNair, 1999; Prapavessis et al., 2003; Walsh et al., 2007) and the 1-2 foot land (McGrath, 2009). The magnitude of peak APGRF and peak VGRF in this study fit within the large ranges reported in the literature but of note, the values in this study are similar to the values in studies that examined running forwards to land and not landing from a drop box.

### *5.2.5 Approach velocity*

Instruction and feedback on landing technique did not significantly alter approach velocity of participants in this study. Previous biomechanical research on netball players determined the average approach velocity for a double foot land was 3.32 $ms^{-1}$ (Otago, 2004) and ranged from 3.33 – 4.3 $ms^{-1}$ for a 1-2 foot land (Neal & Sydney-Smith, 1992; Otago, 2004). The slower take-off velocities reported in this study may be due to the fact that participants in this study were younger; less experienced and were asked to run forwards quickly but were not asked to sprint.

## 5.3 Instruction and feedback intervention

The instruction and feedback intervention in this study was based on the landing guidelines currently used by Netball New Zealand, termed NetballSmart for coaches (NetballSmart, 2007). The current study demonstrated that the use of key principles from these landing guidelines alone was able to influence biomechanical variables during landing in female novice netball players. Three key items were selected from the eight or nine landing instructions in the booklet and these instructions were delivered verbally as well as giving good and bad demonstration examples. During the instruction session, feedback was provided to affirm or correct landing patterns. From pilot testing, it was evident that fewer instructions and fewer words for each instruction were easier for participants to comprehend and incorporate into their landing. For this reason, the key words in the instruction script were deemed most important and repeated when providing feedback during the instruction session. These key words were: “bending at your hips and knees”, “knees in line with your toes, not in front of your toes” and “softly”. The approach used in this study supports the recommendations by Landin (1994) who suggest the use of brief and accurate verbal cues to enhance motor performance. Furthermore, it affirms the ideas of Hodges and Franks (2002) who recommend providing clear pre-practice information about the task goal, providing error information early during skill acquisition and providing feedback that is simple and clearly conveys important information about the task goal.

Although this study aimed to emulate a true coaching situation where a combination of verbal instruction, demonstration and feedback was delivered, it is unknown which of these components of instruction and feedback contributed most to the outcomes of the study. A recently published study, which aimed to answer this dilemma, established that three simple verbal instructions alone, without demonstration or feedback were able to evoke kinematic and kinetic changes (Milner et al., 2012). Specifically, the instruction to land "softly" significantly reduced peak VGRF and increased peak knee flexion angles and the instruction to land with "knees over toes" significantly increased peak knee flexion angles. A further study by Onate et al. (2005) aimed to evaluate various video feedback models where participants viewed a video of an expert, themselves or a combination of themselves and an expert landing. Their study showed significant kinematic and kinetic changes in their control group as well as the feedback groups which can be directly attributed to all groups receiving the simple instruction to land "softly". Of note, however, the study showed that there were greater significant reductions in peak VGRF and increases in peak knee flexion for those who viewed a video of themselves or a combination of themselves and an expert landing. In summary, simply using the instruction to land softly can lead to significant reductions in peak VGRF and increases in peak knee flexion angle. It appears that providing feedback during landing is able to enhance these significant changes.

## 5.4 Clinical implications

### *5.4.1 Injury reduction*

This study was able to demonstrate positive kinematic and kinetic changes to variables that have been associated with lower limb injury, particularly to the ACL. A prospective study of female athletes sustaining an injury to the ACL determined that reduced peak knee flexion during landing and landing with greater VGRF compared to non-injured controls were potential contributing factors to the injury (Hewett et al., 2005). Furthermore, video examination of ACL injuries report that the knee is often close to full extension in combination with tibial rotation (Olsen, Myklebust, Engebretsen, & Bahr, 2004) and that ankle dorsiflexion during landing is significantly less than non-injured controls (Boden, Torg, Knowles, & Hewett, 2009). The current study was able to demonstrate significant increases in peak knee flexion, peak ankle dorsiflexion and significant reductions in peak VGRF for both the double foot and 1-2 foot landing styles in novice netball players. Although no direct conclusions can be made about the use of instruction and feedback towards reducing injury risk, this preliminary study highlights the propensity that instruction and feedback, using key principles from the NetballSmart landing guidelines on landing technique, may have towards reducing lower limb injury.

### *5.4.2 Reduction in gender disparities*

Injuries to the ACL are high amongst young athletes in the 14-19 year age bracket and are much greater in female athletes (Renstrom et al., 2008). Biomechanical studies investigating pre and post pubertal gender differences report that post puberty males experience a neuromuscular spurt as measured by an increase in vertical jump height whereas females do not (Quatman, Ford, Myer, & Hewett, 2006). Furthermore, post puberty, females significantly increase their ground reaction forces (Quatman et al., 2006), anterior knee joint forces, knee extension moments (Hass et al., 2003) and reduce their knee flexion angles during landing compared to their male counterparts (Hass et al., 2003; Yu et al., 2005). This gender divergence begins to occur around age 12 and increases incrementally over adolescent years (Yu et al., 2005). With respect to netball players, a study of insurance data revealed a sharp rise in the incidence of injury claims in the 15-19 year age bracket compared with the 10-14 year age bracket, despite almost double the number of netball players in the younger age group (Otago & Peake, 2007). In light of biomechanical gender disparities post puberty and the sharp rise in injuries seen in netball players post puberty, this study demonstrates the potential to modify gender disparities and potentially influence injury risk factors in a young female age group prior to neuromuscular divergence and onset of injury.

### *5.4.3 Implementation*

Instruction, demonstration and feedback are integral components of any coach’s repertoire (Hodges & Franks, 2002). Therefore, instruction and feedback on landing technique could easily be integrated into existing coaching regimes with very little expense and without the need for specialised equipment. The instruction and feedback used in this study is simple and easy to deliver within a short time frame, making it an ideal strategy aimed at altering kinematic and kinetic factors associated with lower limb injury versus comprehensive, multifactorial training programmes.

## 5.5 Study considerations and limitations

Although the researchers aimed to generate a high quality study and endeavoured to limit confounding factors, some factors that may influence both the internal and external validity of the study have been identified.

### *5.5.1 Participants*

At the outset, the study aimed to randomly stratify four schools with 10 participants from each school to either the instruction or control group. Stratification of schools rather than random assignment was important due to the chance of contaminating the study by participants discussing the landing intervention. Unfortunately only three schools volunteered for the study and the schools were allocated rather than stratified to either the instruction or control group based on the number of volunteers from each school and trying to create an even number of participants in the instruction and control groups. Although baseline statistics revealed no significant differences between the groups, the non-random assignment of participants introduces potential bias to the study.

### *5.5.2 Number of landings assessed*

Natural variability in landing mechanics exists within individuals (James et al., 2007). This was apparent during experimental testing in this study where landing anomalies such as skidding to land, altering take-off velocity and elevation, landing with a wide base and varying trunk position on landing were seen within and between participants. This study aimed to negate this natural variability by taking the average of three landing trials for double foot and 1-2 foot landings. Further improvements may have been achieved if the average of four or more trials had been undertaken as research suggests improved reliability in 3-D kinematic and kinetic measures with a greater number of trials (James et al., 2007; Ortiz et al., 2007).

### *5.5.3 Marker placement and variability*

Within session reliability of lower limb 3-D motion analysis during landing is high, especially when the system is calibrated prior to each testing session, when one person applies the markers and the static marker posture and instruction is standardised (Ford et al., 2007; Piriyaprasarth & Morris, 2007). This study ensured that this criterion was met for every testing session. Reliability of kinematic and kinetic data is reduced by marker motion as a result of reapplication errors, skin movement artefacts and variability in natural human movement (Ferber, McClay Davis, Williams, & Laughton, 2002). Unfortunately due to the dynamic task of landing, there were several occasions where markers came off during landing and had to be reapplied and a further static motion capture performed. The markers that consistently came off were those attached to the footwear of participants rather than the skin. The reapplication of markers in the study may have reduced the reliability of motion analysis data.

#### *5.5.4 Outcome variables investigated*

The study collected kinematic and kinetic data for the ankle, knee, hip, pelvis and trunk in all three planes of motion. While frontal plane motion and forces at the knee have been linked to ACL injury (Hewett et al., 2005), these were not studied due to the small changes in frontal plane kinematics and large variability within and between participants. Large variability in frontal plane kinematics may have stemmed from marker motion arising from the high impact nature of the landing task. The reported outcome variables for this preliminary study were considered an appropriate number for the aims and objectives and the time and cost constraints of the study.

#### *5.5.5 Velocity and centre of mass (COM) position*

Although statistical analyses did not reveal any significant differences in the approach velocity of participants prior to and following instruction and feedback (instruction group) or landing practice (control group), there was a tendency for the instruction group to reduce their approach velocity following instruction, particularly for the double foot land. This may have been due to participants in the instruction group concentrating on incorporating the landing instructions and the feedback given. Increased approach velocity has been found to correlate with an increase in peak VGRF and peak APGRF (braking forces) and has been reported as a factor leading to variability of ground reaction force data (Neal & Sydney-Smith, 1992). This study attempted to control for approach velocity by selecting three trials where the take-off velocity was within 10% of each other but was not strictly controlled.

Other factors that may influence ground reaction forces in netball players are the height of a pass and the foot fall pattern during landing. Players landing to catch a chest pass have been shown to have a greater velocity than players attempting to catch a high pass (Neal & Sydney-Smith, 1992; Steele & Milburn, 1989). This study attempted to control for pass height by delivering a chest pass or pass directed at the sternum of each participant by a netball player with over 20 years playing experience. Although using a netball player to deliver the pass created a more natural environment for participants to catch a ball, natural human variation in passing may have contributed to some variability in the data.

It has been established that netball players landing with initial contact of the heel creates greater peak VGRF than players landing in a forefoot footfall pattern (Neal & Sydney-Smith, 1992; Steele & Milburn, 1989). The aim of this study was to assess the natural landing biomechanics of female novice netball players, both prior to and following instruction and feedback or landing practice. Footfall pattern was therefore not a controlled factor in the study and may have contributed to some variability in the data.

Although the vertical position of the model's COM was shown to significantly increase for both the instruction and control groups following instruction and feedback or landing practice; the results showed that both groups made similar increases in their vertical position of approximately 2-3 cm. This significant alteration in vertical position of the COM was therefore not considered to be a likely contributor of data variability in the study and may have been due to a learning effect over repeated lands and familiarity with the laboratory environment.

### *5.5.6 Footwear*

This study elected for participants to wear the footwear they were presently accustomed to using for netball or a back-up laboratory pair for those who forgot their own. Although a laboratory based study, it was decided that their normal footwear was more likely to enable the participants to land in their natural style. Seventeen different makes of shoes of varying models and in varying states of wear were worn by participants in this study. The midsole density of basketball shoes has been shown to affect ground reaction forces during drop landing in basketball players where shoes with hard midsoles generated greater VGRF and increased knee extensor muscle activity (Zhang, Clowers, Kohstall, & Yu, 2005). Conversely, Steele and Milburn (1987a) in their assessment of netball players running forwards to catch a netball determined there was no significant difference in peak VGRF between a specific netball shoe and a running shoe of the same make. Due to the variability of footwear, it is possible this may have affected the peak VGRF in this study.

### *5.5.7 Practice landings*

Participants were given the opportunity to practice the two landing styles to familiarise themselves with landing in the laboratory. The number of practice lands was not standardised as it was felt that each participant would become accustomed to the laboratory test in their own individual manner. The number of practice lands across all participants ranged from 3-18 for a double foot land and 4-18 for the 1-2 foot land. The instruction group, on average, practiced eight double foot lands and nine 1-2 foot lands prior to baseline testing and the control group, on average, practiced nine double foot lands and nine 1-2 foot lands. Potentially those who practiced more lands may have had an element of fatigue compared to those who practiced fewer and this may have influenced the results.

#### *5.5.8 Laboratory based study*

In order to collect reliable and valid kinematic and kinetic data, this study was conducted in a motion analysis laboratory. The benefit of 3-D motion analysis is collecting data that is more reliable and accurate than visual inspection or two dimensional video camera analysis (Piriyaprasarth & Morris, 2007). The downfall of collecting data in a laboratory is the compromise to external validity of the study findings. As the laboratory was an unfamiliar environment for participants to complete their landings, it is difficult to extrapolate the findings to the real world situation of landing on a netball court.

#### *5.5.9 Long term retention*

This study was a preliminary study to determine the short term effects of instruction and feedback on the kinematics and kinetics of female novice netball players during landing. Although this study found significant changes in the kinematics and kinetics as a result of instruction and feedback; it was a one off session; therefore no inferences can be made about the long term effects on the kinematics and kinetics of netball players following a session using instruction and feedback on landing technique. In this study, participants from the instruction group were asked to recall the three landing instructions at the completion of their movement testing session. The majority (68%) were able to recollect all three instructions and the remainder were able to recall two of the three instructions. This indicated that some learning had taken place as a result of 20 minutes of landing instruction and feedback; however, it is unknown whether the instructions were retained further over time.

### 5.6 Further research

Further research investigating the effect of instruction (with or without feedback) on lower limb landing biomechanics should address the limitations of the current study and expand on several elements. In particular, closer investigation on the effects of instruction on peak anterior knee joint reaction forces is warranted as it appears that instruction has some effect particularly when an athlete is fatigued (McGrath, 2009) or has undergone strength training (Herman et al., 2009). As this study was conducted in a laboratory and instruction and feedback was delivered by a trained physiotherapist, it would be pertinent to determine the effect of instruction and feedback on lower limb kinematics and kinetics of female novice netball players when the instruction and feedback is delivered by a netball coach.  Furthermore, the instruction and feedback should be delivered to netball players in their natural familiar environment of a netball court.  This may compromise the reliability of kinematic and kinetic data due to obvious limitations with mobile 3-D motion analysis but are factors worthy of investigation to improve the external validity of the findings in this study.

The long term retention of instruction and feedback on landing technique using NetballSmart landing guidelines and its effect on the kinematics and kinetics of netball players should be investigated to add impetus to their use.  Studies that have investigated the retention of kinematic and kinetic changes following instruction (with or without feedback) have shown that significant changes remain in the short term but are not retained in the long term (Parsons & Alexander, 2012; Prapavessis et al., 2003). It would be of interest to monitor netball players over the course of a netball season where instruction and feedback on landing technique could be provided regularly, as occurs in a natural coaching environment.  Of interest, could kinematic and kinetic effects be maintained prior to the start of the following season, that is, does retention improve when given repetitive instruction and feedback and not a one off session and can significant effects be maintained over a six month off-season.

To further develop on research by Milner et al. (2012), the individual aspects of simple verbal instruction, demonstration and feedback should be investigated to determine which instruction and/or feedback strategies are most advantageous at altering kinematic and kinetic variables.  This study implemented all three strategies to fit with a coaching scenario; however, the individual effects should be determined.

This study investigated a novice female netball population with an average age of 12 years running forwards to catch a netball and landing double foot and 1-2 foot.  This functional movement task was selected due to being more realistic to what naturally occurs on a netball court than landing from a drop box.  From the literature, it is evident that landing from a drop box compared to landing after running forwards produces differing results.  It was an appropriate task for female novice netball players as it was a familiar simple task that still enabled them to incorporate the instruction and feedback intervention.  It would be logical to develop the functional task into a movement that is even closer to what occurs commonly on a netball court such as propping to change direction prior to landing or getting past a defensive player.

It has been highlighted that this study was able to alter kinematic and kinetic factors associated with ACL injury using instruction and feedback on landing technique. In order to make conclusive statements about the ability of instruction and feedback to reduce injuries in netball, further prospective epidemiological research would need to be conducted.

# Chapter Six

## Summary and Conclusions

### 6.1 Summary of findings

The aim of this study was to determine the effect of instruction and feedback (based on the key principles of NetballSmart landing guidelines) on ankle and knee joint kinematics and kinetics during landing in female novice netball players. The study found that 20 minutes of instruction and feedback on landing technique led to significant changes in the landing kinematics and kinetics of novice female netball players during a single laboratory session. In particular, the study affirmed that instruction and feedback on landing technique increases peak knee flexion angles, reduces peak VGRF and reduces peak knee extension moments (for a double foot land) using landing guidelines that have not previously been evaluated and within a population that has been given little attention in the literature. Furthermore, the study concurred with the limited literature that instruction on landing technique reduces peak APGRF in netball players landing 1-2 foot and increases peak ankle dorsiflexion angles when running forwards to land versus landing from a drop box. In addition, the study demonstrated that instruction and feedback on landing technique reduces peak anterior ankle joint reaction forces and peak vertical joint reaction forces at the ankle and knee.

Several biomechanical variables have been associated with ankle and knee injuries sustained during landing while playing sport. This study showed that instruction and feedback, based on the key principles of the NetballSmart landing guidelines, can influence kinematic and kinetic variables in a way that is potentially beneficial towards reducing the risk of lower limb joint injury. Instruction and feedback on landing technique are simple, cost effective tools that may be useful to sports coaches and health practitioners as a means of minimising lower limb injury risk. Further research should determine the long term effects of instruction and feedback on landing technique and investigate the effects of instruction and feedback in a natural coaching environment.

### 6.2 Conclusions

Landing instruction and feedback, based on the key principles of the NetballSmart landing guidelines, led to a reduction in joint loading and influenced kinematic and kinetic variables associated with a reduced likelihood of lower limb joint injury.  The guidelines appear to be an effective strategy towards altering landing biomechanics in netball players, particularly within a young age group.  Targeting landing biomechanics in novice female netball players offers benefits for reducing lower limb injuries in later adolescence.

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# Appendices

## Appendix A

**Downs and Black Checklist for Measuring Study Quality (Downs & Black, 1998)**

**Reporting**

1. *Is the hypothesis/aim/objective of the study clearly described?*

| | |
|---|---|
| Yes | 1 |
| No | 0 |

2. *Are the main outcomes to be measured clearly described in the Introduction or Methods section?*
If the main outcomes are first mentioned in the Results section, the question should be answered no.

| | |
|---|---|
| Yes | 1 |
| No | 0 |

3. *Are the characteristics of the patients included in the study clearly described?*
In cohort studies and trials, inclusion and/or exclusion criteria should be given. In case-control studies, a case-definition and the source for controls should be given.

| | |
|---|---|
| Yes | 1 |
| No | 0 |

4. *Are the interventions of interest clearly described?*
Treatments and placebo (where relevant) that are to be compared should be clearly described.

| | |
|---|---|
| yes | 1 |
| no | 0 |

5. *Are the distributions of principal confounders in each group of subjects to be compared clearly described?*
A list of principal confounders is provided.

| | |
|---|---|
| yes | 2 |
| partially | 1 |
| no | 0 |

6. *Are the main findings of the study clearly described?*
Simple outcome data (including denominators and numerators) should be reported for all major findings so that the reader can check the major analyses and conclusions. (This question does not cover statistical tests which are considered below).

| | |
|---|---|
| yes | 1 |
| no | 0 |

7. *Does the study provide estimates of the random variability in the data for the main outcomes?*
In non-normally distributed data the inter-quartile range of results should be reported. In normally distributed data the standard error, standard deviation or confidence intervals should be reported. If the distribution of the data is not described, it must be assumed that the estimates used were appropriate and the question should be answered yes.

| | |
|---|---|
| Yes | 1 |
| No | 0 |

8. *Have all important adverse events that may be a consequence of the intervention been reported?*
This should be answered yes if the study demonstrates that there was a comprehensive attempt to measure adverse events. (A list of possible adverse events is provided).

| | |
|---|---|
| Yes | 1 |
| No | 0 |

9. *Have the characteristics of patients lost to follow-up been described?*
This should be answered yes where there were no losses to follow-up or where losses to follow-up were so small that findings would be unaffected by their inclusion. This should be answered "no" where a study does not report the number of patients lost to follow-up.

| | |
|---|---|
| yes | 1 |
| no | 0 |

10. *Have actual probability values been reported (e.g. 0.035 rather than <0.05) for the main outcomes except where the probability value is less than 0.001?*

| | |
|---|---|
| Yes | 1 |
| No | 0 |

**External validity**
All the following criteria attempt to address the representativeness of the findings of the study and whether they may be generalised to the population from which the study subjects were derived.

11. *Were the subjects asked to participate in the study representative of the entire population from which they were recruited?*
The study must identify the source population for patients and describe how the patients were selected. Patients would be representative if they comprised the entire source population, an unselected sample of consecutive patients, or a random sample. Random sampling is only feasible where a list of all members of the relevant population exists. Where a study does not report the proportion of the source population from which the patients are derived, the question should be answered as unable to determine.

| | |
|---|---|
| Yes | 1 |
| No | 0 |
| unable to determine | 0 |

12. *Were those subjects who were prepared to participate representative of the entire population from which they were recruited?*
The proportion of those asked who agreed should be stated. Validation that the sample was representative would include demonstrating that the distribution of the main confounding factors was the same in the study sample and the source population.

| | |
|---|---|
| Yes | 1 |
| No | 0 |
| unable to determine | 0 |

13. *Were the staff, places, and facilities where the patients were treated, representative of the treatment the majority of patients receive?*
For the question to be answered yes the study should demonstrate that the intervention was representative of that in use in the source population. The question should be answered no if, for example, the intervention was undertaken in a specialist centre unrepresentative of the hospitals most of the source population would attend.

| | |
|---|---|
| Yes | 1 |
| No | 0 |
| unable to determine | 0 |

**Internal validity - bias**
14. *Was an attempt made to blind study subjects to the intervention they have received?*
For studies where the patients would have no way of knowing which intervention they received, this should be answered yes.

| | |
|---|---|
| Yes | 1 |
| No | 0 |
| unable to determine | 0 |

15. *Was an attempt made to blind those measuring the main outcomes of the intervention?*

| | |
|---|---|
| Yes | 1 |
| No | 0 |
| unable to determine | 0 |

16. *If any of the results of the study were based on "data dredging", was this made clear?*
Any analyses that had not been planned at the outset of the study should be clearly indicated. If no retrospective unplanned subgroup analyses were reported, then answer yes.

| | |
|---|---|
| Yes | 1 |
| No | 0 |
| unable to determine | 0 |

17. *In trials and cohort studies, do the analyses adjust for different lengths of follow-up of patients, or in case-control studies, is the time period between the intervention and outcome the same for cases and controls?*
Where follow-up was the same for all study patients the answer should yes. If different lengths of follow-up were adjusted for by, for example, survival analysis the answer should be yes. Studies where differences in follow-up are ignored should be answered no.

| | |
|---|---|
| Yes | 1 |
| No | 0 |
| unable to determine | 0 |

18. *Were the statistical tests used to assess the main outcomes appropriate?*
The statistical techniques used must be appropriate to the data. For example nonparametric methods should be used for small sample sizes. Where little statistical analysis has been undertaken but where there is no evidence of bias, the question should be answered yes. If the distribution of the data (normal or not) is not described it must be assumed that the estimates used were appropriate and the question should be answered yes.

| | |
|---|---|
| Yes | 1 |
| No | 0 |
| unable to determine | 0 |

19. *Was compliance with the intervention/s reliable?*
Where there was non-compliance with the allocated treatment or where there was contamination of one group, the question should be answered no. For studies where the effect of any misclassification was likely to bias any association to the null, the question should be answered yes.

| | |
|---|---|
| Yes | 1 |
| No | 0 |
| unable to determine | 0 |

20. *Were the main outcome measures used accurate (valid and reliable)?*
For studies where the outcome measures are clearly described, the question should be answered yes. For studies which refer to other work or that demonstrates the outcome measures are accurate, the question should be answered as yes.

| | |
|---|---|
| Yes | 1 |
| No | 0 |
| unable to determine | 0 |

**Internal validity - confounding (selection bias)**

21. *Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited from the same population?*
For example, patients for all comparison groups should be selected from the same hospital. The question should be answered unable to determine for cohort and case-control studies where there is no information concerning the source of patients included in the study.

| | |
|---|---|
| Yes | 1 |
| No | 0 |
| unable to determine | 0 |

22. *Were study subjects in different intervention groups (trials and cohort studies) or were the cases and controls (case-control studies) recruited over the same period of time?*
For a study which does not specify the time period over which patients were recruited, the question should be answered as unable to determine.

| | |
|---|---|
| Yes | 1 |
| No | 0 |
| unable to determine | 0 |

23. *Were study subjects randomised to intervention groups?*
Studies which state that subjects were randomised should be answered yes except where method of randomisation would not ensure random allocation. For example alternate allocation would score no because it is predictable.

| | |
|---|---|
| Yes | 1 |
| No | 0 |
| unable to determine | 0 |

24. *Was the randomised intervention assignment concealed from both patients and health care staff until recruitment was complete and irrevocable?*
All non-randomised studies should be answered no. If assignment was concealed from patients but not from staff, it should be answered no.

| | |
|---|---|
| Yes | 1 |
| No | 0 |
| unable to determine | 0 |

25. *Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?*
This question should be answered no for trials if: the main conclusions of the study were based on analyses of treatment rather than intention to treat; the distribution of known confounders in the different treatment groups was not described; or the distribution of known confounders differed between the treatment groups but was not taken into account in the analyses. In nonrandomised studies if the effect of the main confounders was not investigated or confounding was demonstrated but no adjustment was made in the final analyses the question should be answered as no.

| | |
|---|---|
| Yes | 1 |
| No | 0 |
| unable to determine | 0 |

26. *Were losses of patients to follow-up taken into account?*
If the numbers of patients lost to follow-up are not reported, the question should be answered as unable to determine. If the proportion lost to follow-up was too small to affect the main findings, the question should be answered yes.

| | |
|---|---|
| Yes | 1 |
| No | 0 |
| unable to determine | 0 |

**Power**
27. *Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%?*
Sample sizes have been calculated to detect a difference of x% and y%.

| | Size of *smallest* intervention group | |
|---|---|---|
| A | $<n_1$ | 0 |
| B | $n_1$-$n_2$ | 1 |
| C | $n_3$–$n_4$ | 2 |
| D | $n_5$–$n_6$ | 3 |
| E | $n_7$–$n_8$ | 4 |
| F | $n_{8+}$ | 5 |

## Appendix B

# MEMORANDUM

## Auckland University of Technology Ethics Committee (AUTEC)

| | |
|---|---|
| To: | Mark Boocock |
| From: | **Madeline Banda** Executive Secretary, AUTEC |
| Date: | 12 April 2011 |
| Subject: | Ethics Application Number 10/306 **The effects of instruction on lower limb kinematics and kinetics during landing in female novice netball players: a preliminary study.** |

Dear Mark

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 13 December 2010 and that on 3 February 2011, I approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 9 May 2011.

Your ethics application is approved for a period of three years until 3 February 2014.
I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 3 February 2014;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. This report is to be submitted either when the approval expires on 3 February 2014 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of AUTEC and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Madeline Banda
**Executive Secretary**
**Auckland University of Technology Ethics Committee**

**Appendix C**

# Year 7 and 8 Female Netball Players wanted for Netball Landing Study

**WOULD YOU LIKE TO BE INVOLVED IN A STUDY AIMED AT PREVENTING INJURIES IN NETBALL?**


Caroline Cross is looking for volunteers to participate in a lab based study at AUT North Shore.

The study will look at landing motion, while catching a netball, using 3D motion analysis.

If you have any further questions about the study please contact Caroline Cross:

Ph: 9219999 ext 7167 or Mob: 021 887 026 or Email: c.cross@xtra.co.nz

**Approved by the Auckland University of Technology Ethics Committee on 3rd February 2011 AUTEC Reference number 10/306**

**Appendix D**

# Participant Information Sheet

**Date Information Sheet Produced:** 03/02/2011

**Study Title**
The effects of instruction on movements and forces during landing in young female netball players.

**An Invitation**
My name is Caroline Cross. I am a Physiotherapist and student at the Health and Rehabilitation Research Institute (HRRI) at Auckland University of Technology (AUT). I am inviting you to take part in a study being funded by Netball New Zealand and New Zealand Physiotherapy groups. This information sheet will help you decide if you wish to be part of the study. It is entirely your choice if you wish to take part and if you agree, you are free to withdraw at any stage without needing to give a reason. There will be no disadvantages if you decide not to be part of the study and if you do, the information about you will be destroyed. You are welcome to ask questions and ask for an explanation at any time that you do not understand.

**Why is Caroline doing this research?**
This research will look at the effects of instruction on how you land. The results of this study will be used to help coaches teach young netball players how to land.

**Why am I being invited to take part in this research?**
The netball co-ordinator at your school is aware of the study and has asked if you would like to take part. To be part of the study you need to be:

- A healthy female aged 10, 11, 12 or 13

You would be unable to participate if you have:

- an injury to your hand, wrist, elbow, shoulder, ankle, knee or hip that prevents you from safely catching a ball and landing
- a heart or breathing condition that makes it unsafe for you to perform repeated movement tasks
- hearing or visual difficulties
- received training in netball landing

**What will happen in this research?**
There are several schools taking part in this research. Each school will belong to either the experimental group, Group A or the comparison group, Group B. You will not be told which group your school belongs to as this may alter the way you perform the movement tasks. Both groups provide valuable information that we can compare. You will be asked to attend the laboratory at the HRRI on the North Shore, for about 1.5 hours. When you arrive, you can ask questions about the study. If you agree to take part, the session will involve:

1. Completing your screening questionnaire and consent forms.
2. We will measure your height and weight.
3. You will do a 10 minute light warm up session involving stationary cycling and stretches to the muscles of your legs and arms.
4. Light weight reflective balls will be attached to various points on your body with tape.
5. You will be asked to run forwards and catch a netball using two different landing styles (double footed and one to two foot). Your motion will be recorded using a nine camera 3D motion system and two video cameras which will measure the angles of your knees and ankles on landing. The forces on landing will be recorded using force platforms.
6. You will have a 30 minute session to practice your landing technique and you may be given some specific things to practice, depending on which group you are in.
7. You will repeat the landing tasks described in step 5.

**Can I hurt myself or do myself any harm? What would happen if I become sore or uncomfortable?**
There is a small risk of injuring yourself when you land. In the unlikely case you injure yourself, ice and a first aid kit will be on hand and the researcher is a qualified physiotherapist who will be able to look after you. If you have any skin allergies or irritations please notify the researcher at the beginning of the study. If you experience discomfort during the study, please notify the researcher as soon as this happens.

**What are the costs and benefits of being part of this research?**
You do not have to pay any money to be part of this research. While there are no direct benefits to you, this research will be used to inform netball coaches about movements and forces during landing.

**Can I get help if am hurt or harmed during the research?**
In the unlikely case you injure yourself as a result of being involved in this study, the Accident Compensation Corporation (ACC) may be able to help. There are certain rules that must be met for them to help you.

**How will my privacy be protected?**
The laboratory windows have curtains so no one outside the laboratory will be able to see you performing the movement tasks. The information you provide will be kept strictly confidential and will be locked away in the HRRI at AUT for ten years. After ten years the information will be destroyed. The information from your landing tasks will be given a number so that it no one, other than the researchers, knows who you are.

**How do I agree to be part of this research?**
If you have read and understood this information sheet and you and your parent or guardian have completed your consent forms (called "Participant Assent Form" and "Parent/Guardian Consent Form"), then you are welcome to take part in the study.

**What should I bring to the laboratory?**


Netball shoes


Low netball socks


Firm shorts


Firm singlet

**Will I find out the results of this research?**
Please tick the question on your form if you wish to receive information about the results of the research. The research results will be shared with Netball New Zealand staff and Physiotherapy Groups who have helped fund this research.

**What do I do if I have concerns about this research?**
Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Mark Boocock, mark.boocock@aut.ac.nz , 921 9999 ext 7167
Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, *madeline.banda@aut.ac.nz*, 921 9999 ext 8044.

**Who do I contact for further information about this research?**
***Researcher Contact Details:***
***Caroline Cross***
***Email*** c.cross@xtra.co.nz ***or phone: 9219999 ext 7167 or mobile 021 887 026***

***Project Supervisor Contact Details:***
***Mark Boocock***
***Email:*** mark.boocock@aut.ac.nz ***or phone: 9219999 ext 7167***

**Approved by the Auckland University of Technology Ethics Committee on 3rd February 2011 AUTEC Reference number 10/306**

**Appendix E**

# Parent/Guardian Information Sheet

**Date Information Sheet Produced:** 03/02/2011

**Study Title**
The effects of instruction on movements and forces during landing in young female netball players.

**An Invitation**
My name is Caroline Cross. I am a qualified physiotherapist and masters student at the Health and Rehabilitation Research Institute (HRRI) at Auckland University of Technology (AUT) and I would like to invite your child to take part in a study being funded by Netball New Zealand and New Zealand Physiotherapy organisations. Participation is entirely voluntary and if you and your child agree to participate, you are both free to withdraw at any stage prior to the completion of data collection without needing to give a reason. There will be no disadvantages if you decide to withdraw from the research and in the event that you do, the information about your child will be destroyed. You are welcome to ask questions and seek clarification about any part of the research at any time that you do not understand.

**What is the purpose of this research?**
This research aims to investigate the effects of instruction on joint movements and forces during landing. The results of this study will be used to inform how coaches teach young female netball players how to land.

**How was my child identified and why are they being invited to participate in this research?**
The netball co-ordinator at your child's/children's school has been contacted and has displayed posters inviting your child/children to participate in the study. To be part of the study your child/children need to be:

- A healthy female aged 10-13
  They would be unable to participate if they have:
- an injury to their hand, wrist, elbow, shoulder, ankle, knee or hip that prevents them from safely catching a ball and landing
- a heart or breathing condition that makes it unsafe for them to perform repeated movement tasks
- hearing or visual difficulties
- received training in netball landing

**What will happen in this research?**
Your child's school has been allocated to an experimental group, Group A, or a control group, Group B. Group B will provide valuable data to compare with Group A. Your child will be required to attend the laboratory at the HRRI at AUT North Shore for approximately 1.5 hours. On arriving you will have the opportunity to ask any questions and if you agree to your child's participation, the session will involve:

1. The completion of assent and consent forms.
2. We will measure your child's/children's height and weight.
3. They will undertake a 10 minute light warm up session involving stationary cycling and stretches to the muscles of their legs and arms.
4. Light weight reflective markers will be attached to various points on their body with tape.
5. They will be required to run forwards and catch a netball using two different landing styles (double footed and one to two foot). Their motion will be recorded using a nine camera 3D motion analysis system and two video cameras which will measure the angles of their

knees and ankles on landing. The forces on landing will be recorded using force platforms.
6. They will undergo a 30 minute landing session with either or instruction or repeated practice.
7. You will repeat the landing tasks described in step 5.

**What are the discomforts and risks and how will these be alleviated ?**
There is a small risk of your child injuring themself on landing. In the unlikely event they are injured, ice and a first aid kit will be on hand and the researcher is a qualified physiotherapist who will be able to administer care. If they have any skin allergies or irritations please notify the researcher at the beginning of the study. Your child is encouraged to notify the researcher immediately if they experience discomfort during the study.

**What are the costs and benefits of participating in this research?**
There are no monetary costs to you or your child in this research. While there are no direct benefits, this research will be used to inform netball coaches about movements and forces during landing.

**What compensation is available for injury or negligence?**
In the unlikely event of a physical injury as a result of your child's participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

**How will my child's privacy be protected?**
The testing laboratory is screened off to the public ensuring your child's privacy at all times. The information they provide will be kept strictly confidential and securely locked in the HRRI at AUT for a period of ten years. Following ten years the information will be destroyed. The data collected from their landing tasks will be assigned a numbered code so that it remains anonymous in any publication of the research.

**How does my child and I agree to participate in this research?**
If you and your child have read and understood the information sheets, upon completion of your assent and consent forms, your child is welcome to participate in the study.

**What should my child bring to the laboratory?**
Your child will be required to wear tight fitting shorts and a top and their netball shoes and socks during the testing session. This allows the light reflective balls to be attached securely to their body.

**Will I receive feedback on the results of this research?**
Please indicate on your consent form if you wish to receive information regarding the results of the research.

**What do I do if I have concerns about this research?**
Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Mark Boocock, mark.boocock@aut.ac.nz , 921 9999 ext 7167
Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, *madeline.banda@aut.ac.nz*, 921 9999 ext 8044.

**Whom do I contact for further information about this research?**
***Researcher Contact Details:***
***Caroline Cross***
***Email*** c.cross@xtra.co.nz ***or phone: 9219999 ext 7167 or mobile 021 887 026***

***Project Supervisor Contact Details:***
***Mark Boocock***
***Email:*** mark.boocock@aut.ac.nz ***or phone: 9219999 ext 7167***

**Approved by the Auckland University of Technology Ethics Committee on 3rd February 2011 AUTEC Reference number 10/306**

**Appendix F**

# Participant Screening Questionnaire

*Study title: The effects of instruction on movements and forces during landing in young female netball players.*

*Project Supervisor: Mark Boocock*

*Researchers: Caroline Cross, Mark Boocock, Duncan Reid*

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Please tick the appropriate response and complete the following questions:

**General information**

1. Are you age 10,11,12 or 13 ○ Yes ○ No
2. What is your date of birth?..........................................................................
3. Do you speak and understand English? ○ Yes ○ No

**Health related questions**

1. Have you had an injury to your ankle, knee, hip, hand, wrist, elbow or shoulder in the last 6 months that has stopped you playing netball?
   ○ Yes ○ No

   If yes, please explain:…..…………………………………………………………..
2. Have you ever experienced any heart problems?
   ○ Yes ○ No

   If yes, please explain:…..…………………………………………………………..
3. Have you ever had any breathing difficulties?
   ○ Yes ○ No

   If yes, please explain:…..…………………………………………………………
4. Have you had any surgery or major health related issues?
   ○ Yes ○ No

   If yes, please explain:…………………………………………………………………..
5. Do you have any hearing or visual difficulties?
   ○ Yes ○ No

   If yes, please explain:…..…………………………………………………………..

**Netball related questions**

1. How many years have you played netball?....……………………………………….
2. Have you ever been taught how to land? ○ Yes ○ No

***Approved by the Auckland University of Technology Ethics Committee on 3rd February 2011 AUTEC Reference number 10/306***

*Note: The Participant should retain a copy of this form.*

**Appendix G**

# Appointment Details

**Name/time/date: ADD**

*Project title: The effects of instruction on movements and forces during landing in young female netball players.*

*Project Supervisor: Mark Boocock*

*Researchers: Caroline Cross, Mark Boocock, Duncan Reid*

**Thank you for agreeing to participate in this study. Below are the details confirming your session at AUT. If you have any questions or are unable to make this appointment time please contact Caroline or Mark as soon as possible. Please make sure you bring:**

Netball shoes

Low netball socks

Firm shorts

Firm singlet


***Researcher Contact Details:***

***Caroline Cross or Mark Boocock***

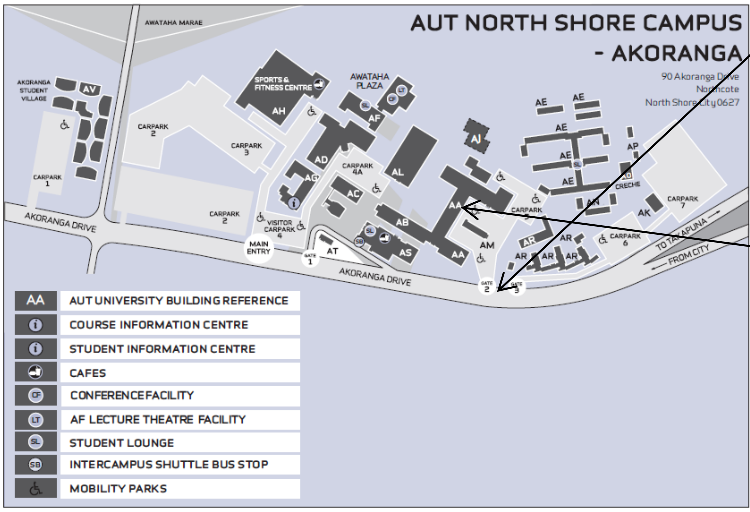
***Email*** c.cross@xtra.co.nz ***or*** mark.boocock@aut.ac.nz ***phone: 9219999 ext 7167 or Caroline mobile 021 887 026***


**Appointment details: ADD**

**Participant name and number: ADD**

**Parent/Guardian name and number: ADD**

**Where to come:**




Enter Gate 2/Car park 5 off 90 Akoranga drive

Drive down and park in one of the the disabled car parks outside AA block (Health Sciences)

Come to the door marked "AA Health and Rehabilitation Research Center" (to left)

Turn left and knock on the door of the Motion Analysis Laboratory 2 AA113 (on right)

***Approved by the Auckland University of Technology Ethics Committee on 3rd February 2011 AUTEC Reference number 10/306***

**Appendix H**

# Participant Assent Form

*Study title: The effects of instruction on movements and forces during landing in young female netball players.*

*Project Supervisor: Mark Boocock*

*Researchers: Caroline Cross, Mark Boocock, Duncan Reid*

**Please tick if you agree with the following statements:**

- ○ I have read and understood the information sheet telling me what will happen in this study and why it is important.
- ○ I have been able to ask questions and to have them answered.
- ○ I understand that my movements will be recorded using video cameras and 3D motion analysis.
- ○ I understand that while the information is being collected, I can stop being part of this study whenever I want and that it is perfectly ok for me to do this.
- ○ If I stop being part of the study, I understand that all information about me, including the video and 3D recordings or any part of them that include me, will be destroyed.
- ○ I understand that my video images will only be used for this project and will not be published without my written permission.
- ○ I understand that my video images are owned by AUT and that I do not own them.
- ○ I understand that the information I provide in the screening questionnaire is private and confidential amongst the research team which includes the project supervisor Mark Boocock, the researchers Caroline Cross and Duncan Reid and the research assistant.
- ○ I understand that the information I provide in this screening questionnaire will be kept in locked storage in the Health and Rehabilitation Research Institute at AUT and that this information will be destroyed after ten years.
- ○ I agree to take part in this research.
- ○ I wish to receive a copy of the report from the research (please tick one):

  Yes ○ No ○

Participant's signature: ......................................................……………………

Participant's name: ......................................................……………………

Participant Contact Details (phone numbers and email):

……………………………………………………………………………………..

……………………………………………………………………………………..

………………………………………………………….Date:…………..……….

***Approved by the Auckland University of Technology Ethics Committee on 3rd February 2011 AUTEC Reference number 10/306***

*Note:The Participant should retain a copy of this form.*

**Appendix I**

# Parent/Guardian Consent Form

*Study title: The effects of instruction on movements and forces during landing in young female netball players.*

*Project Supervisor: Mark Boocock*

*Researchers: Caroline Cross, Mark Boocock, Duncan Reid*

**Please tick if you agree with the following statements:**

○ I have read and understood the information provided about this research project in the Parent/Guardian Information Sheet dated 03/02/2011.

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that my child's motion will be recorded using video cameras and 3D motion analysis.

○ I understand that I may withdraw my child, their video images or any information that we have provided, at any time prior to completion of data collection, without being disadvantaged in any way.

○ If my child and/or I withdraw, I understand that all relevant information including video images and 3D motion analysis data or parts thereof, will be destroyed.

○ I understand that the video images will be used for academic purposes only and will not be published in any form outside of this project without our written permission.

○ I understand that any copyright material created by the video images is deemed to be owned by AUT and that I do not own copyright of any of the images.

○ I understand that the information my child provides in the screening questionnaire is private and confidential amongst the research team which includes the project supervisor Mark Boocock, the researchers Caroline Cross and Duncan Reid and the research assistant.

○ I understand that the information my child provides in the screening questionnaire will be kept in locked storage in the HRRI at AUT and that this information will be destroyed after ten years.

○ I agree to my child taking part in this research.

○ I wish to receive a copy of the report from the research (please tick one):

Yes ○ No ○

Child's name:………………………………………………………………………………………..

Parent/Guardian's signature:....................................……………………………………

Parent/Guardian's name:…........................................……………………………………

Parent/Guardian's Contact Details (Phone numbers and email)

……………………………………………………………………………………………………..

…………………………………………………………………………Date:……………………….

***Approved by the Auckland University of Technology Ethics Committee on 3rd February 2011 AUTEC Reference number 10/306***

*Note: The Parent/guardian should retain a copy of this form.*

**Appendix J**

# Research testing: Baseline script

**Script: Familiarisation to task**

"There are two ways we commonly land in netball: the double foot land and the one to two foot land. A double foot landing involves you landing on both feet at the same time like this (demonstrate) and the one to two foot landing involves you landing on one foot then bringing the other foot down to meet it like this (demonstrate)."

"You will now be able to practice the two types of landing while catching a ball. Firstly the double foot land then the one to two foot land. Ok, follow me…"

"I would like you to run straight forwards quickly from this marked spot (show 3m marker) as if you are on a netball court and catch a ball being passed in front of you. Imagine you are landing on two feet as if you are approaching an offside line (demonstrate). I will be the one passing you the ball."

**(Research Assistant to count practice jumps and Researcher to decide when performing the task well)**

"Now the one to two foot landing. Again, I would like you to run straight forwards quickly from this marked spot (show marker) as if you are on a netball court and catch a ball being passed in front of you. This time imagine you are landing one to two foot as if you are approaching an offside line (demonstrate). Again, I will be the one passing you the ball."

**(Research Assistant to count practice jumps and Researcher to decide when performing task well)**

**NB: if participant does not have a clear dominant leg please state the following:**

"As you start running, please make sure you step forward onto the same leg each time."

**NB: if the 3m run up distance does not look natural for the participant please state the following until a natural run up occurs:**

"This time I would like you to start your run up with your heels touching the 3m line rather than standing behind it".

"This time I would like you to start your run up with your heels on the 3.5m line".

"This time I would like you to start your run up with your toes behind the 2.5m line".

**Script: Randomisation of landing**

"Now that you're familiar with the task, we will toss a coin to decide which type of landing we will record first. Heads is a double foot landing and tails is a one to two foot landing. Heads or tails?"

"Ok, you will start with a **double foot landing/one to two foot landing**".

**Script: Double foot landing**

"I'd like you to do the same movement as you've just practiced, imagining you are running straight forwards quickly as if you are on a netball court and catch a ball being passed in front of you. Again, imagine you are landing on both feet as you are approaching an offside line. You can touch the offside line but you cannot go over it".

"It is important that you look straight ahead to the ball and that you stop and stand still with your arms forward once you have landed. I will let you know when you can move."

"When I tell you, slowly walk back to the start line and I'll let you know when to repeat the movement".

**Demonstrate double foot landing ensuring the leg you step forward on and your take off leg are the same as the participant. Ensure you keep your arms up in the ball release position, body upright and stand still. Say the words: "waiting, waiting, waiting and relax" so participant is clear on what they will hear.**

**Approximatley 30 seconds – one minute rest between each landing**

**Script: one to two foot landing**

"I'd like you to do the same movement as you've just practiced, imagining you are running straight forwards quickly as if you are on a netball court and catch a ball being passed in front of you. Again, imagine you are landing one to two foot as you are approaching an offside line. You can touch the offside line but you cannot go over it".

"It is important that you look straight ahead to the ball and that you stop and stand still with your arms forward once you have landed. I'll let you know when you can move."

"When I tell you, slowly walk back to the start line and I'll let you know when to repeat the movement".

**Demonstrate one to two foot landing ensuring the leg you step forward on and your take off leg are the same as the participant. Ensure you keep your arms up in the ball release position, body upright and stand still. Say the words: "waiting, waiting, waiting and relax" so participant is clear on what they will hear.**

**Approximatley 30 seconds – one minute rest between each landing**

**Appendix K**

# Intervention Script:
# Group A

**Script: Introduction to task**

"I will now give you three brief instructions and show you how I would like you to land for each type of landing."

"You can practice the movement after each instruction until you feel comfy".

"If I think you look good I will ask if you are ready for the next instruction".

"We will now toss a coin to decide which type of landing I will teach you first. Heads is a double foot landing and tails is a one to two foot landing. Heads or tails?"

"Ok, you will start with a **double foot landing/one to two foot landing**."

**Script: Double foot landing**

**"I would like you to run forwards to catch a ball and…**

"land on both feet, bending at your hips and knees as if you are sitting on a chair (demonstrate good and bad examples) like this…. but not like this. **Bending at your hips and knees.**"

**When researcher sees the movement being performed well ask: "Are you ready for the next instruction?"**

"land on both feet making sure that your knees are in line with your toes and not in front of your toes (demonstrate good and bad examples) like this….but not like this. **Knees in line with your toes/not in front of toes.**"

**When researcher sees the movement being performed well ask: "Are you ready for the next instruction?"**

"land on both feet softly (demonstrate good and bad examples) like this…. but not like this. **Softly.**"

**When researcher sees the movement being performed well ask: "Are you ready for the next instruction?"**

"Now you can practice everything together (demonstrate good and bad examples) like this….but not like this. **Bending at your hips and knees, knees in line with your toes/not in front of toes and landing softly.**

"You can practice until you feel comfortable with the movement. I will give you feedback and repeat any key words you should think about."

**When researcher sees the movement being performed well ask: "Are you ready for a quick break?"**

**Food/drink/rest break up to 2 minutes**

**Script: One to two foot landing**

**“I would like you to run forwards to catch a ball and…**

“land one to two foot bending at your hip and knee as if you are sitting on a chair (demonstrate good and bad examples) like this….but not like this. **Bending at your hip and knee.**”

**When researcher sees the movement being performed well ask: “Are you ready for the next instruction?”**

“land one to two foot making sure that your knee is in line with your toes and not in front of your toes (demonstrate good and bad examples) like this….but not like this. **Knee in line with toes/not in front of toes.**”

**When researcher sees the movement being performed well ask: “Are you ready for the next instruction?”**

“land one to two foot softly (demonstrate good and bad examples) like this….but not like this. **Softly.**”

**When researcher sees the movement being performed well ask: “Are you ready for the next instruction?”**

“Now you can practice everything together (demonstrate good and bad examples) like this….but not like this. **Bending at your hip and knee, knee in line with your toes/not in front of toes and landing softly.**

“You can practice until you feel comfortable with the movement. I will give you feedback and repeat any key words you should think about.”

**When researcher sees the movement being performed well ask: “Are you ready for a quick break?”**

**Food/drink/rest break up to 2 minutes**

**Appendix L**

# Intervention Script:
# Group B

**Script: Introduction to task**

"You will now have time to practice the two types of landing thoroughly and further develop your skill with them."

"You will be able to do 20 lands for each type of landing".

"We will now toss a coin to decide which type of landing you will do first. Heads is a double foot landing and tails is a one to two foot landing. Heads or tails?"

"Ok, you will start with a **double foot landing/one to two foot landing.**"

**Script: Double foot landing**

"You can now practice your double foot landing. I will pass you the ball and I will let you know when 20 lands are up. After you have caught the ball stop and stand still then pass the ball back to me and slowly walk back to the starting spot."

**Nb: provide positive feedback such as "good, great, awesome, that's fine, lovely, perfect, nice" when the participant completes a land that is correct ie lands squarely on plates and does not go offside.**

**Food/drink/rest break up to 2 minutes**

**Script: One to two foot landing**

"You can now practice your one to two foot landing. I will pass you the ball and I will let you know when 20 lands are up. After you have caught the ball stop and stand still then pass the ball back to me and slowly walk back to the starting spot".

**Nb: provide positive feedback such as "good, great, awesome, that's fine, lovely, perfect, nice" when the participant completes a land that is correct ie lands squarely on plates and does not go offside.**

**Food/drink/rest break up to 2 minutes**

**Appendix M**

**Summary of Ankle and Knee Kinematics**

*Kinematic Results Double Foot Land*

| Joint Angle (°) | Pre Instruction Mean (SD) | Confidence Interval | Post Instruction Mean (SD) | Confidence Interval | Interaction (*p* value) |
|---|---|---|---|---|---|
| Peak Ankle Dorsiflexion (Instruction) | 17.93 (4.64) | 15.62-20.24 | 27.65 (5.04) | 25.14-30.15 | <0.001 |
| Peak Ankle Dorsiflexion (Control) | 17.70 (5.27) | 15.17-20.24 | 19.38 (7.31) | 15.86-22.91 | |
| Peak Knee Flexion (Instruction) | 65.78 (9.54) | 61.04-70.53 | 86.00 (9.59) | 81.23-90.77 | <0.001 |
| Peak Knee Flexion (Control) | 64.41 (6.97) | 61.05-67.78 | 70.02 (11.69) | 64.39-75.65 | |

*Kinematic Results 1-2 Foot Land*

| Joint Angle (degrees °) | Pre Instruction Mean (SD) | Confidence Interval | Post Instruction Mean (SD) | Confidence Interval | Interaction (*p* value) |
|---|---|---|---|---|---|
| Peak Ankle Dorsiflexion (Instruction) | 14.77 (5.36) | 12.11-17.44 | 25.36 (6.44) | 22.16-28.56 | <0.001 |
| Peak Ankle Dorsiflexion (Control) | 16.87 (7.56) | 13.22-20.51 | 15.89 (7.05) | 12.49-19.29 | |
| Peak Knee Flexion (Instruction) | 54.01 (10.59) | 48.74-59.27 | 72.19 (11.09) | 66.68-77.71 | <0.001 |
| Peak Knee Flexion (Control) | 56.99 (10.75) | 51.81-62.17 | 57.92 (10.90) | 52.67-63.18 | |

**Appendix N**

**Summary of Ankle and Knee Joint Reaction Forces**

*Joint Reaction Forces Results Double Foot Land*

| Joint Reaction Forces (BW) | Pre Instruction Mean (SD) | Confidence Interval | Post Instruction Mean (SD) | Confidence Interval | Interaction (*p* value) |
|---|---|---|---|---|---|
| Peak Anterior Ankle (Instruction) | 0.70 (0.14) | 0.63-0.76 | 0.57 (0.07) | 0.54-0.61 | <0.001 |
| Peak Anterior Ankle (Control) | 0.67 (0.16) | 0.59-0.75 | 0.69 (0.17) | 0.61-0.78 | |
| Peak Vertical Ankle (Instruction) | 1.77 (0.24) | 1.65-1.89 | 1.37 (0.20) | 1.28-1.47 | <0.001 |
| Peak Vertical Ankle (Control) | 1.65 (0.39) | 1.46-1.84 | 1.71 (0.37) | 1.53-1.89 | |
| Peak Anterior Knee (Instruction) | 0.67 (0.12) | 0.61-0.73 | 0.61 (0.08) | 0.57-0.65 | 0.02 |
| Peak Anterior Knee (Control) | 0.62 (0.10) | 0.57-0.66 | 0.63 (0.08) | 0.59-0.67 | |
| Peak Vertical Knee (Instruction) | 1.61 (0.26) | 1.49-1.74 | 1.19 (0.19) | 1.10-1.29 | <0.001 |
| Peak Vertical Knee (Control) | 1.47 (0.41) | 1.28-1.67 | 1.52 (0.38) | 1.34-1.70 | |

*Note*. BW = multiple of body weight.

*Joint Reaction Forces Results 1-2 Foot Land*

| **Joint Reaction Forces (BW)** | **Pre Instruction Mean (SD)** | **Confidence Interval** | **Post Instruction Mean (SD)** | **Confidence Interval** | **Interaction (*p* value)** |
|---|---|---|---|---|---|
| Peak Anterior Ankle (Instruction) | 1.01 (0.16) | 0.93-1.09 | 0.92 (0.14) | 0.85-0.99 | 0.005 |
| Peak Anterior Ankle (Control) | 0.99 (0.21) | 0.89-1.09 | 1.04 (0.23) | 0.93-1.15 | |
| Peak Vertical Ankle (Instruction) | 2.52 (0.37) | 2.33-2.70 | 2.21 (0.37) | 2.02-2.39 | <0.001 |
| Peak Vertical Ankle (Control) | 2.21 (0.42) | 2.01-2.41 | 2.36 (0.41) | 2.16-2.56 | |
| Peak Anterior Knee (Instruction) | 0.82 (0.16) | 0.74-0.89 | 0.83 (0.11) | 0.78-0.89 | 0.644 |
| Peak Anterior Knee (Control) | 0.78 (0.14) | 0.72-0.85 | 0.82 (0.17) | 0.74-0.91 | |
| Peak Vertical Knee (Instruction) | 2.47 (0.38) | 2.28-2.65 | 2.14 (0.37) | 1.95-2.32 | <0.001 |
| Peak Vertical Knee (Control) | 2.16 (0.43) | 1.96-2.36 | 2.31 (0.39) | 2.12-2.50 | |

*Note.* BW = multiple of body weight.

**Appendix O**

**Summary of Ankle and Knee Joint Moments**

*Joint Moments Results Double Foot Land*

| Joint Moments (Nmkg-1) | Pre Instruction Mean (SD) | Confidence Interval | Post Instruction Mean (SD) | Confidence Interval | Interaction (*p* value) |
|---|---|---|---|---|---|
| Peak Ankle Plantar flexion (Instruction) | 0.84 (0.24) | 0.73-0.96 | 0.72 (0.18) | 0.63-0.81 | 0.064 |
| Peak Ankle Plantar flexion (Control) | 0.63 (0.23) | 0.52-0.74 | 0.61 (0.21) | 0.51-0.71 | |
| Peak Knee Extension (Instruction) | 1.80 (0.46) | 1.57-2.03 | 1.66 (0.34) | 1.49-1.83 | 0.008 |
| Peak Knee Extension (Control) | 1.57 (0.55) | 1.30-1.84 | 1.64 (0.52) | 1.39-1.89 | |

*Joint Moments Results 1-2 Foot Land*

| Joint Moments (Nmkg-1) | Pre Instruction Mean (SD) | Confidence Interval | Post Instruction Mean (SD) | Confidence Interval | Interaction (*p* value) |
|---|---|---|---|---|---|
| Peak Ankle Plantar flexion (Instruction) | 1.05 (0.31) | 0.90-1.21 | 1.01 (0.25) | 0.89-1.14 | 0.292 |
| Peak Ankle Plantar flexion (Control) | 0.81 (0.39) | 0.62-0.99 | 0.85 (0.33) | 0.69-1.01 | |
| Peak Knee Extension (Instruction) | 2.02 (0.59) | 1.73-2.31 | 2.08 (0.46) | 1.85-2.31 | 0.914 |
| Peak Knee Extension (Control) | 1.93 (0.64) | 1.62-2.24 | 1.98 (0.60) | 1.69-2.27 | |

**Appendix P**

**Summary of Ground Reaction Forces**

*Ground Reaction Forces Results Double Foot Land*

| Ground Reaction Forces (BW) | Pre Instruction Mean (SD) | Confidence Interval | Post Instruction Mean (SD) | Confidence Interval | Interaction (*p* value) |
|---|---|---|---|---|---|
| Peak APGRF (Instruction) | 0.62 (0.12) | 0.56-0.69 | 0.51 (0.08) | 0.48-0.55 | <0.001 |
| Peak APGRF (Control) | 0.60 (0.17) | 0.53-0.68 | 0.63 (0.17) | 0.55-0.71 | |
| Peak VGRF (Instruction) | 1.86 (0.26) | 1.73-1.99 | 1.46 (0.20) | 1.36-1.56 | <0.001 |
| Peak VGRF (Control) | 1.73 (0.41) | 1.53-1.93 | 1.80 (0.41) | 1.60-2.00 | |

*Note.* BW = multiple of body weight, APGRF = antero-posterior ground reaction forces, VGRF = vertical ground reaction forces.

*Ground Reaction Forces Results 1-2 Foot Land*

| Ground Reaction Forces (BW) | Pre Instruction Mean (SD) | Confidence Interval | Post Instruction Mean (SD) | Confidence Interval | Interaction (*p* value) |
|---|---|---|---|---|---|
| Peak APGRF (Instruction) | 0.96 (0.22) | 0.85-1.07 | 0.83 (0.15) | 0.76-0.91 | 0.01 |
| Peak APGRF (Control) | 0.99 (0.25) | 0.87-1.11 | 0.99 (0.19) | 0.90-1.08 | |
| Peak VGRF (Instruction) | 2.60 (0.37) | 2.42-2.79 | 2.31 (0.40) | 2.11-2.51 | <0.001 |
| Peak VGRF (Control) | 2.28 (0.43) | 2.07-2.48 | 2.46 (0.45) | 2.24-2.67 | |

*Note.* BW = multiple of body weight, APGRF = antero-posterior ground reaction forces, VGRF = vertical ground reaction forces.