The role of an external focus of attention on lower limb landing postures

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This thesis is submitted in total fulfillment of

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Deakin University

May 2015
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Abstract

Injuries to the anterior cruciate ligament (ACL) are disabling for the athlete. Females have been found to be at higher risk of ACL injury in comparison to their male counterparts participating in the same sports. Certain movements, such as landing from a jump and pivoting, are considered high risk for ACL injury. These are common movements in netball, a team sport which has the highest female participation rate in Australia.

The thesis examined the lower limb landing pattern of female netball players following a six-week injury prevention program. The primary aim was to evaluate the use of attentional focus of instruction in the delivery of an established injury prevention program specifically designed for netball players. The secondary aim was to assess the retention of improved landing kinematics following the cessation of the intervention program, to provide insights into the retention of motor learning in an applied community-based setting. The Landing Error Scoring System (LESS) is a clinical screening tool that assesses “at risk” landing postures. An appropriate testing protocol which is suitable for use in the field for sports such as netball allows community sporting organisations to benefit from a low cost, time efficient and effective screening tool.

The study collected data over a 12 week period from 36 participants during the 2014 Victorian Netball League (VNL) season. Eight teams in the VNL were invited to participate in the study, with three teams agreeing to participate. The three netball teams were randomly allocated to an education instruction of an external focus of attention (EFOA) injury prevention program, a Down to Earth (D2E) injury prevention program or a control group. Drop vertical jump (DVJ) landing data was collected at Week 0 (pre-intervention), at Week 6 (post-intervention) and at Week 12 (retention). Each player’s lower limb landing pattern was assessed and scored using the LESS protocol at the conclusion of the 6 week injury prevention program. While the average LESS score for the EFOA group decreased by 0.93 LESS points (4.79 pre-test to 3.86 post intervention) and for the D2E group decreased by 0.28 LESS points (6.73 pre-test to 6.45 post-test) no statistically significant differences were found. Each player’s lower limb landing
pattern was re-assessed and scored using the LESS protocol at the conclusion of a 6 week period following completion of the intervention to investigate retention of ideal landing patterns. The average LESS scores for the EFOA group increased at Week 12 (4.36) when compared to the post intervention test scores at Week 6 (3.86). The D2E scores remained the same from week 6 to week 12 (6.45). During this time the LESS test scores continued to increase for the control group between the Week 6 (5.73) and Week 12 (6.53) tests. No statistical significance for retention was found for the D2E and EFOA interventions.

Results from this thesis showed that there was no significant improvement in LESS scores following the 6 week intervention. Results of the second test for retention showed no significance for either intervention group. Further investigation into the delivery of attentional focus instruction, the retention of improved motor learning patterns and appropriate screening protocols in a community setting may be warranted.
Acknowledgements

I would like to express my sincere appreciation to Dr Natalie Saunders, who was willing to supervise me to undertake further study in an area that I always wanted to know more about. Thank you for your time and patience. You have always been very understanding of the challenges I encountered, remained positive and kept me on track throughout my candidature. Thank you also for accompanying me on the long journeys up to Ballarat to assist with some of my data collection and for your feedback on the countless drafts you have read over the duration of my thesis.

I would also like to thank my co-supervisor, Dr Jason Bonacci, for his straightforward and honest feedback, specifically with the statistical analysis and interpretation.

A special thank you to Aaron Fox for helping me to navigate through the research pathway after a long period away from formal study. Your assistance and advice on symposium and conference presentations in particular was greatly appreciated.

To the Boroondara, Ballarat and Olinda Netball organisations, thank you for granting access to your playing groups for the purposes of this research. To all the players who participated in the study, I thank you for your positive and enthusiastic approach to the study.

I would like to especially thank my wife Alexandra for her patience, counsel and positive reinforcement throughout this endeavour. Taking on a research project was a major change to our family dynamic and I truly appreciate your love and support. Our beautiful daughter Catherine has an amazing role model.
Dedication

To Alexandra & Catherine
Publications and Conference Proceedings

2014 – Podium presentation at Deakin University Research Degree Symposium
Titled “A clinical screening tool for assessing lower limb landing patterns”.

2014 – Be Active Sports Medicine Australia Conference
Poster titled: “Evaluation of a clinical screening tool for assessing lower limb landing patterns in a community setting”.
Table of figures

Figure 3.1: Study overview

Figure 3.2: Demonstration of jump-landing task for Landing Error Scoring System (LESS) clinical screening tool

Figure 3.3: Diagrammatic set up of the Landing Error Scoring System (LESS)
List of tables

Table 2.1:  Summary of randomly controlled intervention programs designed to prevent ACL injury

Table 4.1:  Mean and standard deviation for total LESS scores over time and group

Table 4.2:  Effect size calculations and classifications
Abbreviations

ACL – Anterior Cruciate Ligament
ANOVA – Analysis of Variance
CAH – Constrained Action Hypothesis
D2E – Down to Earth Injury Prevention Program
DVJ – Drop Vertical Jump
EFOA – External Focus of Attention
EMG – Electromyography
GRF – Ground Reaction Forces
IC – Initial Contact
ICC – Intraclass Correlation
IFOA – Internal Focus of Attention
LESS – Landing Error Scoring System
VNL – Victorian Netball League
## Contents

Declaration......................................................................................................................................... i  
Abstract............................................................................................................................................. ii  
Acknowledgements .......................................................................................................................... iv  
Publications and Conference proceedings ....................................................................................... vi  
Table of figures ................................................................................................................................... Error! Bookmark not defined.  
List of tables ....................................................................................................................................... Error! Bookmark not defined.  
Abbreviations .................................................................................................................................... Error! Bookmark not defined.  

Chapter One – Introduction .............................................................................................................. 1  

Chapter Two – Review of Literature .............................................................................................. 4  
  2.1 ACL injury rates and consequences in sport ............................................................................ 4  
  2.2 ACL injury prevention programs ............................................................................................. 6  
  2.3 Instruction and Motor Learning ............................................................................................... 10  
  2.4 Clinical Screening Tools for ACL Injury Risk ......................................................................... 13  
  2.5 Netball .................................................................................................................................... 15  
  2.6 Down to Earth intervention program ..................................................................................... 15  
  2.7 Study Aim .............................................................................................................................. 16  
  2.8 Hypothesis ............................................................................................................................. 16  
  2.9 Significance of Research ......................................................................................................... 16  
  2.10 Summary ............................................................................................................................... 17  

Chapter Three – Methods ............................................................................................................... 19  
  3.1 Participants ............................................................................................................................ 19  
  3.2 Study Protocol ....................................................................................................................... 19  
    3.2.1 Testing protocol .................................................................................................................. 19  
    3.2.2 LESS Screening Tool ....................................................................................................... 22  
    3.2.3 LESS Data Collection ...................................................................................................... 24  
    3.2.4 Down 2 Earth (D2E) intervention program ..................................................................... 25  
  3.3 Experimental procedures ......................................................................................................... 26  
    3.3.1 LESS Data analysis ........................................................................................................... 26  
    3.3.2 Outcome measures .......................................................................................................... 27  
    3.3.3 Statistical analysis ........................................................................................................... 27  
    3.3.4 Interrater Agreement .......................................................................................................... 28  

Chapter Four – Results .................................................................................................................... 29
Chapter Five – Discussion .............................................................................................................. 32
Chapter Six – Conclusion ........................................................................................................... 39
Chapter Seven – Limitations ...................................................................................................... 40
Chapter Eight – Future Directions ........................................................................................ 41
References....................................................................................................................................... 43
Appendix 1...................................................................................................................................... 57
Appendix 2...................................................................................................................................... 64
Appendix 3...................................................................................................................................... 65
Appendix 4...................................................................................................................................... 67
Appendix 5...................................................................................................................................... 68
Appendix 6...................................................................................................................................... 69
Chapter One – Introduction

An injury to the Anterior Cruciate Ligament (ACL) of the knee is immediately disabling for the athlete, with the majority requiring reconstructive surgery and extensive time to rehabilitate (Dempsey et al. 2009; Smith et al. 2012). The lengthy absence from competition following an ACL reconstruction can also affect the athlete’s ability to return to the sport (Dunn, Spindler & Consortium 2010; Lohmander et al. 2007; Lohmander et al. 2004). Despite a high proportion of positive surgical and functional outcomes, it has been reported that only 56% of patients who undergo ACL reconstruction return to their pre-injury level of sports activity (Ardern et al. 2011; Kvist 2004; Kvist et al. 2005). The prevalence of early onset osteoarthritis is high regardless of successful reconstructive surgery and rehabilitation (Dempsey et al. 2009; Gagnier, Morgenstern & Chess 2013; Padua et al. 2009; Renstrom et al. 2008). Females reportedly have a two to eight-fold higher risk of ACL injury compared to their male counterparts in the same sports (Hewett et al. 2012; Lim et al. 2009; Padua et al. 2012; Smith et al. 2012). The consequences of ACL injury at the community level can affect individuals as well as their family environment when attempting to manage the injury (Ardern et al. 2011). The potential physical, emotional and financial burdens from ACL injury highlight the need for ACL injury prevention initiatives.

Side-step cutting, pivoting, rapid deceleration or landing from a jump are considered high risk manoeuvres for ACL injury (Gagnier, Morgenstern & Chess 2013). Prevention education programs aimed at improving lower limb kinematic and neuromuscular function have been developed to increase awareness around high risk landing postures (Gagnier, Morgenstern & Chess 2013; Gilchrist et al. 2008; Gray et al. 1985; Herman et al. 2008; Mandelbaum et al. 2005; Messina, Farney & DeLee 1999; Moses, Orchard & Orchard 2012; Myklebust et al. 2003; Myklebust et al. 1998).
Recent epidemiological data suggests however, that in spite of ongoing initiatives in favour of neuromuscular interventions reducing ACL injury risk, ACL injury rates and the associated gender disparity have not diminished (Agel, Arendt & Bershadsky 2005; Benjaminsen & Otten 2011; Gagnier, Morgenstern & Chess 2013; Spindler & Wright 2008). Thus, the aim of future intervention programs should be to work towards understanding an ideal preventative model inclusive of physical training and education instruction to strengthen the efficacy of such programs.

A possible explanation for ongoing ACL injury rates is that the laboratory-based assessments of sporting movements may not accurately reflect the game environment. Besier et al. (2001) acknowledged this potential disparity, proposing that the transition from conscious awareness training sessions to unexpected and automatic movements during training or game involving complicated motor control adaptations may be lacking. The unplanned conditions of game and training reduce the time to make appropriate kinematic adjustments compared to pre-planned manoeuvres in a laboratory setting (Masters et al. 2008; Steenbergen et al. 2010). Intervention programs targeted to improve automaticity of movement patterns through specific motor learning strategies may provide vital insight into the successful transfer of safe landing practices to the game environment.

Feedback and education methods, including the role an external focus of attention (EFOA) plays in the acquisition of desirable motor skills, may play an important role in injury prevention (Wulf, Höß & Prinz 1998; Wulf, Höß & Prinz 2001). Recent studies have given credence to the benefits of an EFOA in maintaining optimal motor skills under stressful, anxiety provoking conditions and fatigued states in contrast to an internal focus of attention (IFOA) when learning a motor skill (de Loes, Dahlstedt & Thomee 2000; Masters et al. 2008; Wulf, McNevin & Shea 2001). The Constrained Action Hypothesis (CAH) proposes that automaticity of movement is promoted when adopting an EFOA (Kal, van der Kamp & Houdijk 2013; Lawrence et al. 2012), thus EFOA may be a viable strategy to enhance performance regarding motor mechanics (Kal, van der Kamp & Houdijk 2013; Lawrence et al. 2012; Perkins-Ceccato, Passmore & Lee 2003; Wulf 2007). To date however, there has been no research examining the efficacy
of providing instructions with an EFOA in the context of an injury prevention program. It is possible that more conscious efforts to apply motor learning principles in injury prevention research will improve the efficacy of current programs. The application of instructional methods incorporating an EFOA may be crucial in providing the transfer and retention of ideal motor learning required to withstand the rigours of training and game demands (de Loes, Dahlstedt & Thomee 2000; Masters et al. 2008; Wulf, Lauterbach & Toole 1999). Until this is known the transition of desirable motor skills into game-play may be limited.

Previous studies examining the advantages of training movement patterns with an EFOA have concentrated on very specific motor skills such as the putting action in golf (Perkins-Ceccato, Passmore & Lee 2003), correct posture and balance for skiing (Wulf 2007; Wulf, Höß & Prinz 1998) and kicking accuracy for soccer (Wulf 2007; Wulf et al. 2010a). Implementing an injury prevention program with an emphasis on an EFOA directed at whole movement patterns is a unique adoption of the CAH. Interventions aimed at improving lower limb landing patterns by adopting an EFOA challenge the current implementation of injury prevention programs. This has the potential to improve injury prevention programming, in reducing the attentional capacity required for optimal movement execution in training and game settings (Kal, van der Kamp & Houdijk 2013; Lawrence et al. 2012).

The purpose of this research therefore was to examine the role of instruction with an EFOA to improve our understanding of lower limb landing postures. Specifically, this research investigated the efficacy of instructional methods on lower limb landing postures linked to ACL injury of female athletes. The research was also intended to provide insight into the retention of motor learning in an ACL injury prevention program in an applied community-based setting.
Chapter Two – Review of Literature

2.1 ACL injury rates and consequences in sport

2.1.1 ACL injury rates

ACL injury surveillance is a critical element in understanding risks for injury and ultimately injury prevention (Moses, Orchard & Orchard 2012). It has been suggested that despite ongoing initiatives in favour of neuromuscular interventions reducing ACL injury risk, ACL injury rates have not diminished (Agel, Arendt & Bershadsky 2005; Benjaminse & Otten 2011; Gagnier, Morgenstern & Chess 2013; Spindler & Wright 2008). In particular, a review by Agel et al. (2005) surveyed ACL injury rates of NCAA soccer and basketball players over a 13 year period, and found ACL injury rates remained consistent with earlier studies (Arendt & Randall 1995).

When analysing annual ACL injury incidence rates within specific Australian sports, netball has a rate of 188 injuries per 100,000 participants in comparison to the annual incidence of ACL injuries of 52 per 100,000 participants in the Australian population (Janssen et al. 2012). An epidemiological study of netball injuries resulting in hospital admission between 2000-2004 found that ACL injury was the second most common injury behind fractures (Flood & Harrison 2009). An earlier study by Hopper, Elliot and Lalor (1995) reported a lower injury incidence rate of 19 ACL injuries per 100,000 participants in the netball population. A possible explanation for the discrepancy between the two studies may be improved reporting protocols and a greater commitment to long term injury surveillance systems by relevant medical and sporting organisations (Moses, Orchard & Orchard 2012).

2.1.2 Gender bias in ACL injury rates

A gender disparity exists in the rate of ACL injury, with females consistently reported to suffer these injuries more frequently than their male counterparts (Agel, Arendt & Bershadsky 2005; Benjaminse & Otten 2011; Ford et al. 2010;
Gagnier, Morgenstern & Chess 2013; McLean, Walker & van den Bogert 2005; Myklebust, Skjolberg & Bahr 2013; Schmitz et al. 2010; Spindler & Wright 2008). Studies specific to basketball and handball have reported a 3.79 to 8.6 times greater risk of ACL injury in females compared to their male counterparts (de Loes, Dahlstedt & Thomee 2000; Gray et al. 1985; Messina, Farney & DeLee 1999; Myklebust et al. 1998). A prospective cohort study by Myklebust et al., (1998) differentiated between non-contact and contact injury rates for elite European Handball players and found females suffered ACL injuries at a rate of 0.31 per 1000 athlete exposures, compared to males at a rate of 0.06 per 1000 athlete exposures. A seven year study undertaken by de Loes et al. (2000) identified knee injury to be consistently higher in females in comparison to their male counterparts. de Loes et al. identified an 8.6 times greater risk for ACL injury in female gymnasts (de Loes, Dahlstedt & Thomee 2000). While both genders experience ACL injury, a greater emphasis may be required to clarify our understanding of the gender-specific causes of injury rate in female athletes. The status quo in ACL injury rates indicate that further research is required to develop intervention programs specifically targeted towards reducing injury rates in female sporting participants (Benjaminse & Otten 2011; Gagnier, Morgenstern & Chess 2013).

2.1.3 ACL injury consequences

The consequences of an ACL injury on an athlete can be substantial. An ACL injury resulting in reconstructive surgery results in the longest time loss from a sport for the participant compared to other sporting injuries requiring corrective surgery (Hootman, Dick & Agel 2007). Following surgical repair, comprehensive rehabilitation and time away from the sport are common immediate consequences experienced by the athlete (Dempsey et al. 2009). It has been well documented that a lengthy absence from competition following an ACL reconstruction can dramatically affect an athlete’s ability to return to play (Dunn, Spindler & Consortium 2010; Lohmander et al. 2007; Lohmander et al. 2004). In addition, early onset osteoarthritis following ACL injury, potentially resulting in a life-long disability, is a reality (Lohmander et al. 2007; Quatman & Hewett 2009). ACL
injury can have a broad negative impact on participants in community level sport and on their family and work environments. Targeted ACL injury prevention research, aimed at the community level athlete, may therefore result in the development of intervention programmes that are more applicable, and thus likely to be more successful in reducing non-contact ACL injury rates in the wider sporting community.

### 2.2 ACL injury prevention programs

Approximately 80% of ACL injuries occur from a non-contact event and are theoretically preventable (Sadoghi, von Keudell & Vavken 2012). Current injury intervention programs have been implemented and measured in their efforts to reduce ACL injury rates (Gilchrist et al. 2008; Gray et al. 1985; Mandelbaum et al. 2005; Myklebust et al. 2003; Soderman et al. 2000) and/or alter biomechanical or neuromuscular risk factors (Hewett et al. 1999; LaBella et al. 2011; Mandelbaum et al. 2005; Myklebust et al. 2003; Pollard et al. 2006; Walden et al. 2012; Zazulak et al. 2007). Intervention programs aimed at altering lower limb neuromuscular control and biomechanics deemed “at risk” for ACL injury have continued to evolve. A recent meta-analysis (Sadoghi, von Keudell & Vavken 2012) provided strong evidence for a significant, positive effect of ACL injury prevention programs, with female athletes reducing risk of injury by 52%. Analysis to determine the ideal training program to avoid ACL injury was conducted by Sadoghi et al. (2012b). The authors concluded that the inability to determine conclusively that a specific type of intervention was the “best” training program to avoid ACL injury may have been due to the challenge of heterogeneity amongst the studies examined (Sadoghi, von Keudell & Vavken 2012). However, there was general agreement that an ACL injury prevention program should comprise three sessions a week, each of at least ten minutes duration, with a focus on neuromuscular training (Sadoghi, von Keudell & Vavken 2012). Neuromuscular training may consist of strengthening specific muscle groups to improve at risk postures, such as valgus moment and/or tibial valgus and internal rotation (Hewett et al. 1999; Shultz et al. 2012). As is evident from the information contained in Table 2.1, the majority of studies focus on physical skills, with only
a few incorporating education-based components. While it is recommended that all ACL injury prevention programs incorporate neuromuscular training, the instructional or educational method of delivery may enhance the success of the program. Educators commonly use instruction to pass on information to refine and teach motor performance (Benjaminse & Otten 2011). Intervention programs that integrate instruction-based strategies have been shown to be efficacious in reducing the rate of ACL injury (Gilchrist et al. 2008; Petersen et al. 2005). Understanding the mechanisms and variables that influence performance and learning will improve intervention practice. Successful long-term retention of such learning may require an alternative method of education instruction. The role of attentional focus on motor learning and its potential to support an improvement of injury prevention warrants further investigation, particularly with the ongoing ACL injury rates (Benjaminse & Otten 2011).

Improved injury surveillance, rule changes, speed of play and an increase in female sports participation may have all contributed to the increases in ACL injury estimates (Hewett et al. 1999; Quatman & Hewett 2009). The reported success of intervention programs does not appear to have translated to the context of the community level athlete (Quatman & Hewett 2009). It is possible this is due to coaches being unaware as to how to implement injury prevention programs and thus focusing on improved sporting performance (Poolton, Masters & Maxwell 2005). In addition, the lack of knowledge surrounding translation from conscious awareness of motor skills during intervention may explain ongoing ACL injury rates (Hume & Steele 2000; Masters et al. 2008; McManus, Stevenson & Finch 2006; Steenbergen et al. 2010). To date, while education has been incorporated into intervention practice, often to correct poor postures during high-risk tasks, implementing education using evidence-based motor learning strategies seems to be lacking. As a result, mechanisms by which targeted prevention programs are provided and how they impact injury intervention strategies warrant further investigation. Given the high level of participation in sport at the community level in Australia, understanding the essential elements of a program is imperative. This may improve intervention practice and the capacity to implement intervention programs at the community level on a large scale. Adopting strategies with an
EFOA as part of the intervention program may be an appropriate approach to improve the success of interventions in the wider sporting community. In addition, integrating intervention strategies into current training practice would be preferable to increasing the physical loading on athletes. Therefore, efforts to understand the effect of instruction using evidence-based motor learning strategies versus education and physical training practice are also warranted. Until the essential elements of an intervention program in the wider sporting community are known and properly implemented, it is difficult to design targeted strategies that provide a protective benefit for all involved. Such targeted strategies are important, as prevention programs that form a part of regular preparation for competition may have important implications for performance improvements in applied settings.
Table 2.1  Summary of randomly controlled intervention programs designed to prevent ACL injury

<table>
<thead>
<tr>
<th>Study</th>
<th>Sport / Teams</th>
<th>Ages</th>
<th>Length</th>
<th>Frequency</th>
<th>Duration</th>
<th>Type</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heidt et al. (1995)</td>
<td>Soccer</td>
<td>14-18 year (range)</td>
<td>75 min</td>
<td>3 days per week in preseason</td>
<td>7 weeks</td>
<td>Cardiovascular, plyometrics, strength, flexibility, agility and sports specific drills</td>
<td>After 4 month observation, ACL injury rate in intervention group was 2.38% and 3.10% in control group</td>
</tr>
<tr>
<td>Hewett et al. (1999)</td>
<td>Soccer, Volleyball, Basketball</td>
<td>14-16 year (range)</td>
<td>Approx. 30 min</td>
<td>3 days per week in preseason</td>
<td>6 weeks</td>
<td>Stretching, plyometrics, weight training</td>
<td>Peak jump landing forces decreased by 22% Knee adduction/abduction moments decreased by approximately 50%</td>
</tr>
<tr>
<td>Myklebust et al. (2003)</td>
<td>Handball</td>
<td>21-22 year (mean)</td>
<td>15 min</td>
<td>3 days per week rest of the season (3 seasons)</td>
<td>7 weeks</td>
<td>Balance with mats, wobble boards</td>
<td>Year 1 – ACL incidence rate 0.14/1000 hours intervention  Year 2 - 0.13/1000 hours  Year 3 – 0.09/1000 hours</td>
</tr>
<tr>
<td>Mandelbaum et al. (2005)</td>
<td>Soccer</td>
<td>14-18 year (range)</td>
<td>20 min</td>
<td>2-3 times per week in-season</td>
<td>3 competitive soccer seasons (12 weeks per season)</td>
<td>Basic warm-up, stretching, strengthening, plyometrics, agility</td>
<td>88% decrease in ACL injury in intervention group compared to control group in season one &amp; 74% in season 2</td>
</tr>
<tr>
<td>Petersen et al. (2005)</td>
<td>Handball</td>
<td>Control: 19.8 and Intervention: 19.4 (mean)</td>
<td>10 min</td>
<td>3 times per week in preseason. Once a week for the rest of the season.</td>
<td>8 weeks</td>
<td>Education, balance board, exercise, jump training</td>
<td>Intervention group ACL incidence rate 0.04/1000 hours athlete exposure  Control group 0.21/1000 hours athlete exposure</td>
</tr>
<tr>
<td>Steffen et al. (2008)</td>
<td>Soccer, Volleyball, Basketball</td>
<td>15.4 year (mean)</td>
<td>15 min</td>
<td>15 consecutive sessions. Once a week for the rest of the season.</td>
<td>7.5 months</td>
<td>Core stability, balance, plyometrics</td>
<td>Intervention group ACL incidence rate 0.06/1000 hours  Control group 0.08/1000 hours</td>
</tr>
<tr>
<td>Gilchrist et al. (2008)</td>
<td>Soccer</td>
<td>19.9 (mean)</td>
<td>20 min</td>
<td>3 times per week in-season</td>
<td>1 competitive soccer season (4-5 months)</td>
<td>Basic warm-up, stretching, strengthening, plyometrics, agility, Video education</td>
<td>Overall ACL injury in intervention group 1.7 times less than the control group</td>
</tr>
<tr>
<td>LaBella et al (2011)</td>
<td>Soccer, Basketball</td>
<td>16.2 (mean)</td>
<td>20 min</td>
<td>3 times per week pre and in-season</td>
<td>1 competitive season (4-5months)</td>
<td>Strengthening, plyometrics, balance, agility.</td>
<td>Intervention injury rate 0.08/1000 hours athlete exposure  Control injury rate 0.48/1000 hours athlete exposure</td>
</tr>
</tbody>
</table>
2.3 Instruction and Motor Learning

Educators commonly use instruction to pass on goal-related information to refine and teach motor performance (Benjaminse & Otten 2011). Design and delivery of ACL injury prevention programs should consider how skill learning can be facilitated and how performance can be optimised (Gokeler et al. 2015; Wulf, Chiviacowsky & Drews 2015). Understanding the mechanisms and variables that influence performance and learning will improve intervention practice. To date, there has been converging evidence demonstrating that the focus of attention induced by instructions or feedback provided to learners can have a significant impact on motor skill learning (Wulf, McNevin & Shea 2001).

2.3.1 Attentional Focus

Directing one’s movement through an EFOA has been found to result in superior motor performance compared to adopting an internal focus of attention (IFOA) (Gokeler et al. 2015; Kal, van der Kamp & Houdijk 2013; Wulf, McNevin & Shea 2001; Wulf & Su 2007). Wulf, McNevin and Shea (2001b) proposed the Constrained Action Hypothesis (CAH) to explain the efficacy of differing attentional focus on performance. According to the CAH ‘trying to consciously control one’s movements constrains the motor system by interfering with automatic motor control processes that would ‘normally’ regulate the movement’ (Wulf et al., 2001b, p. 1144). (p. 1144) EFOA refers to the acquisition of a motor skill without the concurrent acquisition of explicit knowledge about the performance of that skill that is normally processed in an automatic way (Wulf, McNevin & Shea 2001). By contrast, adopting an IFOA refers to focussing on the movement pattern itself and includes more deliberate and conscious control of movement, thereby constraining or disrupting ‘normal’ automatic control process.

Support for the CAH has been demonstrated across a variety of domains and populations (Lawrence et al. 2012; Wulf 2007). The CAH has provided a possible explanation for the effects of focus of attention in a variety of tasks, such as improved movement accuracy (Southard 2011; Zachry et al. 2005) expediting the motor skill learning process (Wulf, Höß & Prinz 1998), enhancing movement
automisation (Kal, van der Kamp & Houdijk 2013; Zachry et al. 2005), balancing (Shea & Wulf 1999), jumping (Prapavessis & McNair 1999; Wulf et al. 2010b) and greater risk to skill failure under pressure (Ong, Bowcock & Hodges 2010). Positive outcomes were demonstrated when implementing the use of EFOA suggesting that an EFOA may be a welcome addition to further enhance ACL injury prevention programs. Studies examining the nature of attentional focus have tended to investigate relatively simple learning and performance changes based solely on performance outcomes (e.g., distance of throw, jump height or successful attempts) (Prapavessis & McNair 1999; Southard 2011; Wulf et al. 2010b; Zachry et al. 2005). Further examination of the effects of different attentional focus tasks and automaticity of movement is required to investigate the assumptions of the CAH in the context of an ACL injury prevention program.

A common method to assess automaticity of movement is to consider the effects of secondary task loading on the primary motor task performance (Abernethy 1988). The assumption is that the demand on working memory is substantially higher with controlled movements in comparison to automised movements. Therefore, the execution of a secondary task is expected to interfere with the performance on a consciously controlled motor task (i.e., movements performed with an IFOA) but should not affect performance on an automised task (i.e., movements performed with EFOA) to the same extent. To date, only a few studies have investigated the effects of attentional focus on a dual task performance. Wulf, McNevin and Shea (2001b) found an EFOA was associated with improved balancing performance, and swifter reactions to auditory stimuli during balancing compared to an IFOA. Poolton et al., (2006) found similar findings for golf putting performance when attention was focussed externally, but not when attention was focussed internally. Although these results show promising developments with possible transfer of EFOA instruction into more complex motor learning scenarios, such as improving lower limb landing mechanics, a limitation of these studies is that they did not control for differences in task prioritization in dual task conditions.

A study by Kal et al., (2013) aimed to measure attentional focus on automisation of movement by assessing dual task interference through the analysis of
movement execution parameters associated with automaticity (Kal, van der Kamp & Houdijk 2013). The dual task procedure consisted of a single leg motor task and a cognitive letter fluency task (participants were required to name words with a specified letter in a certain amount of time). Electromyographic (EMG) activity was assessed to indicate to what extent the movements are under automatic or conscious control. The rationale was that more consciously controlled movement results in more EMG (internal focus) activity, as opposed to the external focus and automatically performed movement requiring less EMG activity (Kal, van der Kamp & Houdijk 2013; Wulf et al. 2010b). The results showed an EFOA displayed superior motor performance under the dual task condition compared to the IFOA. Of particular interest was the IFOA condition demonstrated an interference with the secondary cognitive task only, and not the performance of the motor task. Kal et al., found EFOA remained robust under dual test conditions and supported previous studies on attentional focus and the CAH. Dual task interference and EFOA may provide a greater explanation to the sustained ACL injury rates in spite of ongoing initiatives in favour of neuromuscular interventions reducing ACL injury risk (Agel, Arendt & Bershadsky 2005; Benjaminse & Otten 2011; Gagnier, Morgenstern & Chess 2013; Spindler & Wright 2008). Intervention programs adopting EFOA in favour of IFOA may find a greater transfer of improved lower limb landing patterns, particularly under competitive game conditions.

2.3.2 Retention of motor skills

Research has provided strong evidence for improvements in motor learning resulting from adoption of an EFOA being more effectively retained than when adopting an IFOA (Kal, van der Kamp & Houdijk 2013; Lawrence et al. 2012; Wulf 2007; Wulf, McNevin & Shea 2001; Wulf & Su 2007). A key issue, particularly at the conclusion of an injury intervention program, is whether the external focus advantage is a temporary learning effect or more permanent.Retention of skill with EFOA instruction has been established in ski simulator (stabilometer platform), (Wulf, Höß & Prinz 1998), golf pitching performance (Wulf, Lauterbach & Toole 1999; Wulf & Su 2007) and performing a “lay up” basketball shot (Zachry et al. 2005). A possible limitation to these studies is the
test for retention was administered between one and seven days post skill instruction. Although results for EFOA and retention from these studies are encouraging, further research is required to test for skill retention in longer time frames.

Typically an ACL injury prevention program will commence at the pre-season phase and continue for 6-12 weeks (Heidt et al. 2000; Hewett et al. 1999; Mandelbaum et al. 2005; Myklebust et al. 2003; Petersen et al. 2005). Other programs have continued throughout the entire season (Gilchrist et al. 2008; Padua et al. 2012; Steffen et al. 2008). Irrespective of program length, long term retention of desirable motor skills to prevent injury are crucial. Padua et al., (2012) examined the retention of lower limb landing patterns using a clinical assessment tool (Landing Error Scoring System (LESS)) following a 3-month and 9-month intervention. Following a 3-month ‘detraining period’ Padua et al., (2012) observed retention of movement quality in post test scores in the 9-month intervention group. However, the 3-month intervention group returned to their pre-test scores following the retention test. Interestingly the attentional instruction given to the participants were internally focussed. The results may indicate that extended duration training may have facilitated “learning” of a new movement pattern, however transfer of the skill to the robust nature of game play is unknown. Longitudinal studies examining ACL injury rates following an ACL intervention program may be required to determine the short and long term benefits of ACL injury prevention initiatives.

2.4 Clinical Screening Tools for ACL Injury Risk

The use of valid and reliable field-based screening tools to evaluate individuals at risk for ACL injury is essential to target appropriate intervention programs in the wider sporting community (Onate et al. 2010; Padua et al. 2012). While laboratory based measures provide the gold standard for investigating biomechanical and neuromuscular risk factors, they are limited in their clinical application (Onate et al. 2010). An appropriate testing protocol which is suitable for use in the field for sports such as basketball, netball and volleyball allows community sporting organisations to benefit from a low cost, time efficient and effective screening
tool. It is therefore reasonable to use the LESS in the context of conducting a community based intervention program.

Existing clinical screening tools that have been developed to identify athletes with an increased risk of lower limb and ACL injury include the side step, side jump and shuttle run, (McLean et al. 2005) repeated 10 second tuck jump, (Myer, Ford & Hewett 2008) the LESS (Padua et al. 2009) and anthropometric, strength and biomechanical landing measures (Myer, Ford & Hewett 2011). The LESS presents as the strongest clinical screening tool in comparison to the other aforementioned screening tools due to established validity and reliability posited in the literature to date (DiStefano et al. 2009; Gokeler et al. 2014; Onate et al. 2010; Padua et al. 2011; Padua et al. 2009). To determine inter-rater reliability Padua et al. (2009) randomly selected 50 subjects from a pool of 2691 subjects participating in a LESS trial. Statistical analysis showed ICC$_{2,k}$ and standard error of measure (SEM) 0.84 and 0.71 respectively, indicating good inter-rater reliability. A subsequent study by Onate et al. (2010) to assess the validity of the LESS compared 3-dimensional (3D) motion analysis and concurrently evaluated inter-rater reliability of novice versus expert raters. Kappa correlation between the expert and novice raters ranged from moderate to excellent (k = .459-.875) and intraclass correlation coefficient was excellent (ICC$_{2,1} = .835, P < .001$) supporting the earlier results of Padua et al. (2009). Developed as an injury risk factor screening tool with clinical applications to detect poor jump-landing biomechanics, the LESS is a simple and inexpensive evaluation tool (Onate et al. 2010). A prospective study by Smith et al. (2012) concluded that the LESS was not a predictive tool for ACL injury. To date there is not a clinical screening or laboratory based assessment tool that can reliably predict the occurrence of an ACL injury in an individual. The LESS identifies individuals with poor jump-landing technique who may be at risk for non-contact ACL injuries (DiStefano et al. 2009; Onate et al. 2010; Padua et al. 2012). The LESS endeavours to measure outcomes relating to injury risk. The output provided by a LESS assessment may assist in determining an appropriate injury prevention program to reduce injury risk.
2.5 Netball

Netball is a fast-paced game predominantly played by females, and has the highest female participation rates for team sports in Australia (ABS 2015). Typical movement patterns in netball include sudden changes of direction or rapid decelerations, leaping and landing from one or two feet (Hume & Steele 2000; McManus, Stevenson & Finch 2006). An injury surveillance study conducted by Hume and Steele (2000) examined the injury rates of 940 participants at a sub-elite netball competition. The authors reported the ankle and knee were the most frequently injured body parts (Hume & Steele 2000). Of 113 injuries that were reported, 2% were reported to be an ACL rupture (Hume and Steele, 2000). 30% of injuries were reported to occur during a change of direction, an incorrect landing or a combination of movements involving a poor landing (Hume and Steele, 2000). Netball’s high female participation rate coupled with injury risk suggest that netball provides an ideal cohort to study ACL injury and lower limb landing postures. In particular, how the provision of targeted prevention programs can provide information for ongoing injury prevention intervention strategies.

2.6 Down to Earth intervention program

The ‘Down to Earth’ (D2E) program (Saunders et al. 2010) is a specifically designed intervention program for netball. The development of the D2E program is based on exercises used in successful intervention programs by Hewett et al., (1996) and Myklebust et al., (2003) (Table 2.1) with exercise modifications specific to netball embedded into the program. The D2E program has previously been successfully implemented in community netball programs with 88% of coaches believing the program improved their players’ ability to perform correct landing techniques in games (Saunders et al. 2010).

D2E incorporates a progression of coach led and home-based exercises over a six-week period to enhance the capability of players to land safely and effectively during game and training situations. Presently the D2E program is incorporated into the Australian National Coaching Program module. The D2E program incorporates both EFOA and IFOA elements. The guidelines for safe and effective
landing which form the basis of the feedback throughout the schedule are predominantly IFOA instructions. For example, guideline 1 “Control the hip and knee” and guideline 2 “Keep the knee and toe direction the same” demonstrate IFOA, as they focus on the movement pattern itself, which includes a more deliberate and conscious control of movement. The final guideline for feedback also calls for the participant to adopt an IFOA by ensuring a “bent knee on landing” combined with an EFOA of a “soft” landing. The 6 week coach directed training program includes EFOA drills and skills, however the coaching instruction is through the feedback guidelines and is predominately IFOA.

2.7 Study Aim

The purpose of this research was to examine the role of instructional methods on motor learning, specifically lower limb landing postures of female athletes following an intervention program, in an effort to enhance our understanding surrounding ACL injury prevention strategies. In addition, the secondary aim was to determine whether instruction with an EFOA leads to greater retention of preferred motor skills.

2.8 Hypothesis

It was hypothesised that:

i. There would be an improvement in lower limb landing postures resulting in a reduced LESS score at 6 weeks for the D2E EFOA instruction group when compared to the established D2E injury prevention program and the control group; and

ii. Retention of improved lower limb landing postures would be greater with the D2E EFOA group when compared to the established D2E injury prevention program and the control group after 12 weeks.

2.9 Significance of Research

Existing ACL injury prevention programs traditionally adopt strategies that focus on the improvement of movement patterns through an IFOA. Whilst these
programs have proved efficacious in the laboratory settings, translation and retention of ideal movement patterns to the training and game environment involving unexpected and automatic movements has not improved. Specifically, this research investigated the efficacy of instructional methods in conjunction with a tailored intervention program targeting effective lower limb control. The findings provide insights into the effectiveness of targeted instruction methods on lower limb landing postures as part of an overall injury prevention program. The EFOA intervention program and the LESS screening tool were chosen as they involve uncomplicated delivery and low technological demands. As such, potentially successful outcomes of the intervention would be deliverable and translatable in a manner which is immediately applicable and accessible to the wider community.

2.10 Summary

Injury prevention programs have been implemented in an effort to reduce ACL injury (Gilchrist et al. 2008; Gray et al. 1985; Hewett et al. 1999; Mandelbaum et al. 2005; Myklebust et al. 2003; Pollard et al. 2006; Soderman et al. 2000; Walden et al. 2012; Zazulak et al. 2007). While these programs have been deemed successful, ACL injury rates have remained relatively unchanged (Agel, Arendt & Bershadsky 2005). Innovative strategies are required to bridge the gap between successful ACL injury prevention programs in clinical settings and ACL injury rates in the wider sporting community. Future intervention programs may need an EFOA to improve the retention of motor learning specifically in a lower limb landing posture. Until this is known, targeted strategies that provide a protective benefit for all involved cannot be effectively designed.

In Australia, netball provides an ideal cohort to study lower limb landing postures associated with ACL injury. The physical demands of the sport involve the execution of high-risk sporting tasks that have been linked to ACL injury. In addition, given its high female participation levels, netball also provides an ideal cohort to consider the most appropriate form of intervention that has regard for, and targets the constraints of, community sport.
This research investigated the efficacy of targeted instruction methods used with a tailored intervention program. The purpose was to gain insight into the effectiveness of targeted instruction methods as part of an overall injury prevention program.
Chapter Three – Methods

3.1 Participants

Female netball players (aged 18 years and above) volunteered to take part in this study and provided written informed consent prior to commencement of participation and testing. Players for the study were recruited from the Victorian Netball League (VNL). Eight teams in the VNL were invited to participate in the study, with three teams agreeing to participate. A further two teams were excluded due a perceived conflict of interest. Participant age, weight, height, injury history, playing experience and level of competition were collected prior to the first testing session. The inclusion criteria for the study involved:

1. Aged 18 years of age or above;
2. Regularly (one or more times a week) competed in competitive team sport competition;
3. Physically able to perform the prescribed movement tasks;
4. Had no lower limb joint injury in the six months preceding testing.

3.2 Study Protocol

3.2.1 Testing protocol

Testing for the study was undertaken over a twelve-week period. An overview of the study protocol is contained in Figure 3.1. Each participant was required to report to their team training session in Week 0 (Testing Session One) where they were tested using the LESS. Participants were randomly allocated a position in the testing order.

Following Testing Session One, group allocation was undertaken. Due to the intervention being embedded into the recruited team’s training sessions, a cluster randomisation protocol was used, with teams randomly allocated to either a control group, or one of the two intervention groups (Figure 3.1). Participants in
the teams allocated to the intervention groups were then allocated to either the established D2E program (http://www.netball.asn.au/_uploads/res/1_85401.pdf) or the modified D2E EFOA program exclusively containing the EFOA instructions to be included as part of their regular training practice for the subsequent six weeks (Appendix 1). The control group continued with regular training practice for twelve weeks. The modified D2E (EFOA) intervention and the established D2E program were delivered by the primary researcher. Subject attendance was recorded by the primary researcher before the commencement of each training session for the duration of the intervention. Overall attendance for each subject was calculated as a percentage value for each training session attended by the individual against the maximum number of training sessions offered for each intervention group (see Appendix 2).

After the six-week intervention period, participants were required to report to their usual training venue where they undertook the same test performed during Testing Session One. The order for the LESS assessment was once again randomly allocated across participants with testing completed before the training session commenced. Following Testing Session Two the intervention ceased and all participants resumed their regular training practice. The primary researcher ceased delivery of the intervention and instructed team coaches to return to normal training practices as prior to the intervention. In week twelve, participants were required to report to their usual training venue where they undertook the same test performed during Training Session One. The order for the LESS assessment was once again randomly allocated across participants with testing completed before the training session commenced.
** Refer to Appendix 2 for individual training opportunities and subject participation for EFOA and D2E interventions.

Figure 3.1: Study overview
3.2.2 LESS Screening Tool

The LESS clinical screening tool involves the performance of a Drop Vertical Jump (DVJ) landing task. The DVJ landing task incorporates both horizontal and vertical movements (Figure 3.2). Participants are required to jump from a 30cm high box to a distance 50% of their height away from the box on the ground and immediately rebound for a maximal vertical jump on landing (Figure 3.3) (Padua et al. 2009). During task instruction, emphasis was placed on participants jumping as high as they could once they landed from jumping off the box. Participants did not receive any feedback or coaching on their landing technique unless they were performing the task incorrectly. After task instruction, participants were given as many practice trials as needed (typically 2) to perform the task successfully. A successful jump was characterized by (1) jumping off of both feet from the box; (2) jumping forward, but not vertically; (3) landing with the entire foot of the non-dominant lower extremity in the landing area; and (4) completing the task in a fluid motion. Participants performed 3 successful trials of the DVJ landing task. Total testing time, including setup, was typically 5 minutes or less per subject.

Figure 3.2: Demonstration of jump-landing task for LESS clinical screening tool (Adapted from (Padua et al. 2012)).
Figure 3.3: Diagrammatic set up of the Landing Error Scoring System (LESS)
3.2.3 LESS Data Collection

Two standard digital video cameras were used to capture a frontal and sagittal plane view of each participant’s landing trial. Both the frontal and sagittal cameras were positioned according to the LESS protocol, 3.54 metres away from the landing area and 1.22 metres from the lens of the camera to the floor (Padua et al. 2009). A 30 cm box was placed a distance 50% of the participant’s height from the landing area (Padua et al. 2009) with the participant performing the DVJ landing task off this box onto the landing area (Figure 3.2).

The LESS score is calculated from the video recording of three successful landing trials. The LESS score is a count of landing technique “errors” based on a range of observable items (Padua et al. 2009). A higher LESS score indicates poor landing technique in landing from a jump, while a lower score indicates a better landing jump technique (Padua et al. 2009). Appendix 3 provides operational definitions, the camera view used and the scoring details for each item. There are 17 scored items in the LESS. The maximum score attainable is 19. Items 1-6 address lower extremity and trunk positioning at the time of initial contact (IC) with the ground. Items 7-11 assess errors in positioning of the feet at IC, at the time the entire foot is in contact with the ground, and the time between IC and maximum knee flexion. Items 12-15 assess the lower extremity and trunk movements between IC and the moment of maximum knee flexion and valgus. Items 16 and 17 are ‘global’ assessments of overall sagittal plane movement and the rater’s general perception of landing quality (Padua et al. 2009). Scoring was undertaken by the same investigator across all participants. Participants were asked to remove any knee or ankle braces for the LESS trials. Ankle taping was allowed as long as the participant continued to tape in a consistent manner for all the LESS trials and time points throughout the study.
3.2.4 Down 2 Earth (D2E) intervention program

The D2E program has been adapted from current intervention programs (Hewett et al., 1996, Myklebust et al., 2003) to meet the specific physiological demands of netball. The D2E program includes a fading feedback schedule for safe and effective landing to optimise ideal skill transfer to the game setting (Saunders 2006). A strength of the D2E program was that the simple 15-20 minute intervention could be embedded into an ongoing training regime for the community level athlete. This time efficient programme relevant to the needs of competitive netball players also maximises compliance. In addition to the six-week intervention program, the D2E intervention includes a suggested warm up (with guidelines for safe and effective landing) and a home based program for players to follow concurrently with the intervention (http://www.netball.asn.au/uploads/res/1_85401.pdf for the established D2E program). The guidelines for safe and effective landing given to participants include a direction to keep the knee and the toe direction the same. For the purposes of the intervention used in the current study, the coach led only program under D2E was followed (Saunders et al. 2010).

3.2.5 Modified Down 2 Earth (D2E EFOA) intervention program

The modified D2E program comprised solely of EFOA instruction. For the D2E EFOA intervention program all identified IFOA education and feedback instruction throughout the six-week intervention program were replaced with EFOA instruction and feedback. The modified D2E EFOA program requires participants for some tasks to hold a stick horizontally as part of the EFOA instruction. The reference to a “stick” throughout the modified D2E EFOA program (Appendix 1) is a broom handle used for EFOA instruction during dynamic landing conditions. The fading feedback with regards to movement instruction was also followed, congruent with the established D2E program. This exchange of IFOA instructions for EFOA instruction and exercise manipulation was the only variation to the
established D2E program. For example, the established D2E guidelines for effective landing encourage the participant to “keep the knee and toe direction the same”. With the assistance of the coach or another player the participant is required to place increased emphasis on the movement pattern itself, thus demonstrating IFOA movement pattern. The instructional exchange to an EFOA is to instruct the participant to “point shoelaces ahead and keep the stick as balanced horizontally as possible”. The EFOA instruction is delivering a motor skill to the participant without the explicit knowledge of the knee and/or foot position so the landing pattern skill can be performed as a whole movement pattern and therefore processed automatically.

With the exception of feedback and exercise prescription manipulation to reflect a greater EFOA discussed above, the established D2E program, including the warm-up, was followed for the EFOA D2E program. However, the suggested home based program component of the established D2E program was not included as part of the study due to difficulties surrounding compliance and monitoring.

3.3 Experimental procedures

3.3.1 LESS Data analysis

The frontal and sagittal plane video from the LESS DVJ landing task was imported into ImageJ video analysis software. ImageJ is an open source processing program designed for scientific multidimensional images. Each participant was given a score for each trial according to the LESS criteria using this video (Appendix 3). The values obtained from the 3 trials were averaged to obtain the participant’s final LESS score (Smith et al. 2012). The rater scoring the LESS tasks was blinded to the group each participant belonged to and the time point of each trial.
3.3.2 Outcome measures

The participant’s average score (out of 19) across their 3 trials served as the outcome measure for the LESS clinical screening tool (Appendix 3).

3.3.3 Statistical analysis

Statistical analyses were conducted using Statistical Package for the Social Sciences software (version 18.0.0, SPSS Inc., Chicago, IL). An alpha level of 0.05 was used for all statistical tests. Normality of data distribution and equal variance between groups was confirmed using the Shapiro-Wilk test and Levene statistic across all data subsets. The standard calculation for effect size \(d\) (Cohen 1988) 95% confidence intervals (95% CI) were calculated for differences in means where applicable.

A mixed 3x3 repeated measures analysis of variance (ANOVA) was used to examine group x time interactions by comparing total LESS scores at baseline (Week 0), at the end of the intervention period (Week 6) and six weeks later to examine retention (Week 12). Where statistically significant main effects or interactions were identified by the ANOVA, pairwise comparisons using Tukey’s HSD test with a Bonferroni correction were used post-hoc to identify where the differences lie.

Based on a statistical power analysis test (Faul et al., 2007) for repeated measure analysis (GPOWER 3.1.7), a minimum of 42 participants were required for the study to achieve 80% statistical power with an expected alpha level of 0.05. Cluster design was considered for this study. The need for independence in responses between the two intervention groups and the control group was essential. The need to avoid contamination between groups, delivery of the intervention and the anticipated effect of the intervention were also considered in the final design of the study (Emery 2007).
3.3.4 Interrater Agreement

Two people were used to test agreement of the LESS criterion DVJ assessment tool. Fourteen LESS criterion trials were randomly selected from the cohort at different testing time points to reduce possible biases from raters while scoring subjects. Kappa statistical analysis was used to assess agreement between the raters on individual LESS items with intraclass correlation coefficient (ICC) calculation used to assess the overall LESS score between the raters. The primary researcher has over 15 years’ experience as an accredited exercise scientist. The second rater is an accredited exercise physiologist. Individual LESS criterions analysis were calculated on the number of equal scores between the two raters. An individual item analysis assessment on percentage agreement, based on the number of even scores between the raters was included to accompany the Kappa statistics.
Chapter Four – Results

The means and standard deviations for total LESS scores for each group at each time point are presented in Table 4.1. Results showed no significant effect for time (Wilks’ Lambda = .90, $F (2, 32) = 1.69, p < .201$) or interaction for time by group (Wilk’s Lambda = .93, $F (4, 64) = .565, p <.689$).

Table 4.1: Participant characteristics (age (years), height (cm), weight (kg)) and mean, standard deviation (SD) and 95% confidence intervals (CI) for total LESS scores over time for Group 1 (EFOA, n=14), Group 2 (D2E, n=11), Group 3 (Control, n=11).

<table>
<thead>
<tr>
<th>Group</th>
<th>Time</th>
<th>Mean ± SD</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>EFOA</td>
<td>Baseline: Week 0</td>
<td>4.79 ± 1.37</td>
<td>3.86-5.71</td>
</tr>
<tr>
<td></td>
<td>End of intervention:</td>
<td>3.86 ± 1.29</td>
<td>2.78-4.93</td>
</tr>
<tr>
<td></td>
<td>Week 6</td>
<td>4.36 ± 1.15</td>
<td>3.60-5.12</td>
</tr>
<tr>
<td></td>
<td>Retention: Week 12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D2E</td>
<td>Baseline: Week 0</td>
<td>6.73 ± 1.95</td>
<td>5.68-7.77</td>
</tr>
<tr>
<td></td>
<td>End of intervention:</td>
<td>6.45 ± 1.97</td>
<td>5.24-7.67</td>
</tr>
<tr>
<td></td>
<td>Week 6</td>
<td>6.45 ± 1.63</td>
<td>5.60-7.31</td>
</tr>
<tr>
<td></td>
<td>Retention: Week 12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>Baseline: Week 0</td>
<td>6.18 ± 1.83</td>
<td>5.14-7.23</td>
</tr>
<tr>
<td></td>
<td>End of intervention:</td>
<td>5.73 ± 2.61</td>
<td>4.51-6.94</td>
</tr>
<tr>
<td></td>
<td>Week 6</td>
<td>6.55 ± 1.44</td>
<td>5.69-7.40</td>
</tr>
<tr>
<td></td>
<td>Retention: Week 12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Though non-significant, average LESS scores decreased across both intervention groups and the control group at the end of intervention period. The greatest decrease was in the EFOA group (a reduction in mean total LESS score of 0.93). LESS scores at Week 12 were higher than Week 6 for all three groups, although in respect of each of the intervention groups, the LESS scores remained slightly lower than the baseline LESS scores. The mean total LESS score for the control group increased at Week 12 above the baseline score. Effect sizes for changes in LESS scores in each group at Week 6 and 12 are presented in Table 4.2. Classification offered by Cohen (1988) for effect size is: .8 = large, .5 = moderate, .2 = small.

Table 4.2: Effect size calculations for each group at the end of intervention (Week 6) and retention period (Week 12).

<table>
<thead>
<tr>
<th>Group / Time</th>
<th>Week 6</th>
<th>Week 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>EFOA</td>
<td>0.47</td>
<td>0.23</td>
</tr>
<tr>
<td>D2E</td>
<td>-0.10</td>
<td>-0.10</td>
</tr>
<tr>
<td>Control</td>
<td>-0.13</td>
<td>0.14</td>
</tr>
</tbody>
</table>

There was excellent reliability between the two raters LESS overall scores (ICC = .867, $P<.001$). LESS criterion items 1, 2, 7, 9 and 11 had 100% agreement between the raters, with the same score given to all subjects by both raters, thus no Kappa results are reported for those items. Appendix 4 sets out Kappa values and percentage agreement on LESS criterion. As shown in Appendix 4, the raters had significant agreement on items 3 (k =
.708, \( P < .008, \) 86% observed agreement), 6 (\( k = .811, \ P < .002, \) 93% observed agreement), 8 (\( k = .462, \ P < .04, \) 79% observed agreement) and 16 (\( k = .853, \ P < .047, \) 57% observed agreement).
Chapter Five – Discussion

There is strong evidence that ACL injury prevention programs reduce the risk of ACL injury, particularly in females (Gilchrist et al. 2008; Hewett et al. 1999; Mandelbaum et al. 2005; Sadoghi, von Keudell & Vavken 2012). Previous studies have shown a possible effect for reducing the risk of lower limb injury when targeting female athletes (Heidt et al. 2000; Hewett et al. 1999; Mandelbaum et al. 2005; Myklebust et al. 2003; Petersen et al. 2005). It has also been proposed that the inclusion of specific attentional focus instructions embedded in the intervention program may contribute to improved lower limb landing patterns (Benjaminse et al. 2010). However to date, attentional focus and its role in injury prevention was unknown. The purpose of the current study was to examine the role of an instructional motor learning strategy and the role it may play in an ACL prevention program. EFOA was used in an attempt to enhance our understanding of the landing patterns of female netball players during the performance of a DVJ landing task. It was hypothesized that there would be a greater reduction (i.e improvement) in LESS score from baseline (Week 0) to end of intervention testing at Week 6 in the EFOA group when compared to the established D2E injury prevention program and the control group.

Statistical analysis revealed no significant main effects for time or for group by time interaction for each of the intervention programs. A study by Gokeler et al., (2014) which examined a fatigue protocol of participants who had undergone recent reconstructive surgery to the ACL by reference to changes in LESS scores provided similar results (Gokeler et al. 2014). Similar to the current study, Gokeler et al. (2014) found that while LESS scores were higher in their control group compared to the group of participants tested, the difference was not significant. However, studies by DiStefano et al., (2009) and Padua et al., (2012) found statistically significant differences when conducting intervention programs targeting...
lower limb landing patterns and using the LESS as an evaluation tool. Padua et al. investigated retention of desirable lower limb landing patterns using the LESS. Di Stefano et al. examined the influence of sex, age, technique and exercise program on movement patterns after an ACL injury prevention program using the LESS as an assessment tool. The magnitude of mean difference found in the current study (EFOA intervention group 4.79±1.37 pre-test, 3.86±1.29 post-test; D2E intervention group 6.73±1.95 pre-test, 6.45±1.97 post-test; control group 6.18±1.83 pre-test, 5.73±2.61 post-test) was similar to that found by DiStefano et al. (5.75±1.9 pre-test, 4.76±1.74 post-test).

A possible explanation for a non-significant main effect for the current study may be the smaller sample size of participants (n=36) compared to the studies conducted by DiStefano et al. (2009) and Padua et al. (2012), which comprised 170 and 140 participants respectively. The study by Gokeler et al. (2014) also had small participant numbers (n=20). Initially the current study had 44 participants, however due to playing injury, illness and withdrawal, only 36 participants completed the entire study. As a result the current study may have been underpowered to detect differences.

Time efficient intervention programs are an important consideration when designing a study that involves public health effect and adoption by the community at large. The current study incorporated a 15-20 minute intervention duration and included a multifaceted neuromuscular program containing balance, plyometric, agility and strengthening exercises. This approach was similar to the approaches used by DiStefano et al. (2009) and Padua et al. (2012), which embedded a 15-20 minute intervention program in the training practice warm up at the commencement of the playing season.

The current study, along with Padua et al. (2012) and DiStefano et al. (2009), all coincided with the commencement of the playing season. While not statistically significant, it appears there were observational improvements in LESS scores for all three groups in the current study during the intervention.
period. It is possible that pre-season specific training and competitive match play may improve general conditioning. This may decrease the neuromuscular risk factors sensitive to the LESS for at risk landing postures. The current study found the LESS scores showed a slight observational decrease at the conclusion of the intervention for all groups, including the control group. The absence of a control group in each of the studies conducted by Padua et al. (2012) and DiStefano et al. (2009), may make comparisons with the current study intervention groups challenging. The presence of a control group in future studies would allow testing to differentiate between changes in testing scores which might occur in any event, compared to changes due to the intervention program(s). Therefore, the presence of a control group in future studies may assist in strengthening the contention that lower limb injury prevention programs are effective and necessary, and that the LESS may be an effective clinical evaluation tool for field-based evaluation.

It has been suggested that early implementation of ACL injury prevention programs at adolescence may help reduce ACL injuries, in particular in female cohorts under the age of 18 (Yu et al. 2005). The disparity in the mean and standard deviation in age between DiStefano et al. (2009) (13 ± 2 years), Padua et al. (2012) (14 ± 2 years) and the current study (23 ± 4 years) is noteworthy and may have resulted in a lower incremental change in LESS scores between the baseline and end of intervention comparisons. Grandstrand et al. (2006) implemented a study with participants as young as 10 years old and did not observe any improvements in injury risk factors, concluding that the program may have been too difficult for participants to complete. Further longitudinal investigation into determining the appropriate age to apply injury prevention strategies for athletic female populations is warranted.

To date the current study is the only one to evaluate adult participants’ LESS scores following an ACL intervention program. Where LESS scores have
been examined in the context of an adult population, it has been solely for screening purposes (Padua et al., 2009). In those situations, the purpose for obtaining the LESS scores was to focus on the risk factors contributing to ACL injury (Padua et al., 2009). This contrasts the purpose for obtaining LESS scores in the current study, which was to assess changes in LESS scores due to targeted instructional methods and retention of such instruction.

Motor learning theory indicates that learning a new skill should be accompanied by relatively permanent changes in the performance of a task (Steenbergen et al. 2010; Wulf et al. 2010a). Current injury intervention programs have been implemented and measured in their efforts to reduce injury rates and/or alter biomechanical or neuromuscular risk factors (Gilchrist et al. 2008; Gray et al. 1985; Mandelbaum et al. 2005; Myklebust et al. 2003; Soderman et al. 2000). There has also been recent attention given to the retention of ideal movement quality following the conclusion of an injury prevention program as an important measure of a successful intervention (Padua et al. 2012; Prapavessis et al. 2003). The current study therefore also aimed to evaluate the retention of desirable lower limb landing postures following the D2E and EFOA intervention programs. It was hypothesised that there would be a greater reduction in LESS score at Week 12 in the EFOA group when compared to the D2E group and the control group.

Statistical analysis revealed no significant main effects for time and no significant result for group by time interaction for either intervention. LESS scores appeared to increase following the 12-week period for the EFOA intervention group and remain the same for the D2E group when compared to the 6 week test. Similarly, it appears the control group LESS scores increased when compared with Week 0 and Week 6. The mean EFOA group LESS score increased by 0.5 points (4.36 ± 1.15) at week 12 compared to the end of intervention score (3.86 ± 1.29). The mean D2E LESS score
remained identical at intervention end (6.45 ± 1.97) and (6.45 ± 1.63). The control group mean score at week 12 increased by 0.78 points (6.55 ± 1.44) compared to the week 6 mean score 5.73 ± 2.61. While the retention scores for the current study were higher in the EFOA group at retention testing compared with end of intervention, the retention scores were lower than the baseline test scores, showing fewer landing errors being recorded. Although not statistically significant, the D2E results also showed retention scores lower than baseline test scores. However the D2E results indicated higher landing errors being recorded when compared with the EFOA group. The results in the current study can be compared with the results of previous studies by Padua et al. (2012), who also used the LESS to investigate retention of desirable lower limb landing patterns, and Prapavessis et al., (2003), which examined Ground Reaction Forces (GRF) and retention of improved landing patterns.

Padua et al., (2012) assessed LESS scores following a 3 month (short duration) and 9 month (long duration) intervention with a 3 month follow up assessment for retention. The study found retention test scores increased slightly compared to post intervention testing scores, however scores remained lower when compared to the baseline testing scores (Padua et al. 2012). Prapavessis et al., (2003) examined Ground Reaction Forces (GRF) and retention of improved landing patterns following an augmented feedback intervention with a 3 month follow-up for retention. Following the evaluation for retention GRF had returned to the baseline testing levels. The results documented by Padua et al., (2012) correspond with the current study, although retention testing for the current study took place 6 weeks post intervention. A possible explanation for the results obtained by Prapavessis et al., (2003) may be found in the length of the intervention compared to Padua et al., (2012) and the current study. The intervention for Prapavessis et al., (2003) study comprised of one week of augmented feedback for 3 sessions. The educational instruction in the Prapavessis et al., (2003) study also included elements of EFOA by providing feedback and
instructions to the participants on “soft” landing strategies. In contrast to Padua et al., (2012) and the current study, Prapavessis et al., (2003) did not incorporate an intervention program resembling game-like sporting manoeuvres, functional neuromuscular training, plyometrics, proprioceptive, speed and resistance training aimed at improved lower limb motion patterns.

The assessment of retention over time of any intervention program is an important consideration. Several studies examined the role of EFOA for retention over a relatively short time frame of one to seven days (Kal, van der Kamp & Houdijk 2013; Wulf, McNevin & Shea 2001; Wulf & Su 2007). Most studies in the area of motor learning use these short intervals to determine learning effects (Peh, Chow & Davids 2011). While these studies have demonstrated a degree of permanency or retention to the effects of an external focus of attention it is not clear whether the retention of skill acquisition can be observed over longer periods of time for the purposes of an effective ACL prevention program. The current study assessed retention in the context of an ACL injury prevention program 6 weeks post intervention. The results of the current study did not show any significance for retention, although LESS scores for both intervention groups remained lower than the pre-test levels. In contrast the control group scores were higher at retention test compared with the pre-test scores. An ACL intervention program should endeavour to have participants retain ideal landing patterns following the intervention (Padua et al., 2012). The retention of improved movement quality is desirable to provide a long-term protective effect. While the results of the current study did not show any significance for retention, Padua et al. (2012) found that the 9 month intervention group showed significantly lower LESS scores at the retention testing than the 3 month intervention group. It may be appropriate that future studies which investigate the role of attentional focus in the context of an ACL intervention program assess retention both in the long and short term following completion of the intervention. This may help determine if ideal
lower limb landing patterns can be retained in participants. Further, additional research to evaluate the learning effects of intervention programs more broadly may be advantageous to determine retention or transfer of desirable skills reinforced in these programs.
Chapter Six – Conclusion

This research had two aims, both intended to enhance our understanding surrounding female ACL injury prevention strategies. The primary aim was to examine the role of attentional focus, specifically EFOA instruction, when embedded in an ACL injury prevention program specifically designed for netball players. The secondary aim was to assess the retention of improved landing kinematics following the cessation of the intervention program, to provide insights into the retention of motor learning in an applied community-based setting. Using the LESS protocol the study examined the lower limb landing patterns of female netball players following a six-week injury prevention program. Each player’s lower limb landing pattern was then re-assessed, again using the LESS protocol, at the conclusion of a 6 week period following completion of the intervention. The study showed that there was no significant improvement in LESS scores following the 6 week ACL injury prevention program. No statistical significance for retention was found for either the D2E or the EFOA interventions. Although the LESS has been found to be a valid and reliable screening tool, a possible reason for these results may include that the LESS may not have been sensitive enough to detect smaller biomechanical changes. Further investigation is needed into the delivery and effects of attentional focus instruction, the possible retention of improved motor learning patterns resulting from such instruction and appropriate screening protocols in an applied community-based setting.
Chapter Seven – Limitations

Some limitations of this study should be noted. The study was limited by small group sizes, which could have limited our ability to detect statistical differences between groups. The D2E program and the EFOA program were identical in exercise prescription, with only the mode of instruction manipulated in the exercise education delivery. The D2E program contained a combination of EFOA and IFOA education instruction. The EFOA program in this study substituted IFOA education instruction for additional EFOA education instruction and as such contained solely EFOA education instruction. This similarity between these two intervention programs may have made comparisons between the interventions and hence, distinction between attentional focus, difficult to evaluate.

The LESS has been found to be both a reliable and a valid field assessment tool for identifying potentially high risk movement patterns during dynamic jump landing (Padua et al. 2009). However, the LESS may not be sensitive enough to detect changes from an intervention when using an observation testing technique. The results of the current study, similar to those of Gokeler et al. (2014), may also indicate that this lack of sensitivity is greater where participant numbers are small.

Another issue to consider is that the drop vertical jump may not be the best task for evaluating injury risk in the case of netballers. While it is difficult to find a task that challenges the knee and the ACL while maintaining a safe controlled, reproducible screening environment, measurement of landing mechanics during other types of tasks may prove more predictive of injury risk.
Chapter Eight – Future Directions

Well-controlled ACL injury-intervention programs reduce the incidence of ACL injuries (Alertorn-Geli et al. 2009; Griffin et al. 2006; Hewett, Myer & Ford 2005). However, studies have yet to demonstrate how to effectively and sustainably implement such programs in different settings. Doing so requires widespread implementation and high compliance and retention rates. Further research into the cognitive process of attentional focus and its role in developing appropriate injury prevention strategies may broaden our understanding of more effective ACL injury prevention programs. It may also assist in determining how best to implement such programs across the broader sporting community. Feedback on technique, and training processes more generally, is often given during training to assist an athlete in developing ideal movement patterns. Further study is warranted to determine ideal training variables and educational methodology (eg, frequency, timing, duration and attentional focus) for improving motor learning and optimising the transfer of desired motor skills to sports-specific movement performed on the field. EFOA has demonstrated permanency when tested for retention in basic motor learning. However, most studies in the area of motor learning use relatively short retention intervals, typically lasting from one to seven days to determine learning effects. Future attentional research focussed on ACL injury prevention may need to include retention evaluation at a range of time points to determine the long term effects, if any, of the intervention. Such research may also provide an insight into the ideal duration for the acquisition of ideal motor skills.

The LESS was developed as an injury risk factor screening tool with clinical applications in an attempt to bridge the gap between laboratory studies and their successful application in the broader community. The LESS is a simple, inexpensive evaluation tool that may be effective in separating athletes into high-risk and low-risk subgroups. However, additional research is
warranted to provide further insight into whether individuals with poor lower limb landing patterns are at increased risk for non-contact ACL injury during athletic events. Such additional research, particularly focusing on movement patterns in competitive game scenarios, could assist in concurrently developing more specific evaluation tools and injury prevention programs. Whilst it would be a major undertaking, developing a range of clinical screening tools specific to particular sports could improve our understanding of non-contact ACL injury risks specific to those sports.

In the case of netball, single leg landings are more common in training and game play situations. Enhancing the LESS to comprise a single leg landing test, in addition to the existing drop vertical jump test, would mean it more closely replicates a netball landing condition (and possibly landing conditions in other sports such as basketball and volleyball) and may improve its predictive at-risk capabilities.

Further research on EFOA and its place in an ideal injury prevention program may be the first step in the long running quest to solve the ACL injury puzzle.
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Appendix 1
Modified Down 2 Earth Safe and Effective Landing (D2E EFOA) intervention program

<table>
<thead>
<tr>
<th>Key Points for Safe and Effective Landing (D2E Program)</th>
<th>D2E Program Instructions</th>
<th>External Focus of Attention Instructions</th>
</tr>
</thead>
</table>
| 1. Control the HIP & KNEE when landing DO NOT allow the hip & knee to swing inward or outward on landing | • Try getting the player to stand on 1 foot with hands on hip, player then collapses (letting the knee swing inwards) one at a time to feel the non-preferred position.  
• Try getting the player to land or perform balance activities with hands on hips, trying to keep them level; a mirror may assist this task. | • Focus on keeping the stick level and the two floor markers. Try to land directly on the floor markers.  
• Try to land softly with no sound. |
<p>| 2. Keep the knee and toe direction the same | • Try getting the player to land (2 feet or 1 foot) or hop along a line with a coach or another player watching to see if the toes &amp; knees/s follow the same line. See if the player can identify this as well, particularly if they are just hopping. | • Shoelaces pointing straight ahead in front of you hop along the line with the stick attempting to keep it as balanced (horizontally as possible). |
| 3. Ensure a soft and slightly bent knee on landing | • Try getting the player to listen to the sound they make when they land. They need to try &amp; perform a soft, quiet landing rather than a loud ‘thud’ landing. | • Jump as high as possible with the stick. Keep the stick as level as possible at all times whilst performing a soft landing |</p>
<table>
<thead>
<tr>
<th>Coach Directed Training</th>
<th>D2E Program Instructions</th>
<th>External Focus of Attention Instructions</th>
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</thead>
<tbody>
<tr>
<td><strong>Week One</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Standing on both feet, jump and land</td>
<td>• Try getting the player to listen to the sound they make when they land. They need to try &amp; perform a soft, quiet landing rather than a loud ‘thud’ landing.</td>
<td>• Focus on the cone placed in front of you. Jump towards the cone with the stick in both hands trying to keep it level at all times. • Aim to land softly with as little sound as possible.</td>
</tr>
<tr>
<td>2 x 10 repetitions - 30s rest</td>
<td>Feedback between sets</td>
<td></td>
</tr>
<tr>
<td>2. 2 Feet jump, 1 foot land</td>
<td>• Try getting the player to listen to the sound they make when they land. They need to try &amp; perform a soft, quiet landing rather than a loud ‘thud’ landing.</td>
<td>• Focus on the floor square and aim to land on the floor marker at the end of the court • Aim for a soft landing with no sound</td>
</tr>
<tr>
<td>2 x 10 repetitions each leg – 30s rest</td>
<td>Feedback between sets</td>
<td></td>
</tr>
<tr>
<td>3. Stationary lunge</td>
<td>• Starting position as per photo 1 slowly drop the rear knee to assume a lunge position. • Both knees should be at 90° at the lowest point of the exercise</td>
<td>• With stick in hand. Step forward with leading foot onto the floor marker and slowly drop your rear knee to assume the lunge position. Both knees should be at right angles at the end of the movement.</td>
</tr>
<tr>
<td>2 x 10 repetitions each leg – 30s rest</td>
<td>Feedback between sets</td>
<td></td>
</tr>
<tr>
<td>4. 2 Feet jump and land NESW*</td>
<td>• Stand on a spot with both feet • Jump forward then back to where you started • Then jump to the right and return to the start. Repeat this jump backwards and then to the left</td>
<td>• Starting on the floor marker the middle of the cones, jump to each cone arrangement with stick in both hands attempting to land on both feet at the same time, keeping the stick as level as possible. Return to the floor square in the middle of the cones before moving to the next set of cone markers. • Try to land at each point with as little sound as possible.</td>
</tr>
<tr>
<td>2 x 5 NESW cycles – 30s rest</td>
<td>Feedback between sets</td>
<td></td>
</tr>
<tr>
<td>5. 2 Feet jump and land with the ball</td>
<td>• Pass and catch a ball while performing a 2 feet jump, 2 foot land.</td>
<td>“Spring” up and pass the ball in front of you and touch the ground with as little sound as possible on two feet.</td>
</tr>
<tr>
<td>2 x 10 repetitions – 30s rest</td>
<td>Feedback between sets</td>
<td></td>
</tr>
<tr>
<td>6. 2 Feet jump, 1 foot land with the ball</td>
<td>• Pass and catch the ball while performing a 2 feet jump, 1 foot land.</td>
<td>“Spring” and push the ball in front of you and touch the ground with as little sound as possible on one foot.</td>
</tr>
<tr>
<td>2 x 10 repetitions each leg – 30s rest</td>
<td>Feedback between sets</td>
<td></td>
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<tr>
<td>Coach Directed Training</td>
<td>D2E Program Instructions</td>
<td>External Focus of Attention Instructions</td>
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<tr>
<td><strong>Week Two</strong></td>
<td></td>
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<tr>
<td>1. <strong>2 Feet jump, 1 foot land with the ball</strong></td>
<td>• Pass and catch the ball while performing a 2 feet jump, 1 foot land.</td>
<td>• “Spring” and push the ball in front of you and touch the ground with as little sound as possible on one foot.</td>
</tr>
<tr>
<td>2 x 10 repetitions each leg – 30s rest Feedback between sets</td>
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</tbody>
</table>
| 2. **2 Feet jump, and land NESW** | • Stand on a spot with both feet  
• Jump forward then back to where you started  
• Then jump to the right and return to the start. Repeat this jump backwards and then to the left | • Starting on the floor marker the middle of the cones, jump to each cone arrangement with stick in both hands attempting to land on both feet at the same time, keeping the stick as level as possible. Return to the floor square in the middle of the cones before moving to the next set of cone markers.  
• Try to land at each point with as little sound as possible. |
| 2 x 10 repetitions – 30s rest Feedback between sets | | |
| 3. **Run up and land while catching the ball in the air** | • Player A runs towards player B passes the ball. Player A catches the ball while executing a leap land. | • Track the speed of the ball through the air leaping to catch and landing softly like a sponge. |
| 3 x 8 repetitions each leg – 30s rest Feedback between sets | | |
| 4. **2 feet jump and 2 feet land with rotation** | • Starting on both feet, jump and rotate 90° in the air and land on both feet. Repeat this until you complete 2 full cycles | • Jump and spin with a stick in a half circle and land on 2 feet with as little sound as possible  
• Try to keep the stick level (horizontally level) at all times |
| 2 x 2 cycles – 30s rest Feedback between sets | | |
| 5. **Walking lunges** | • Step forward and lunge. Push off the back leg and step through to another lunge. Repeat this for two thirds of the court. | • With the stick in the outstretched position horizontally, step forward and lunge. Push off the back leg and step through to another lunge. Repeat this for two thirds of the court. |
| 2 x 2 thirds of the court – 30s rest Feedback between sets | | |
| 6. **2 feet jump, 1 foot land with rotation** | • Start on both feet, jump and rotate 90° in the air and land on one foot. Place the other foot and repeat this until you repeat 2 full cycles | • Jump and spin with a stick in a half circle and land on 1 foot with as little sound as possible  
Try to keep the stick level (horizontally level) at all times |
| 2 x 2 cycles for each leg – 30s rest Feedback between sets | | |

*NESW (North, East, South, West) has been used to describe a sequence that would involve jumping forward, backward, left and right in a pattern defined in each exercise.*
<table>
<thead>
<tr>
<th>Coach Directed Training</th>
<th>D2E Program Instructions</th>
<th>External Focus of Attention Instructions</th>
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</thead>
<tbody>
<tr>
<td><strong>Week Three</strong></td>
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<td></td>
</tr>
<tr>
<td>1. 2 Feet jump, 1 foot land with the ball</td>
<td>• Pass and catch the ball while performing a 2 feet jump, 1 foot land.</td>
<td>• “Spring” and push the ball in front of you and touch the ground with as little sound as possible on one foot</td>
</tr>
<tr>
<td>2 x 10 repetitions each leg – 30s rest</td>
<td><strong>Feedback between sets</strong></td>
<td></td>
</tr>
<tr>
<td>2. Hop NSEW</td>
<td>• Stand on a spot with both feet</td>
<td>• Starting on the floor marker the middle of the cones, hop to each cone arrangement with stick in both hands attempting to hold the stick level (horizontal) at all times. Return to the floor square in the middle of the cones before moving to the next set of cones.</td>
</tr>
<tr>
<td>2 x 2 cycles each leg – 30s rest</td>
<td><strong>Feedback between sets</strong></td>
<td>• Try to land at each point with as little sound as possible.</td>
</tr>
<tr>
<td>2. Run up and land, pivot pass behind to a known player.</td>
<td>• Player A runs towards player B passes the ball. Player B passes the ball. Player A catches the ball whilst executing a leap land. Player A pivots and passes Player C.</td>
<td>• Track the speed of the ball through the air leaping to catch and landing softly like a sponge – spin the toe of your shoe and pass.</td>
</tr>
<tr>
<td>3 x 8 repetitions each leg – 30s rest</td>
<td><strong>Feedback between sets</strong></td>
<td></td>
</tr>
<tr>
<td>3. Step lunge</td>
<td>• Start with feet together, step forward and lunge. Push off front foot, back to original standing position. Repeat with opposite leg</td>
<td>• With the stick positioned horizontally in front of you step forward and lunge. Push off front foot, back to original standing position. Repeat with opposite leg.</td>
</tr>
<tr>
<td>2 x 10 Reps each leg – 30s rest</td>
<td><strong>Feedback between sets</strong></td>
<td>• Try to keep the stick level at all times</td>
</tr>
<tr>
<td>4. Quick feet and lunge</td>
<td>• Perform 3 quick steps on the spot followed by a lunge. Push off front foot back to the original standing position. Repeat with opposite leg</td>
<td>• With the stick positioned horizontally, perform 3 quick steps on the spot followed by a lunge. Push off front foot back to the original standing position. Repeat with opposite leg.</td>
</tr>
<tr>
<td>2 x 10 Reps each leg – 30s rest</td>
<td><strong>Feedback between sets</strong></td>
<td>• Try to keep the stick level at all times</td>
</tr>
<tr>
<td>Coach Directed Training</td>
<td>D2E Program Instructions</td>
<td>Implicit Learning with External Focus of Attention Instructions</td>
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<td><strong>Week Four</strong></td>
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</table>
| 1. Step lunge with ball | • Start with feet together, step forward and lunge while passing a ball back and forth to a wall or another player. Push off front foot, back to original standing position. Repeat with opposite leg. | • Pass the ball to another player or wall.  
• Foot to land on floor marker then spring back to starting position.  
• Repeat with opposite leg. |
| 2 x 5Reps each leg – 30s rest | 2 x 5Reps each leg – 30s rest Feedback between each exercise |                                                             |
| 2. Quick feet and lunge with ball | • Perform 3 quick steps on the spot followed by a lunge. Pass a ball back and forth to a wall or another player. Push off front foot back to the original standing position. Repeat with opposite leg. | • Quick spring steps followed by pass and lunge towards the floor square. |
| 2 x 5Reps each leg – 30s rest Feedback between each exercise | 3 x 8 repetitions each leg – 30s rest Feedback between sets only |                                                             |
| 3. Run up and land, pivot- pass behind to an unknown player. | • Player A runs towards player B passes the ball. Player A catches the ball while executing a leap land. Player A pivots and passes to Player C or D. As Player A lands, Player B calls out which player C or D, to pass to. | • Focussing on the spin & speed of the ball, catch the ball in the air with a soft “no sound” landing. |
| 3 x 8 repetitions each leg – 30s rest Feedback between sets only |                                                             |                                                             |
| 4. Quick feet and side step | • Perform 3 quick steps on the spot followed by a side lunge. Push off back to the original standing position. Repeat with opposite leg. | • Focus ahead about 15 meters  
• 3 quick steps followed by a lunge to a floor marker. |
<p>| 2 x 10 repetitions for each leg – 30s rest Feedback between sets |  |                                                             |</p>
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<thead>
<tr>
<th>Coach Directed Training</th>
<th>D2E Program Instructions</th>
<th>Implicit Learning with External Focus of Attention Instructions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Week Five</strong></td>
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<td></td>
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<tr>
<td>1. Quick feet and lunge with ball</td>
<td>• Perform 3 quick steps on the spot followed by a lunge. Pass a ball back and forth to a wall or another player. Push off front foot back to the original standing position. Repeat with opposite leg</td>
<td>• 3 quick steps followed by a lunge • Focus on the speed and spin of the ball through the air</td>
</tr>
<tr>
<td>2 x 5 Reps each leg – 30s rest Feedback between each exercise</td>
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<tr>
<td>2. Quick feet and side step with ball</td>
<td>• Perform 3 quick steps on the spot followed by a side lunge, while passing the ball. Push off back to the original standing position. Repeat with opposite leg</td>
<td>• 3 quick steps followed by a side step to a floor marker • Focus on the speed and spin of the ball through the air</td>
</tr>
<tr>
<td>2 x 10 repetitions for each leg – 30s rest Feedback between sets</td>
<td></td>
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</tr>
<tr>
<td>3. Break from a defender (DEF)</td>
<td>• Player A breaks from a defender and runs towards player B. Player B passes the ball. Player A catches the ball whilst executing a leap land. Player A pivots and passes to Player C</td>
<td>• Focus on the speed and spin of the ball through the air • Soft landing and spin, focus on the player you are passing to.</td>
</tr>
<tr>
<td>Run up and land, pivot pass behind to a known player.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 x 8 repetitions each leg – 30s rest Feedback between sets</td>
<td></td>
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</tr>
<tr>
<td>4. Jump lunge/land</td>
<td>• Start in lunge position with the RIGHT leg forward jump and change legs in the air. Land in a lunge position with the LEFT leg forward. Repeat with left leg forward.</td>
<td>• With 2 cones on either side perform fast scissor kicks through the air touching the cones with your palms simultaneously with a soft landing • “Focus – Fast-Soft”</td>
</tr>
<tr>
<td>2 x 5 repetitions for each leg starting forward – 30s rest Feedback between sets</td>
<td></td>
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<tr>
<td><strong>Week Six</strong></td>
<td></td>
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</tr>
<tr>
<td><strong>1. Jump lunge/land with ball</strong></td>
<td>2 x 5 repetitions for each leg starting forward – 30s rest Feedback between sets</td>
<td><strong>Start in lunge position with the RIGHT leg forward jump and change legs in the air while passing the ball. Land in a lunge position with the LEFT leg forward. Repeat with left leg forward.</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Focus on the spin and speed.</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Fast scissor kicks through the air with a soft landing “Focus – Fast-Soft”</strong></td>
</tr>
<tr>
<td><strong>2. Break from a defender (DEF) Run up and land, pivot pass behind to an Unknown player.</strong></td>
<td>3 x 8 repetitions each leg – 30s rest Feedback between sets</td>
<td><strong>Player A breaks from a defender and runs towards player B. Player B passes the ball. Player A catches the ball whilst executing a leap land. Player A pivots and passes to Player C as Player A lands. Player B calls out which player C or D, to pass to.</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Focus on the speed and spin of the ball through the air Soft landing and spin, focus on the player you are passing to.</strong></td>
</tr>
<tr>
<td><strong>3. Moving jump lunge/land</strong></td>
<td>2 x ½ court – 30s rest Feedback between sets</td>
<td><strong>Start in lunge position with the RIGHT leg forward jump and change legs in the air while moving forward. Land in a lunge position with the LEFT leg forward. Repeat with left leg forward.</strong></td>
</tr>
<tr>
<td></td>
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<td><strong>With stick in hand outstretched horizontally, fast scissor kicks through the air with a soft landing</strong></td>
</tr>
<tr>
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<td><strong>Keep the stick level at all times</strong></td>
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<tr>
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<td></td>
<td><strong>“Focus – Fast-Soft”</strong></td>
</tr>
<tr>
<td><strong>4. Hop NSEW</strong></td>
<td>2 x 3 NSEW 30s rest</td>
<td><strong>Stand on a spot with both feet</strong></td>
</tr>
<tr>
<td></td>
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<td><strong>Jump forward then back to where you started</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Then jump to the right and return to the start. Repeat this jump backwards and then to the left</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Starting on the floor marker the middle of the cones, hop to each cone arrangement attempting to land at the same time as touching the cones with your palms. Return to the floor square in the middle of the cones before moving to the next set of cones.</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Try to land at each point with as little sound as possible.</strong></td>
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</table>
Appendix 2

EFOA Intervention Group: Training opportunities and adherence

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D2E Intervention Group: Training opportunities and adherence

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</table>
### Appendix 3

**Landing Error Scoring System (LESS) items, camera view used and scoring criteria. Adapted from Padua et al (2009).**

<table>
<thead>
<tr>
<th>LESS Item</th>
<th>Operational Definition</th>
<th>Camera View</th>
<th>LESS Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Knee flexion angle at initial contact</td>
<td>At the time point of initial contact, if the knee of the test leg is flexed more than 30 degrees, score YES. If the knee is not flexed more than 30 degrees, score NO.</td>
<td>Side</td>
<td>Y = 0 N = 1</td>
</tr>
<tr>
<td>2 Hip flexion angle at initial contact</td>
<td>At the time point of initial contact, if the thigh of the test leg is in line with the trunk then the hips are not flexed and score NO. If the thigh of the test leg is flexed on the trunk, score YES.</td>
<td>Side</td>
<td>Y = 0 N = 1</td>
</tr>
<tr>
<td>3 Trunk flexion angle at initial contact</td>
<td>At the time point of initial contact, if the trunk is vertical or extended on the hips, score NO. If the trunk is flexed on the hips, score YES.</td>
<td>Side</td>
<td>Y = 0 N = 1</td>
</tr>
<tr>
<td>4 Ankle plantar-flexion angle at initial contact</td>
<td>If the foot of the test leg lands toe to heel, score YES. If the foot of the test leg lands heel to toe or with a flat foot, score NO.</td>
<td>Side</td>
<td>Y = 0 N = 1</td>
</tr>
<tr>
<td>5 Knee valgus angle at initial contact</td>
<td>At the time point of initial contact, draw a line straight down from the centre of the patella. If the line goes through the midfoot, score NO. If the line is medial to the midfoot, score YES.</td>
<td>Front</td>
<td>Y = 1 N = 0</td>
</tr>
<tr>
<td>6 Lateral trunk flexion angle at initial contact</td>
<td>At the time point of initial contact, if the midline of the trunk is flexed to the left or the right side of the body, score YES. If the trunk is not flexed to the left or right side of the body, score NO.</td>
<td>Front</td>
<td>Y = 1 N = 0</td>
</tr>
<tr>
<td>7 Stance width - Wide</td>
<td>Once the entire foot is in contact with the ground, draw a line down from the tip of the shoulders. If the line on the side of the test leg is inside the foot of the test leg then greater than shoulder width (wide), score YES. If the test foot is internally or externally rotated, grade the stance width based on heel placement</td>
<td>Front</td>
<td>Y = 1 N = 0</td>
</tr>
<tr>
<td>8 Stance width - Narrow</td>
<td>Once the entire foot is in contact with the ground, draw a line down from the tip of the shoulders. If the line on the side of the test leg is outside of the foot then score less than shoulder width (narrow), score YES. If the test foot is internally or externally rotated, grade the stance width based on heel placement</td>
<td>Front</td>
<td>Y = 1 N = 0</td>
</tr>
<tr>
<td>9 Foot position - Toe In</td>
<td>If the foot of the test leg is internally more than 30 degrees between the time period of initial contact and max knee flexion, then score YES. If the foot is not internally rotated more than 30 degrees between the time period of initial contact to max knee flexion, score NO.</td>
<td>Front</td>
<td>Y = 1 N = 0</td>
</tr>
<tr>
<td>10 Foot position - Toe Out</td>
<td>If the foot of the test leg is externally rotated more than 30 degrees between the time period of initial contact and max knee flexion, then score YES. If the foot is not externally rotated more than 30 degrees between the time period of initial contact to max knee flexion, score NO.</td>
<td>Front</td>
<td>Y = 1 N = 0</td>
</tr>
<tr>
<td>11 Symmetric initial foot contact</td>
<td>If one foot lands before the other or if one foot lands heel to toe and the other lands toe to heel, score NO. If the feet land symmetrically, score YES.</td>
<td>Front</td>
<td>Y = 0 N = 1</td>
</tr>
<tr>
<td>12 Knee flexion displacement</td>
<td>If the knee of the test leg flexes more than 45 degrees from initial contact to max knee flexion, score YES. If the knee of the test leg does not flex more than 45 degrees, score NO.</td>
<td>Side</td>
<td>Y = 0 N = 1</td>
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<tr>
<td>Item</td>
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<tr>
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<td>-------------</td>
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<td>------</td>
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<tr>
<td>13</td>
<td>Hip flexion at max knee flexion</td>
<td>If the thigh of the test leg flexes more on the trunk from initial contact to max knee flexion angle, score YES</td>
<td>Y = 0 N = 1</td>
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<tr>
<td>14</td>
<td>Trunk flexion at max knee flexion</td>
<td>If the trunk flexes more from the point of initial contact to max knee flexion, score YES. If the trunk does not flex more, score NO</td>
<td>Y = 0 N = 1</td>
</tr>
<tr>
<td>15</td>
<td>Knee valgus displacement</td>
<td>At the point of max knee valgus on the test leg, draw a line straight down from the centre of the patella. If the line runs through the great toe or is medial to the great toe, score YES. If the line is lateral to the great toe, score NO</td>
<td>Y = 1 N = 0</td>
</tr>
<tr>
<td>16</td>
<td>Joint displacement</td>
<td>Watch the sagittal plane motion at the hips and knees from initial contact to max knee flexion angle. If the subject goes through large displacement of the trunk, hips, and knees then score SOFT. If the subject goes through some trunk, hip, and knee displacement but not a large amount, then AVERAGE. If the subject goes through very little, if any trunk, hip, and knee displacement, then STIFF</td>
<td>SOFT = 0 AVG. = 1 STIFF = 2</td>
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<tr>
<td>17</td>
<td>Overall impression</td>
<td>Score EXCELLENT if the subject displays a soft landing and no frontal plane motion at the knee, score POOR if the subject displays a stiff landing and large frontal plane motion at the knee. All other landings, score AVERAGE</td>
<td>EX. = 0 AVG. = 1 POOR = 2</td>
</tr>
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</table>

For items 1-15, a positive score was defined as an error on at least 2 of the 3 trials. For items 16 & 17, a positive score was defined as Average on at least 2 of 3
## Appendix 4

Kappa values and percentage agreement on LESS criterion.

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<tr>
<td>4: Ankle plantar flexion angle at initial contact</td>
<td>1.0</td>
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<tr>
<td>5: Knee valgus angle at initial contact</td>
<td>1.0</td>
<td>&lt;.001</td>
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</tr>
<tr>
<td>6: Lateral trunk flexion angle at initial contact</td>
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<td>8: Stance width – Narrow</td>
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<td>10: Foot position – Toe out</td>
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<td>100%</td>
</tr>
<tr>
<td>12: Knee flexion displacement</td>
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<td>100%</td>
</tr>
<tr>
<td>13: Hip flexion at maximum knee flexion</td>
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<td>14: Trunk flexion at maximum knee flexion</td>
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<td>17: Overall impression</td>
<td>.304</td>
<td>.047</td>
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Memorandum

To: Dr Natalie Saunders
School of Exercise and Nutrition Sciences

B

cc: Mr Simon John Moule

From: Deakin University Human Research Ethics Committee (DUHREC)
Date: 10 December, 2013
Subject: 2013-294
The role of an external focus of attention on lower limb landing postures
Please quote this project number in all future communications

The application for this project was considered at the DU-HREC meeting held on 09/12/2013.

Approval has been given for Dr Natalie Saunders, School of Exercise and Nutrition Sciences, to undertake this project from 01/12/2013 to 01/12/2017.

The approval given by the Deakin University Human Research Ethics Committee is given only for the project and for the period as stated in the approval. It is your responsibility to contact the Human Research Ethics Unit immediately should any of the following occur:

• Serious or unexpected adverse effects on the participants
• Any proposed changes in the protocol, including extensions of time.
• Any events which might affect the continuing ethical acceptability of the project.
• The project is discontinued before the expected date of completion.
• Modifications are requested by other HRECs.

In addition you will be required to report on the progress of your project at least once every year and at the conclusion of the project. Failure to report as required will result in suspension of your approval to proceed with the project.

DUHREC may need to audit this project as part of the requirements for monitoring set out in the National Statement on Ethical Conduct in Human Research (2007).

Human Research Ethics Unit
research-ethics@deakin.edu.au
Telephone: 03 9251 7123
Appendix 6

PLAIN LANGUAGE STATEMENT AND CONSENT FORM

TO: Participants

Plain Language Statement

Date: 16.12.2013

Full Project Title: The role of an external focus of attention on lower limb landing patterns

Principal Researcher: Dr Natalie Saunders

Associate Researcher(s): A/Prof Michael Spittle, Dr Jason Bonacci, Mr Simon Moule

Thank you for taking the time to read this Information Statement.

This Participant Information Statement contains detailed information about the research project. Its purpose is to explain to you as clearly as possible all the procedures involved in the project before you decide whether or not to take part in it.

Please read this information carefully. Feel free to ask questions about anything in the document, and discuss the project with relatives or friends.

Once you understand what is involved in the project and if you agree to take part in it, you will be asked to sign the Consent Form. By signing the Consent Form, you indicate that you understand the information and that you give your consent to participate in the project.

You will be given a copy of the Participant Information Sheet and Consent Form to keep as a record.

Participation in this study is voluntary. If you do not wish to take part you are not obliged to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage. Your decision whether or not to participate will not affect your relationship with Deakin University.
1. What is the purpose of this research project?

You are invited to take part in this research project. This is because you are a netball player competing at a level which requires attendance at training/practice sessions during the week aside from competition. The research project aims to determine if an exercise program incorporated into the warm up and tailored towards the demands of netball will assist in reducing lower limb injury. This project is also aiming to determine the retention of skills learnt from the exercise program after the program has concluded.

2. What will I be asked to do?

When you accept to participate in this study, you will be screened by one of the investigators to ensure that you meet all the criteria as a participant in this study. You will be invited to participate in this study if:

- You are 18 years of age or above
- You do not currently have an injury to the knee
- You do not have a lower limb injury that will affect your ability to complete an exercise program as part of your normal training practice
- You have no previous history of a serious knee injury or lower limb surgery

It is hoped that a sufficient number of players within a team will agree to participate in the study at which point, teams will be randomly allocated to either one of the two intervention groups or a control group. Your individual participation in this study will involve the following:

1) An initial testing session will be conducted (see below for details).
2) You will complete a 6 week exercise program integrated into your warm up as part of your regular training practice.
3) Following the 6 week program a repeat testing procedure (repeat initial testing procedure) will be conducted. This will be followed by another testing session 6 weeks later (at 12 weeks from program commencement). No additional training will occur between the six and 12-week testing sessions.

Location

All testing sessions, physical screening and running sessions will be conducted at your training venue.
**Testing Sessions**

Testing will be conducted on three separate occasions for initial testing, at six weeks, followed by a final testing session at 12 weeks.

At the initial and six-week testing session all tasks and analysis techniques being performed will initially be explained and you will be given the opportunity to ask any questions of the researchers. Individual demographics (eg. age, height, weight) will be collected at all testing sessions. Participants will be required to jump from a 30cm high box to a distance 50% of their height away from the box to the ground and immediately rebound for a maximal vertical jump on landing. Testing of each participant should take no longer than 10 minutes (includes warm-up & data collection) while being monitored using video techniques.

**Exercise program**

Your team will be randomly allocated into either one of the two intervention groups (established injury prevention program OR established program including external focus of attention) or the usual training practice group (control group). If your team is selected in one of the two intervention groups, you will be expected to participate in a structured and progressive six week exercise program embedded in your warm up as part of your usual training practice.

The team assigned to the usual training/practice group will continue their normal training routine for the duration of the study.

3. **What will I gain by participating?**

By participating in this research you are contributing to an improved understanding of the prevention lower limb landing mechanics and injury prevention. You may also gain a greater understanding of how to warm up and physically prepare more effectively for competition. The researchers will be happy to provide you with any of your results or answer to questions you may have.

4. **Are there any risks involved?**

There is minimal risk associated with participation in this research. As all running tasks have the ability to cause injury there is the risk of incurring a lower limb injury during testing or exercise sessions. The tasks that you will be required to perform however present the same, if not lower risk of injury than those performed in a normal sport and netball. The research team includes a qualified physiotherapist and an accredited exercise physiologist, and in the unlikely event of an injury occurring research staff will provide initial care. However, accessing ongoing care and any treatment relating to the injury will be at your expense. Deakin University and its staff are not liable for any injury, nor any costs associated with any injury, as a result of your participation in this research.
**Will the information I provide be kept private?**

Any information obtained in connection with this research project that can identify you will remain confidential and will only be used for the purpose of this research project. Information will only be disclosed with your permission, except as required to by law. If you give us permission by signing the Consent Form, we plan to publish the results at conferences and in scientific journals. In any publication or presentation, your information will be provided in such a way that you cannot be identified.

5. **Results of the Project**

Results of this project will be available to you by mail or e-mail, at your request.

6. **Further information or Any Problems**

If you require further information or if you have any problems concerning this project you can contact one of the principal researchers. The researcher responsible for this project is:

   Dr. Natalie Saunders  03 9246 8284

**Complaints**

If you have any complaints about any aspect of the project, the way it is being conducted or any questions about your rights as a research participant, then you may contact:

The Manager, Research Integrity, Deakin University, 221 Burwood Highway, Burwood Victoria 3125, Telephone: 9251 7129, research-ethics@deakin.edu.au

Please quote project number: 2013-294
PLAIN LANGUAGE STATEMENT AND CONSENT FORM

TO: Participant

Date: 16.12.2013

Full Project Title: The role of an external focus of attention on lower limb landing patterns

Reference Number: 2013-294

I have read and I understand the attached Plain Language Statement.

I freely agree to participate in this project according to the conditions in the Plain Language Statement.

I have been given a copy of the Plain Language Statement and Consent Form to keep.

The researcher has agreed not to reveal my identity and personal details, including where information about this project is published, or presented in any public form.

Participant’s Name (printed) ……………………………………………………………………

Signature ……………………………………………………… Date …………………………

Please mail or fax this form to:

Dr Natalie Saunders
School of Exercise and Nutrition Sciences, Faculty of Health, Deakin University
221 Burwood Highway
Burwood VIC 3125 or Fax 9244 5551
**PLAIN LANGUAGE STATEMENT AND CONSENT FORM**

**TO:** Participant

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<thead>
<tr>
<th>Withdrawal of Consent Form</th>
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<td><strong>Date:</strong> 16.12.2013</td>
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<td><strong>Full Project Title:</strong> The role of an external focus of attention on lower limb landing patterns</td>
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<td>**Reference Number:**2013-294</td>
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I hereby wish to WITHDRAW my consent to participate in the above research project and understand that such withdrawal WILL NOT jeopardise my relationship with Deakin University.

**Participant’s Name (printed) .................................................................**

Signature .............................................................Date .........................

Please mail or fax this form to:

Dr Natalie Saunders  
School of Exercise and Nutrition Sciences, Faculty of Health, Deakin University  
221 Burwood Highway  
Burwood VIC 3125

**Or Fax** 9244 5551